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Environmental Monitoring at Hanford for 1987

R. E. Jacquish, Editor
P. J. Mitchell, Editor

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PREFACE

Environmental monitoring at the Hanford Site is conducted by the Battelle Memorial Institute, Pacific Northwest Division, as part of its contract to operate the Pacific Northwest Laboratory (PNL) for the U.S. Department of Energy. The data collected provide a historical record of radionuclide and radiation levels attributable to natural causes, worldwide fallout, and Hanford operations. Data are also collected to monitor the status of chemicals on the Site and in the Columbia River.

This report represents a single, comprehensive source of offsite and onsite environmental monitoring data collected during 1987 by PNL's Environmental Monitoring Program. Appendix A contains data and data summaries for results obtained during 1987 that include statistical estimates of variation. Information in Appendix A is intended for readers with a scientific interest or for those who wish to evaluate results in a manner not included here. Those interested in reviewing the raw data can do so at the Department of Energy - Richland Operations' Public Reading Room at the Federal Building in Richland, Washington.

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Numerous PNL personnel were responsible for a productive environmental monitoring program during 1987. Important contributions were made by those people who collected samples, maintained equipment, provided laboratory analyses, managed data, evaluated results, and provided clerical support. The programs described in this report were managed by the Office of Hanford Environment under the direction of Dr. R. H. Gray. Special thanks go to R. W. Hanf for technical coordination and M. E. Strong for report coordination. Thanks also to L. K. Grove, B. V. Johnston, and S. G. Weiss for technical editing. Valuable word processing support was provided by B. J. Cunningham, D. J. Kennedy, L. M. Valdez, and P. C. Young.

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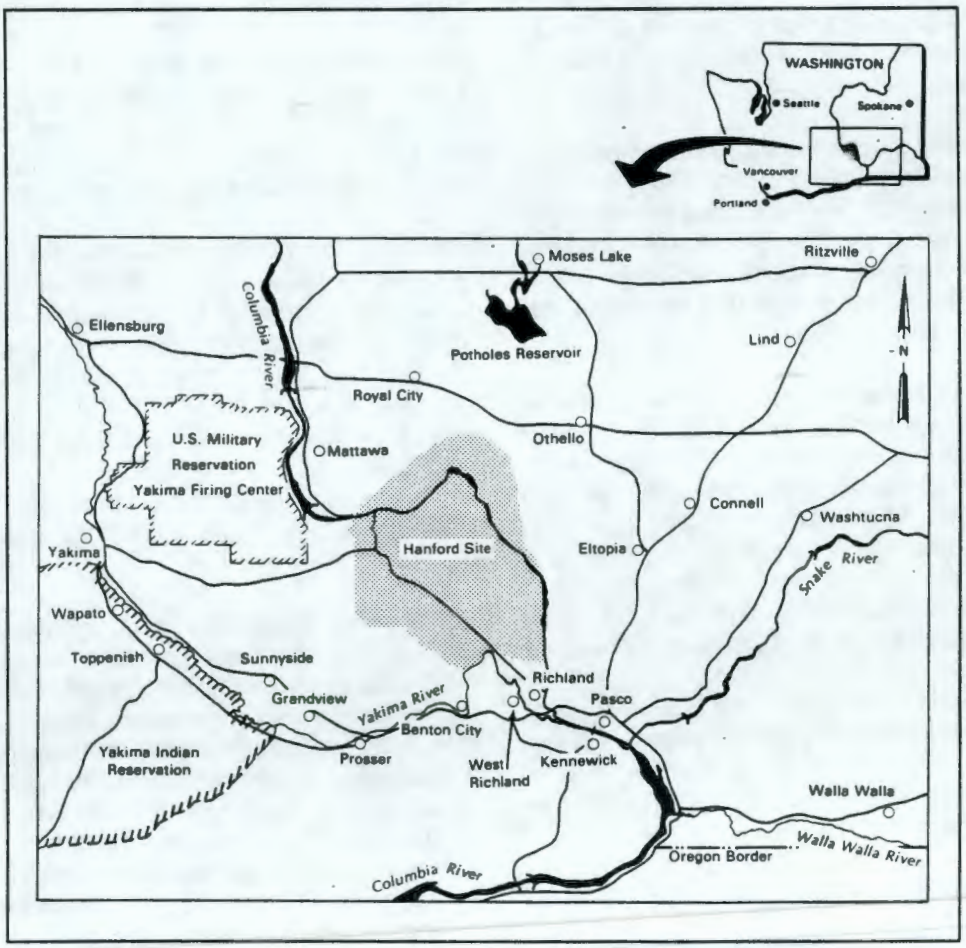
SUMMARY

Environmental monitoring activities performed by the Pacific Northwest Laboratory for the U.S. Department of Energy (DOE) on the Hanford Site for 1987 are discussed in this report. Samples of environmental media were collected to determine radionuclide and chemical concentrations at locations in the geographical area shown in the figure below. Results are discussed in detail in subsequent sections of this report.

Surveillance of radioactivity in the Hanford vicinity during 1987 indicated concentrations well below applicable DOE and U.S. Environmental Protection Agency (EPA) standards (Appendix C). Radioactive materials released from Hanford operations (Appendix G) were generally indistinguishable above background in the offsite environment. Continued influence from the 1986 reactor accident at the Chernobyl Nuclear Power Station in the U.S.S.R. was not apparent this year. Chemical concentrations in air were below applicable standards established by the EPA and the State of Washington. Chemicals detected in the ground water beneath the Site can be attributed to both Site operations and natural background levels. Several chemicals regulated by the EPA and the State of Washington exceeded EPA drinking water standards (DWS).

ENVIRONMENTAL MONITORING RESULTS

Air — In 1987, the annual average Hanford Site perimeter concentrations of ^{85}Kr, uranium, and



Geographical Sampling Area

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$^{239,240}Pu$ were numerically greater than levels measured at distant monitoring stations. These differences were not significantly different statistically (at the 5% significance level). Iodine-129 was numerically larger at the perimeter stations than at the distant stations and the difference was significant statistically (beyond the 0.5% significance level). However, even the maximum individual perimeter sample for any radionuclide was only 0.5% of the applicable DOE Derived Concentration Guide (DCG). The total dose from air emissions is compared to Clean Air Act and DOE dose standards in the section "Potential Radiological Doses from 1987 Hanford Operations," Section 4.0. Annual average NO_2 concentrations at all sampling locations remained well below federal and Washington State ambient air standards. (See "Air Monitoring," Section 3.1.)

Ground Water — Ground-water analyses were compared to the EPA's DWS and the DOE's DCG as a basis for evaluating levels of contamination. Observed levels during 1987 were similar to those in previous years.

Radionuclides in ground water, including gross alpha, gross beta, ^{3}H, ^{60}Co, ^{90}Sr, ^{99}Tc, ^{106}Ru, ^{129}I, and ^{131}I were above the DWS in the immediate vicinity of operational areas. Only ^{3}H in the 200 Areas and ^{90}Sr in the 100-N Area were above the DCG. Tritium continued to move with the ground water and discharge to the Columbia River.

Monitoring results also indicated that certain chemicals regulated by the EPA and the State of Washington were present in Hanford ground water near the operating areas. Nitrate concentrations resulting from Site operations exceeded the DWS in parts of the 100, 200, and 300 Areas and in the 600 Area southwest of the old Hanford townsite. Chromium concentrations were above the DWS at 100-H, 100-D, and the surrounding area. Cyanide was observed in, and north of, the 200-East Area. Fluoride was above the DWS in a few wells in the 200-West Area. Several organic chemicals, primarily carbon tetrachloride, were observed to be above the DWS in wells in the 200-West Area. (See "Ground-Water Monitoring," Section 3.2)

Surface Water — During 1987, low levels of some radionuclides continued to be detected in samples of Columbia River water collected upstream of the Site at Priest Rapids Dam and downstream of the Site at the Richland Pumphouse. As in past years, radionuclides consistently observed in measurable quantities in the river water were ^{3}H, ^{90}Sr, ^{129}I, ^{234}U, ^{238}U, and $^{239,240}Pu$. Concentrations of ^{90}Sr, ^{234}U, ^{238}U, and $^{239,240}Pu$ were similar in water collected from both locations. Tritium and ^{129}I concentrations were consistently higher in water collected at the Richland Pumphouse than in water from Priest Rapids Dam. All radionuclides observed in Columbia River water during 1987 exist in worldwide fallout, as well as in effluents from Hanford facilities. Tritium and uranium are also naturally occurring in the environment. Concentrations of radionuclides identified in the river water during 1987 were below concentration limits established for drinking water by the EPA and the State of Washington.

Nonradiological water quality parameters measured during 1987 were similar to those reported during previous years and within Washington State Water Quality Standards.

Four onsite ponds were routinely sampled for radiological constituents during 1987. Concentrations of radionuclides in water collected from these ponds were similar to those observed during past years. (See "Surface-Water Monitoring," Section 3.3.)

Food and Farm Products — Low levels of radionuclides attributable to worldwide fallout were found in several foodstuff and farm product samples during 1987. Concentrations in samples collected near the Hanford Site were similar to those measured in samples collected away from the Site. Foodstuffs irrigated with water taken from the Columbia River, and downstream of the Site, had the same low, radionuclide concentrations as foodstuffs grown in other areas. (See "Food and Farm Product Monitoring," Section 3.4.)

Wildlife — Samples of deer, fish, gamebirds, waterfowl, and rabbits were collected where potential radionuclide uptake was considered most likely, or at nearby locations where wildlife samples were available. Analytical results of terrestrial wildlife samples collected during 1987 were similar to those observed in recent years. Radionuclide levels in muscle tissue of fish collected near the Site were similar to radionuclide levels seen in upstream samples. The dose that a person who consumed any of the wildlife sampled could have received, even at the maximum radionuclide concentrations measured in 1987, was below applicable DOE standards. (See "Wildlife Monitoring," Section 3.5.)

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Soil and Vegetation — During 1987, low concentrations of radionuclides were measured in onsite and offsite samples of surface soils and rangeland vegetation. However, evaluations of the samples provided no indication of significant increases in concentrations of radionuclides in offsite samples that could be attributed to Hanford operations. Results from special soil samples collected downwind from Hanford did not indicate a measurable buildup of Hanford-derived plutonium. (See "Soil and Vegetation Monitoring," Section 3.6.)

Penetrating Radiation — Dose rates from external penetrating radiation measured in local residential areas were similar to those observed in previous years, and no contribution from Hanford activities could be identified. Measurements made near publicly accessible onsite operating areas and along the Hanford Reach of the Columbia River continued to show several locations where dose rates were higher than those attributable to background sources but were still well below applicable DOE radiation protection standards. (See "Penetrating Radiation Monitoring," Section 3.7.)

Comparison of Measured and Calculated Concentrations — Calculated environmental radionuclide concentrations were compared to measured values and were verified as reasonable estimates. A review of monitoring results from other organizations in Washington State and the Hanford vicinity showed that radionuclide concentrations were similar to national ambient simulation levels. (See "Comparison of Measurements with Calculations and Other Monitoring Results," Section 3.8.)

POTENTIAL RADIATION DOSES FROM 1987 HANFORD OPERATIONS

Measured external radiation exposure and calculated radiation doses to the public from 1987 Hanford operations were well below applicable regulatory limits. The calculated effective dose potentially received by a maximally exposed individual (i.e., the hypothetical individual who receives the maximum calculated radiation dose using maximum assumptions for all routes of exposure) was about 0.05 mrem for 1987, compared to a dose of 0.09 mrem estimated for 1986. The collective effective dose to the population residing within 80 km of the Site was 4 person-rem in 1987 compared to 9 person-rem for 1986. These doses are much less than the doses received from common sources of radiation, such as natural background radiation. They are also much less than the recommended DOE radiation protection standards for protection of the public, which are an average of 100 mrem/yr for prolonged exposure and 500 mrem/yr for occasional annual exposure to a maximally exposed individual. (See "Potential Radiological Doses from 1987 Hanford Operations," Section 4.0.)

QUALITY ASSURANCE

Comprehensive quality assurance (QA) programs were maintained to ensure that the data collected were accurate and representative of actual concentrations in the environment. Standard quality assurance/quality control techniques were used during the sample collection, laboratory analysis, data management, and dose calculation activities. Data quality was verified by a continuing program of analytical laboratory quality control (QC), interlaboratory cross-checks, replicate sampling and analysis, and splitting samples with other laboratories. The QA/QC evaluations documented that the monitoring data were valid. (See "Quality Assurance," Section 5.0.)

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1.0 INTRODUCTION

K. R. Price

Various nuclear and nonnuclear activities have been conducted at the Hanford Site since 1943. The most environmentally significant activities have been the production of nuclear materials for national defense and the associated chemical processing and management of waste products. The U.S. Department of Energy (DOE) conducts effluent control, effluent monitoring, and environmental monitoring at the Hanford Site through contractor organizations. Results are reported to regulatory agencies and the public to demonstrate compliance with applicable rules and regulations. An environmental monitoring program has been conducted at the Hanford Site for the past 44 years. Since 1965, this program has been conducted by the Pacific Northwest Laboratory (PNL), which is operated for the DOE by the Battelle Memorial Institute.

Environmental monitoring activities provide for the measurement, interpretation, and evaluation of sample data and other types of measurements to assess current onsite and offsite environmental impact, to determine compliance with pertinent regulations, and to evaluate the near-term adequacy of onsite waste management practices. Results are not intended to characterize the Hanford environs for long-term waste disposal. The PNL monitoring program (with the exception of the ground-water monitoring) does not include effluent or environmental monitoring within the production or processing areas, which are operated by another contractor. Radionuclide monitoring data are collected to assess the radiation doses from exposure to current effluent releases and to determine compliance with state and federal regulations. Potential environmental impacts are evaluated, with emphasis on the most important environmental pathways.

Since 1946, environmental monitoring results have been recorded in quarterly reports; and since 1958, results have been made publicly available as annual reports (ground-water monitoring reports began in 1956). Results in recent years (through 1984) have been published as separate reports under the titles:

- Environmental Surveillance at Hanford for Calendar Year (monitoring results for the offsite environs)
- Environmental Status of the Hanford Site for Calendar Year (monitoring results for the onsite environs; discontinued as of 1984)
- Ground-Water Monitoring at the Hanford Site for Calendar Year (monitoring results for the onsite subsurface environs; discontinued as of 1984).

Beginning in 1985, these three reports were combined into one document that summarized the data collected each calendar year. This report includes information on all samples and measurements made in the offsite and onsite environment. A brief description of the Hanford Site and ongoing operations, the nature of environmental monitoring activities, and the results and interpretation of environmental monitoring data for 1987 are included. The radiological impact of Hanford operations was assessed by calculating the potential radiation dose to people living in the vicinity of the Hanford Site.

This report emphasizes the radiological status of the Hanford environment and vicinity. Chemical concentrations in air, Columbia River water, and ground water are also discussed. In general, the data were compared to background or control measurements taken at distant locations during 1987 and to data obtained during the past 5 years. Section 4.0, entitled "Potential Radiological Doses from 1987 Hanford Operations," discusses an assessment of radiological doses from the Hanford Site. Potential doses are calculated for a hypothetical maximally exposed individual and for the local population. The dose rates at publicly accessible areas are also discussed.

Radionuclide data are expressed in terms of curies, microcuries, picocuries, or attocuries. The curie (Ci)

is the fundamental unit used to express radioactivity and defines the amount of a substance present based on its rate of radioactive disintegration. A microcurie (μCi) is one millionth (10^{-6}) of a curie. A picocurie (pCi) is one millionth-millionth (10^{-12}) of a curie. An attocurie (aCi) is one millionth-millionth-millionth (10^{-18}) of a curie. Environmental monitoring results often involve very small numbers that are best expressed as picocuries or attocuries.

Metric units are used throughout the report. As an additional aid in expressing small numbers and variable environmental results, data are graphed using either linear or logarithmic (compressed) scales. The radionuclides and corresponding symbols commonly used in this report are listed in Table 1.1. A more complete account of radionuclides addressed by environmental monitoring can be found in Tables G.1, G.3 and G.5, Appendix G. Gross alpha and gross beta results are from screening-type analyses that measure all alpha- or beta-emitting radionuclides in the sample, without specifying the radionuclide present.

Chemicals and the corresponding symbols used in this report are listed in Table 1.2. Because chemical concentrations are often very low, they are expressed as micrograms per liter (μg/L) or, occasionally, milligrams per liter (mg/L).

Environmental monitoring data for 1987 are listed in Appendix A, and a glossary and list of acronyms and abbreviations are presented in Appendix B. Applicable standards and special permits are described in Appendix C. Sample analysis procedures are described in Appendix D. Data analysis methods are summarized in Appendix E. Dose calculation methods used in 1987 are discussed in Appendix F. Appendix G contains effluent data as reported by the operating contractor.

TABLE 1.1. Radionuclide Nomenclature

Radionuclide	Symbol
Antimony-125	^{125}Sb
Carbon-14	^{14}C
Cesium-137	^{137}Cs
Cobalt-60	^{60}Co
Iodine-129	^{129}I
Iodine-131	^{131}I
Krypton-85	^{85}Kr
Nickel-63	^{63}Ni
Plutonium-238	^{238}Pu
Plutonium-239,240	$^{239,240}Pu$
Ruthenium-106	^{106}Ru
Strontium-90	^{90}Sr
Technetium-99	^{99}Tc
Tritium	^{3}H
Uranium (total)	U or uranium
Uranium-234	^{234}U
Uranium-235	^{235}U
Uranium-238	^{238}U

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TABLE 1.2. Elemental and Chemical Constituent Nomenclature

Constituent	Symbol
Aluminum	Al
Ammonium	NH_4^+
Antimony	Sb
Arsenic	As
Barium	Ba
Beryllium	Be
Bicarbonate	HCO_3^-
Boron	B
Cadmium	Cd
Calcium	Ca
Carbonate	CO_3^{2-}
Chloride	Cl^-
Chromium (species)	Cr^{6+}
Chromium (total)	Cr
Copper	Cu
Fluoride	F
Iron	Fe
Lead	Pb
Magnesium	Mg
Manganese	Mn
Mercury	Hg
Nickel	Ni
Nitrate	NO
Phosphate	PO_4^{3-}
Potassium	K
Selenium	Se
Silver	Ag
Sodium	Na
Strontium	Sr
Sulfate	SO_4^{2-}
Vanadium	V
Zinc	Zn

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2.0 BACKGROUND INFORMATION

2.1 DESCRIPTION OF THE HANFORD SITE

K. R. Price, P. J. Mitchell, and M. D. Freshley

The U.S. Department of Energy's Hanford Site is located in a rural region of southeastern Washington and occupies an area of about 1450 km². The Site (shown in Figure 2.1) lies about 320 km northeast of Portland, Oregon, 270 km southeast of Seattle, Washington, and 200 km southwest of Spokane, Washington. The Columbia River flows through the northern edge of the Site and forms part of the eastern boundary. The southern boundary of the Site includes the Rattlesnake Hills, which exceed 1000 m in elevation. Both confined and unconfined aquifers are present beneath the Site. The main geologic units are the Columbia River Basalt Group, the Ringold Formation, and a series of glaciofluvial sediments. The Hanford Project was established in 1943 and was originally designed, built, and operated to produce plutonium for nuclear weapons.

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SURFACE CHARACTERISTICS OF THE SITE

The semiarid land on which the Hanford Site is located has a sparse covering of desert shrubs and drought-resistant grasses. The most broadly distributed type of vegetation on the Site is the sagebrush/cheatgrass/bluegrass community. Most abundant of the mammals is the Great Basin pocket mouse. Of the big-game animals, mule deer is most widely found, while the cottontail rabbit is the most abundant small-game animal. Coyotes are also plentiful. The bald eagle is a regular winter visitor to the islands and riparian communities along the Columbia River.

The Columbia River, which originates in the mountains of eastern British Columbia, Canada, flows through the northern edge of the Hanford Site and forms part of the Site's eastern boundary. The river drains a total area of approximately 70,800 km² enroute to the Pacific Ocean. Flow of the Columbia River is regulated by 11 dams within the United States, 7 upstream and 4 downstream of the Site. Priest Rapids Dam is the nearest impoundment upstream of the Site, and McNary Dam is the nearest dam downstream. (The Hanford reach of the Columbia River extends from Priest Rapids Dam to the head of Lake Wallula, which is created by McNary Dam.) This is the only stretch of the Columbia River within the United States that is not impounded by a dam. The width of the river varies from approximately 300 m to about 1000 m. Flow through this stretch of the river is relatively swift, with numerous bends and several islands present throughout the reach.

The flow rate of the Columbia River through the Site is regulated primarily by Priest Rapids Dam. Flows in the Hanford reach fluctuate significantly because of the relatively small storage capacity and the operational practices of the nearby upstream dams. A minimum regulated flow rate of 1000 cubic meters per second (m³/s) (36,000 cfs) has been established at Priest Rapids. Typical daily flows range from 1000 m³/s to 7000 m³/s (250,000 cfs), with peak spring runoff flows of up to 12,600 m³/s (450,000 cfs). Typical annual average flows at Priest Rapids Dam are 2800 m³/s (100,000 cfs) to 3,400 m³/s (120,000 cfs). Monthly mean flows typically peak from April through June and are lowest from September through October.

The temperature of the Columbia River varies seasonally. Minimum temperatures are observed during January and February, and maximum temperatures typically occur during August and September. Monthly temperatures for the river range from approximately 3°C to about 20°C during the course of a year. Solar radiation, water storage management practices at upstream dams, and flow rate of the river dictate, to a large extent, the thermal characteristics of the Columbia River along the Hanford reach.

The Columbia River system has been developed extensively for hydroelectric power, flood control, navigation, irrigation, and municipal and industrial water supplies. In addition, the Hanford reach is used for a variety of recreational activities including fishing, hunting, boating, water skiing, and swimming.

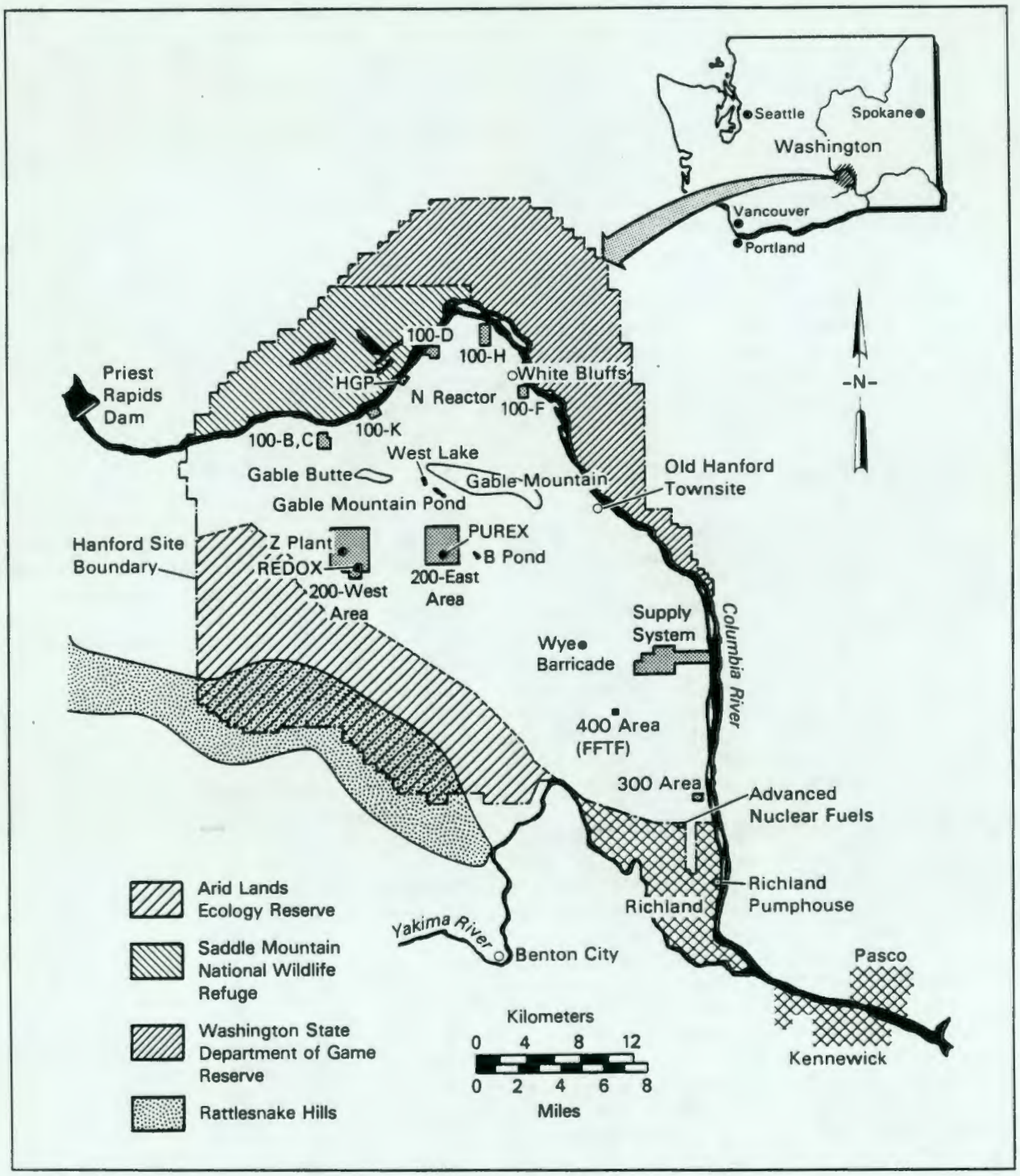

FIGURE 2.1. DOE's Hanford Site

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The State of Washington has classified the stretch of the Columbia River from the Washington-Oregon border to Grand Coulee Dam (which includes the Hanford reach) as Class A and established water quality criteria and water use guidelines for this class designation. Because these criteria do not include specific limits for radionuclides, U.S. Environmental Protection Agency (EPA) and State of Washington drinking water limits were used for comparison. Other surface water on the Site consists of West Lake (a small, natural pond) and a number of ditches and artificial ponds created for routine disposal of waste water.

Hanford's climate is dry and mild; the area receives approximately 16 cm of precipitation annually. About 40% of the total precipitation occurs during November, December, and January; only 10% falls in July, August, and September. Approximately 45% of all precipitation from December through February is snow. The average minimum and maximum temperatures in July are 16°C and 32°C. For January, the average minimum and maximum temperatures are -6°C and 3°C.

Monthly average wind speeds range from about 10 km/h in summer to 14 km/h in winter. The prevailing regional winds are from the northwest, with occasional cold-air drainage into valleys and strong crosswinds. The region is a typical desert with frequent strong temperature inversions that occur at night and break during the day, resulting in unstable and turbulent wind conditions.

Land near the Hanford Site is primarily used for agriculture and livestock grazing. Agricultural lands are found north and east of the Columbia River and south of the Yakima River. These areas contain orchards, vineyards, and fields of alfalfa, wheat, and vegetables. The Hanford Site north of the Columbia River contains both a state wildlife management area and a federal wildlife refuge. The northeast slope of the Rattlesnake Hills along the southwestern boundary of the Site is designated as the Arid Lands Ecology Reserve (ALE) and is used for ecological research by DOE. The area is also designated a National Environmental Research Park (NERP).

The major population center nearest to the Hanford Site is the Tri-Cities (Richland, Pasco, and Kennewick), which is situated on the Columbia River downstream from the Site and has a population of approximately 90,000. Approximately 340,000 people live within an 80-km radius of the Hanford Site. This number includes people living in the Tri-Cities, the Yakima area, several small communities, and the surrounding agricultural areas. More detail on Site characteristics and activities is available in the Hanford defense waste environmental impact statement (DOE 1987a).

SUBSURFACE CHARACTERISTICS OF THE SITE

The DOE operations on the Site have resulted in the production of large volumes of waste water that have historically been discharged to the ground through cribs, ditches, and ponds. These discharges greatly influence the physics and chemistry of the subsurface. Approximately 2.42 billion liters of liquid effluent in the 200 Areas were disposed to the ground during 1987, including process cooling water and water containing low-level radioactive wastes. Approximately 0.8 billion liters of liquid effluent in the 100-N Area were disposed to liquid waste disposal facilities and the sanitary sewer. Discharge of waste water to the ground at Hanford began in the mid-forties and reached a peak in 1955. After 1955, discharge to cribs declined because of improved treatment of waste streams and deactivation of various facilities (Graham et al. 1981). Since restart of the Plutonium Uranium Extraction (PUREX) Plant and related facilities in late 1983, discharge of PUREX-related effluents has resumed.

Subsurface structures, such as cribs, were primarily used for the disposal of water containing radioactive wastes, while surface ponds and ditches were primarily used for disposal of uncontaminated cooling water (Graham et al. 1981). Sanitary wastes are discharged to the ground via tile fields. Most liquid disposal occurred in the separations area, which includes the 200-East and 200-West Areas (Figure 2.1). Smaller amounts of waste water were disposed in the 100 and 300 Areas. Discharges of waste water to the ground in the 400 Area were minimal.

Geologic and hydrologic properties of the subsurface, including stratigraphy and physical and chemical properties of the host rock, influence the movement of liquid effluents. The geology and hydrology beneath the Site and the physical nature of liquid effluent movement are described in more detail in the following sections.

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Geology

The main geologic units beneath the Hanford Site include, in ascending order, the Columbia River Basalt Group, the Ringold Formation, and a series of glaciofluvial sediments informally known as the Hanford formation. A generalized geologic cross section of the Site is shown in Figure 2.2.

The Columbia River Basalt Group is a thick series of basalt flows. The basalts have been warped and folded, producing anticlines that, in some places, crop out at the land surface. The Ringold Formation overlies the basalts except in some localized areas. This formation consists of fluvial and lacustrine sediments and is separated into four lithologic units: basal, lower, middle, and upper. The basal and middle units consist mostly of semiconsolidated gravels and sands, whereas the lower and upper units consist mainly of bedded silts and sands. Beneath the 200-West Area, sediments of the upper Ringold Formation have been reworked by the wind and deposited as a silt layer called the Palouse soil. The Hanford formation rests atop the Ringold Formation or Palouse soil and atop basalts in places where the Ringold Formation has been removed. These sediments were deposited by the ancestral Columbia River when it was swollen by glacial meltwater. The glaciofluvial sediments consist primarily of gravels and sands, with some silts (Newcomb, Strand, and Frank 1972).

Hydrology

Both confined and unconfined aquifers are present beneath the Site. The confined aquifers where ground water is under pressure greater than that of the atmosphere, are found primarily within the Columbia River basalts. In general, the unconfined or water-table aquifer is located in the Ringold Formation and glaciofluvial sediments, as well as some more recent alluvial sediments in areas adjacent to

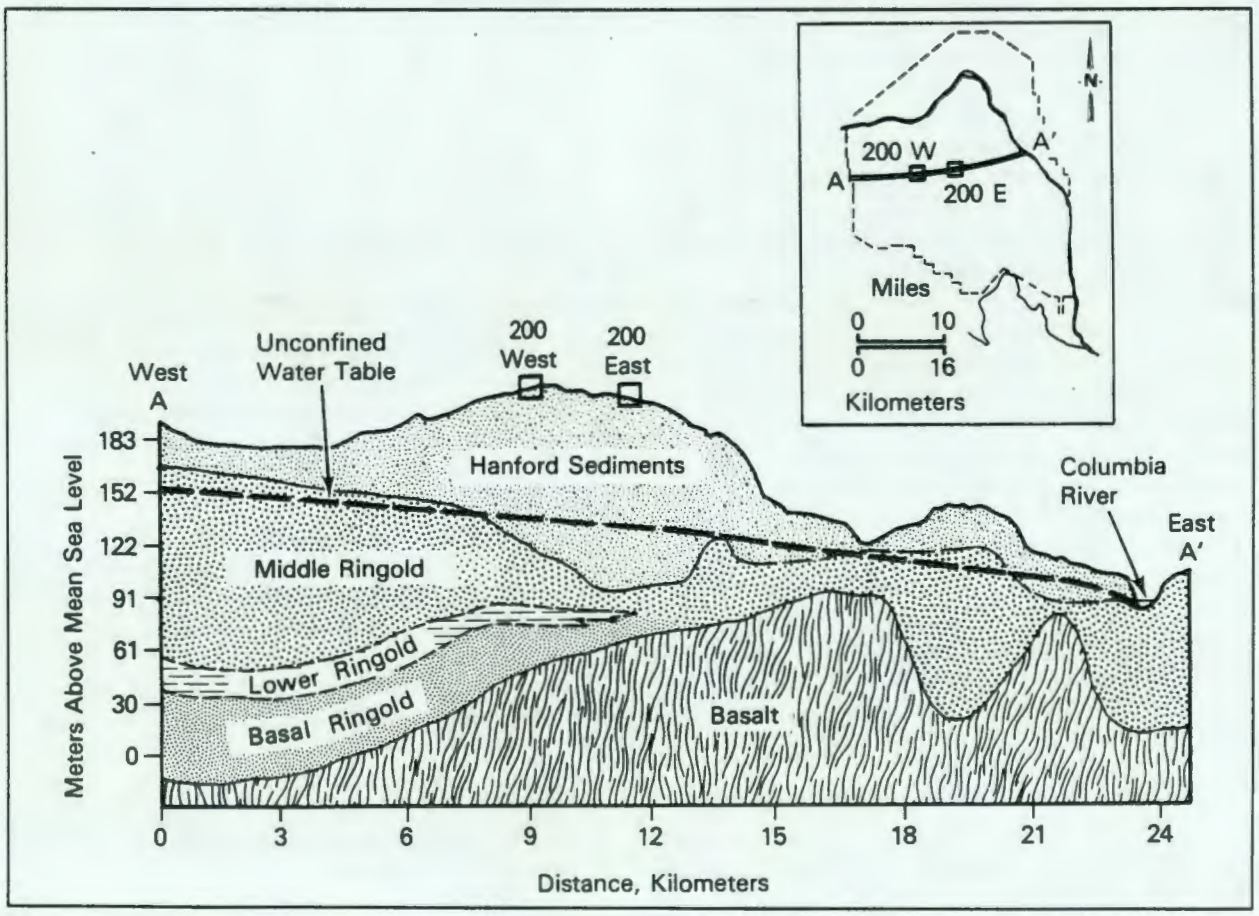

FIGURE 2.2. Geologic Cross Section of the Site (modified from Tallman et al. 1979)

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the Columbia River (Gephart et al. 1979). This relatively shallow aquifer has been affected by wastewater disposal at Hanford more than the confined aquifers (Graham et al. 1981). Therefore, the unconfined aquifer is the most thoroughly monitored aquifer beneath the Site.

The unconfined aquifer is bounded below by either the basalt surface or, in places, the relatively impervious clays and silts of the lower unit of the Ringold Formation. Laterally, the unconfined aquifer is bounded by the anticlinal basalt ridges that ring the basin and by the Yakima and Columbia rivers. The basalt ridges above the water table have a low permeability and act as a barrier to lateral flow of ground water (Gephart et al. 1979). The saturated thickness of the unconfined aquifer is greater than 61 m in some areas of the Hanford Site and pinches out along the flanks of the basalt anticlines. Depth from the ground surface to the water table ranges from less than 0.3 m near the Columbia River to over 106 m in the center of the Site. Elevation of the water table above mean sea level for June 1987 is shown in Figure 2.3.

Recharge to the unconfined aquifer originates from several sources (Graham et al. 1981). Natural recharge occurs from precipitation at higher elevations and runoff from ephemeral streams, such as Cold Creek and Dry Creek to the west. The Yakima River recharges the unconfined aquifer as it flows along the southwest boundary of the Hanford Site. The Columbia River recharges the unconfined aquifer during high stages when river water is transferred to the aquifer along the river bank. The unconfined aquifer receives little, if any, recharge from precipitation directly on the Hanford Site because of a high rate of evapotranspiration from native soil and vegetation. However, studies described by Heller, Gee, and Meyers (1985) suggest that precipitation may contribute more recharge to the ground water than was originally thought.

Large-scale artificial recharge occurs from offsite agricultural irrigation and liquid-waste disposal in the operating areas. Recharge from irrigation in the Cold Creek Valley enters the Hanford Site as ground-water flow across the western boundary. Artificial recharge from waste-water disposal occurs principally in the separations area. Recharge to the ground water from facilities in the separations area (including B Pond and Gable Mountain Pond, as well as the various cribs and trenches in the 200-West and 200-East Areas) is estimated to add ten times as great an annual volume of water to the unconfined aquifer as is contributed by natural inflow to the area from precipitation and irrigation waters to the west (Graham et al. 1981).

The operational discharge of water has created ground-water mounds near each of the major waste-water disposal facilities in the separations area. These mounds have altered the local flow pattern in the aquifer, which is generally from the recharge areas in the west to the discharge areas (primarily the Columbia River) in the east. Water levels in the unconfined aquifer have changed continuously during Site operations because of variations in the volume of waste water discharged. Consequently, the movement of ground water and its associated constituents has also changed with time.

In addition to the separations area, ground-water mounding also occurs in the 100 and 300 Areas. Ground-water mounding in these areas is not as significant as in the separations area because of differences in discharge volumes and subsurface geology. In the 100 and 300 Areas, water levels are also greatly influenced by river stage.

Liquid Effluent Movement

As significant quantities of liquid effluents are discharged to the ground at Hanford waste disposal facilities, these effluents percolate downward through the unsaturated zone to the water table. As effluents move through the unsaturated zone, adsorption onto soil particles, chemical precipitation, and ion exchange delay the movement of some uncomplexed radionuclides, such as ^{90}Sr, ^{137}Cs, and $^{239,240}Pu$. Other ions, such as nitrate (NO_3^-), and radionuclides, such as ^{3}H, ^{99}Tc, and ^{129}I, are not as readily retained by the soil. These constituents move through the soil column at varying rates and eventually enter the ground water. Subsequently, the non-attenuated constituents move downgradient in the same direction as and at a rate nearly equal to the flow of ground water. As the constituents move with the ground water, radionuclide concentrations are reduced by spreading (dispersion) and radioactive decay .

MAJOR ACTIVITIES

Four major DOE operating areas exist at the Hanford Site [i.e., 100, 200, 300, and 400 Areas (Figure 2.1)]. The 100 Areas include facilities for the N Reactor and

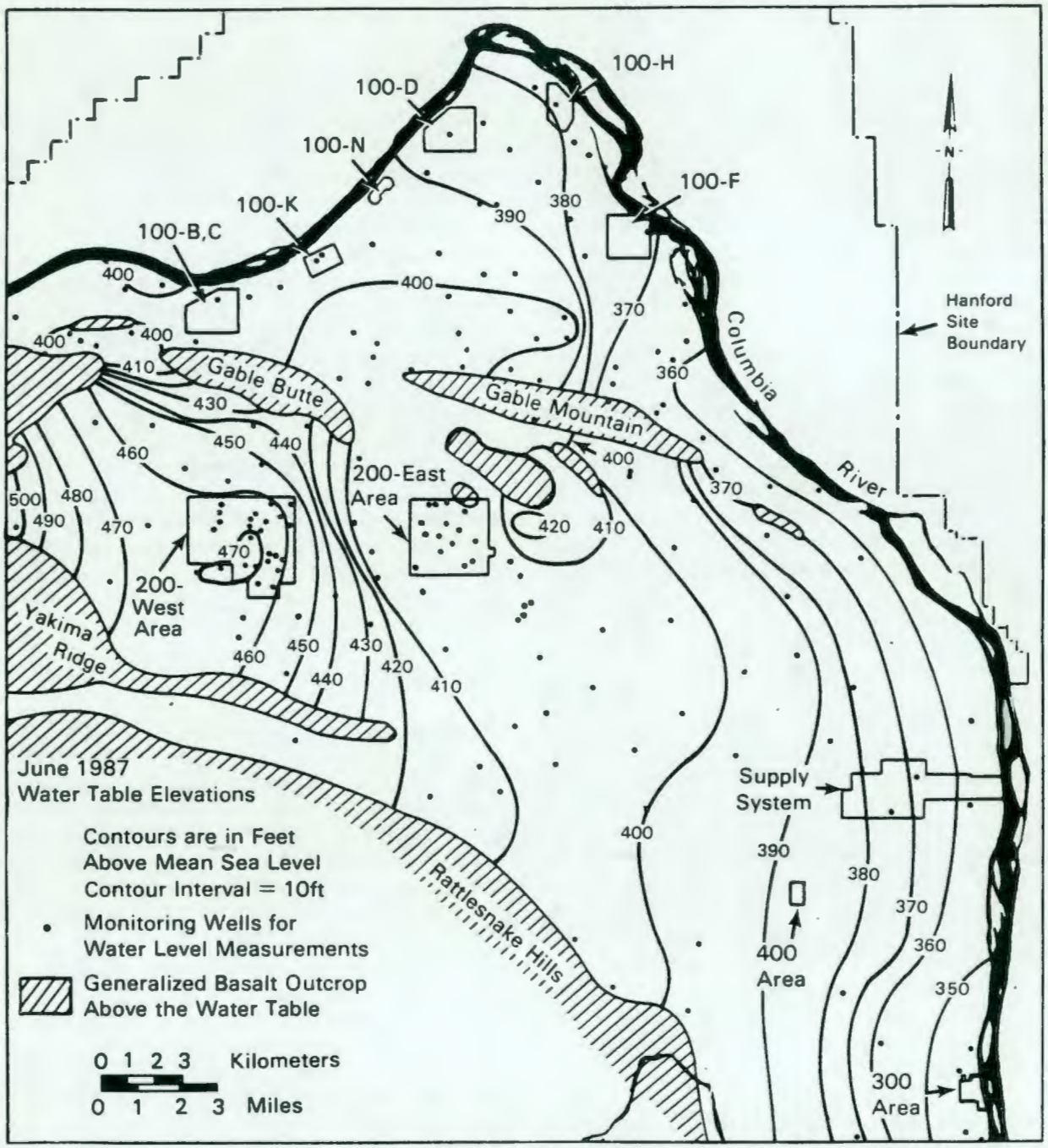

FIGURE 2.3. Water Table Elevations for June 1987 (Schatz, Ammerman, and Serkowski 1987)

the eight deactivated production reactors along the Columbia River. The reactor fuel reprocessing plant (PUREX), Plutonium Finishing Plant (Z Plant), and waste-management facilities are on a plateau about 11.3 km from the river, in the 200 Areas. The 300 Area, just north of the city of Richland, contains the reactor fuel manufacturing facilities and research and development laboratories. The Fast Flux Test Facility (FFTF) is located in the 400 Area, approximately 8.8 km northwest of the 300 Area.

Privately owned facilities located within the Hanford Site boundaries include the Washington Public Power Supply System (Supply System) Hanford

Generating Project (HGP) adjacent to N Reactor, the Supply System power reactor and office buildings, and a low-level radioactive-waste burial site operated by U.S. Ecology. The Advanced Nuclear Fuel Corp. (formerly Exxon) fuel fabrication facility is immediately adjacent to the southern boundary of the Hanford Site.

Former operations by Rockwell Hanford Operations and UNC Nuclear Industries were consolidated into a single contract during 1987. Principal DOE contractors at Hanford at the end of 1987 included the following:

Westinghouse Hanford Company (WHC) — responsible for operating the Hanford Engineering Development Laboratory, including the FFTF test reactor; fabricating N Reactor fuel and operating N Reactor; reprocessing fuel and managing waste; decommissioning old facilities; and providing Site support services, such as security, fire protection, central stores, and electrical power distribution.

Battelle Memorial Institute (BMI) — responsible for operating PNL for DOE. Activities at PNL include research and development in the physical, chemistry, life, and environmental sciences; and advanced methods of nuclear waste management. The PNL is also responsible for environmental monitoring at the Site.

Kaiser Engineers Hanford Company (KEH) — responsible for architectural and construction engineering.

Hanford Environmental Health Foundation (HEHF) — responsible for occupational medicine and environmental health support services.

Boeing Computer Systems Richland (BCSR) — responsible for computer operations and support services.

Operational Highlights

The following are highlights of operational activities at Hanford during 1987:

- The N Reactor operated for 6.4 days and supplied steam to the Supply System to generate 860 megawatts of electrical power. The short operating time was caused by a scheduled, extended shutdown of the reactor to permit work on safety improvement modifications. Since its startup, the N Reactor has supplied steam for the production of over 65-billion kilowatts of electricity that were supplied to the Bonneville Power Administration power-grid covering the Pacific Northwest.

- The PUREX Plant fuel reprocessing facility located in the 200-East Area operated for 2 months during 1987. This is the fourth year of operation since restart in 1983. The Uranium Oxide Plant (UO_3) underwent modifications and did not operate in 1987. The Plutonium Reclamation Facility at Z Plant operated for approximately 6 months in 1987.

- The FFTF operated successfully during 1987, achieving a 100% operational efficiency factor for the year. A capacity factor of 76.5% and an availability factor of 78% also set new FFTF records. Also for the first time, FFTF achieved a 105-day continuous run at full power. The test reactor was used to produce radioactive elements for medical and commercial purposes. Several research and laboratory facilities operated to support the FFTF and other Hanford activities.

- The 300 Area Fuel Fabrication Facilities, which produce fuel elements for N Reactor, did not operate during 1987.

- Several retired facilities in the 100 Area underwent various stages of decommissioning. Cleanup of the 183-H basins progressed with the cleanout and lining of basin no. 3. The 183-B water treatment facility and the 1608-D, -DR, -F, and -H lift stations were demolished and buried in situ. After demolition, the sites were backfilled and restored to the natural contour of the surrounding land.

Work at Hanford during 1987 also included Hanford NERP and ALE studies, Basalt Waste Isolation Project (BWIP) activities, and continued operation of various national research and laboratory facilities.

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2.2 ENVIRONMENTAL MONITORING

K. R. Price

All DOE sites conduct environmental monitoring and report results on an annual basis, according to DOE Orders 5480.1A and 5484.1. The policy of DOE is to operate facilities such that radiation doses to members of the public are maintained as low as reasonably achievable (ALARA) consistent with technology and associated cost and applicable dose standards. A primary purpose of environmental monitoring is to estimate and assess radiation doses to individuals and groups of individuals (a population) who potentially could be exposed to radioactive materials and radiation in the environment from present and past operations of Hanford facilities. The risk to people is evaluated by comparing potential doses received from Hanford sources to established standards and to doses received from natural background and fallout radiations. Another purpose of environmental monitoring is to determine concentrations and assess potential impacts of nonradiological materials in the environment. A third purpose is to detect and assess any increasing trends in environmental radiation dose rates and in radioactive and nonradioactive material concentrations found in various kinds of environmental samples that may result from Hanford operations. The final purpose is to inform the public as well as federal, state, and local regulatory agencies of changes in the radiological and nonradiological status of the environment.

SCOPE

The scope of environmental monitoring encompasses all potential effluents, including chemical and radioactive materials. Monitoring activities are selected to be responsive to both routine and potential releases of effluents according to the severity of possible impact on the environment or public health. Activities also provide a feedback system to evaluate the adequacy and effectiveness of containment and effluent control systems. The DOE and appropriate facility manager are notified if off-standard conditions or adverse trends are detected in the environment near operating areas.

OBJECTIVES

The objectives of the program include the following:

- assessing environmental impacts to the off-site public during 1987 from Hanford Site operations
- verifying that in-plant controls for the containment of radioactive and nonradioactive materials within controlled areas (i.e., on the Site) are adequate
- monitoring to determine potential buildup of long-lived radionuclides in uncontrolled areas (i.e., off the Site)
- providing information to regulatory agencies and the public that helps assess operational impacts and identify noteworthy changes in the radiological and nonradiological status of the environment.

CRITERIA

The criteria for environmental monitoring are derived from requirements set forth in applicable federal, state, and local regulations, and recommendations given in the monitoring guide published for use at DOE sites (Corley et al. 1981). These criteria have been applied through the use of critical radionuclides, exposure pathways, and exposure rates. Experience gained from environmental monitoring activities conducted at Hanford for over 40 years has also provided significant support for program planning and data evaluation.

The primary pathways available for movement of radioactive materials and chemicals from Hanford operations to the public are the atmosphere, surface water, and ground water. Figure 2.4 illustrates these potential routes and the subsequent network of possible exposure pathways to humans. The significance of each pathway is determined from data and models that estimate the amount of radioactive material potentially available to be transported along the pathway and its resultant radiation dose. To ensure that radiological analyses of samples are

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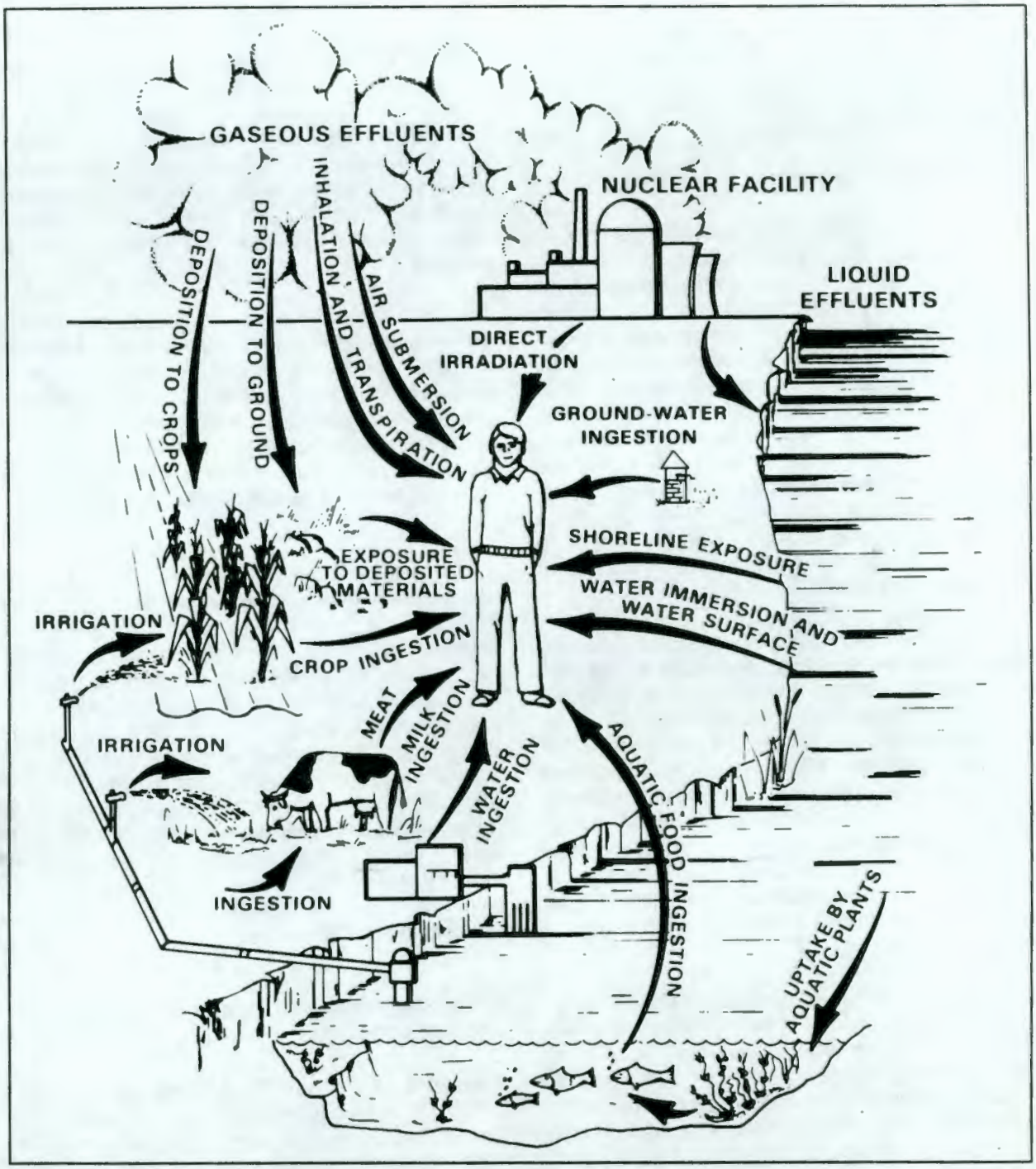

FIGURE 2.4. Primary Radiation Exposure Pathways

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sufficiently sensitive, minimum detectable concentrations of critical radionuclides in air, water, and food were established and appear in Table D.1, Appendix D. Minimum detectable concentrations for other types of samples are also listed.

MONITORING DESIGN

Environmental monitoring at Hanford is designed in response to specific characteristics of the Site and its operating facilities. Operating facilities have effluent control systems to reduce the amounts of materials released to the environment and systems to measure the quantities of effluents that are released. The history of effluent releases from each facility, along with known biological effects of radiation exposure, are used to determine what is important to monitor. Environmental monitoring consists of collecting and analyzing samples and measuring radiation. Monitoring at Hanford is designed to meet the objectives of the program and is not intended to provide a detailed radiological characterization of the Site or the surrounding area.

Environmental monitoring investigates environmental pathways that may contribute to radiation exposure of the public. Pathways are derived from the results of studies and observations on the movement of radionuclides through the environment and through food chains. Pathways are monitored from near the facilities releasing effluents to the location of offsite residents. The monitoring design at Hanford uses a stratified sampling approach to monitor these pathways. Samples are collected and radiation is measured according to three zones that extend away from main onsite operating areas to the offsite environs.

The first zone extends from operating facilities to the Site perimeter. Air monitoring stations surround each operating area because air transport is a critical pathway, in terms of the potential, for rapid transport of radioactive materials off the Site. In addition to air monitoring, samples of soil, native vegetation, and wildlife are collected and radiation measured to determine the effectiveness of effluent controls and any buildup of radioactive materials from long-term operations. Onsite road and railroad rights-of-way and retired waste disposal areas are also monitored.

The second monitoring zone consists of a series of air sampling stations positioned around the Site perimeter. Data from these stations document the levels of radioactivity at the Site boundary. Agriculture is an important industry near the Site; therefore, milk, crops, soil, and native vegetation are monitored to detect any influence from Hanford on locally produced food and farm products. The Columbia River is included in the second zone. River water is monitored upstream of the Site and at Richland where it is used for public drinking water. Water pumped from the Columbia River for irrigation is also monitored.

The third monitoring zone consists of communities and other distant locations within a 80-km radius of the Site. Monitoring at communities provides a visible assurance to the public that Hanford effluents are monitored and radionuclide concentrations recorded at populated areas. Distant locations are also monitored to provide data to compare with data collected from the Site perimeter and onsite locations.

The potential radiation dose received by the public can be estimated from environmental monitoring data. However monitoring results from the offsite environs and communities near the Site usually do not indicate an impact from Hanford operations. When the monitoring cannot detect a Hanford impact, potential radiation doses to the public are calculated using data from effluent measurements and computer models. The computer models are specific to the Hanford Site and vicinity and include local dietary habits and recreational use of the Columbia River. These models simulate the movement of radioactive materials through the environment, food pathways, and consumption by the public, and the resulting radiation dose.

ENVIRONMENTAL PROTECTION STANDARDS AND PERMITS

Operations at the Hanford Site are controlled to conform to various federal and state standards and permits. Radiological releases are regulated by DOE orders pursuant to the Atomic Energy Act, the Clean Air Act, and the Safe Drinking Water Act. Nonradiological releases are subject to the same state and federal laws and regulations as any civilian facility.

Environmental radiation protection standards are published in DOE Order 5480.1A (DOE 1981a). In 1985, DOE issued a revision to this order that incorporates a system for evaluating and controlling

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radiation exposures to members of the public in uncontrolled areas. The revision is based on recommendations of the International Commission on Radiation Protection (ICRP 1977; 1979-1982). These revisions are contained in a DOE directive, "Radiation Standards for Protection of the Public in the Vicinity of DOE Facilities," Revision 1, September 3, 1985. (See Table C.5, Appendix C.) The standards limit exposure to members of the public to 100 mrem per year for prolonged exposures, and to 500 mrem per year for maximum occasional exposure (not to exceed 5 consecutive years). These standards also limit whole-body dose to 25 mrem per year for air pathways, in compliance with 40 CFR 61, Subpart H (EPA 1983). Dose calculations reflecting the revised standards are now calculated using 50-year Committed Dose Equivalent Factors and Effective Dose Equivalent Factors. The radionuclide concentration guides for air and water in DOE Order 5480.1A are no longer current. Instead, DOE has prepared draft tables of Derived Concentration Guides (DCG) that are similar in form to the tables in DOE Order 5480.1A but reflect the new standard. As stated in DOE Order 5480.1A , DOE is required to cooperate with the EPA, state, interstate, and local agencies in the prevention, control, and abatement of environmental pollution.

Water quality standards for the Columbia River are implemented by the Washington State Department of.Ecology (WDOE 1982). Of importance to Hanford operations is the designation of the Hanford reach of the Columbia River as Class A Excellent. This designation requires that the water be usable for substantially all needs, including raw drinking water, recreation, and wildlife. Class A water standards are summarized in Appendix C. The Clean Water Act requires the issuance of permits for liquid discharges to the Columbia River under the National Pollutant Discharge Elimination System (NPDES). Eight Hanford discharge points have been covered under an NPDES permit issued to DOE by the EPA. The DOE has requested a continuation of the permit. This permit authorizes the release of nonradiological liquid discharges to the river and requires sampling, monitoring, and reporting for each discharge.

Applicable ambient air quality standards are enforced by the Benton, Franklin, Walla Walla Counties Air Pollution Control Authority. Standards for nitrogen dioxide in air are also given in Appendix C. The Clean Air Act of 1977 requires facilities emitting pollutants that may affect air quality to have Prevention of Significant Deterioration (PSD) permits. A PSD permit was issued to the DOE-Richland Operations Office (RL) by the EPA in 1980 and legally limits the amount of nitrogen oxides released annually from the PUREX Plant and the UO_3 Plant.

The release of chemical wastes to the environment is restricted by limits described in the Resource Conservation and Recovery Act (RCRA). Chemical waste activities on the Hanford Site are regulated jointly by EPA and WDOE. Waste regulations require facilities that treat, store, or dispose of chemical wastes to have permits. Facilities that are known to have received chemical wastes but do not intend to continue operations must submit closure and post-closure permit applications. The DOE has submitted the appropriate permit applications for active and inactive facilities seeking closure.

PROGRAM DESCRIPTION

Environmental monitoring provides for the measurement and interpretation of the impact of Hanford operations on the public and the onsite and offsite environment. Concentrations of measured radioactive materials are compared to applicable standards, concentration guides, and natural levels of radiation and radioactive materials (including worldwide fallout). The program is designed to examine all significant exposure pathways, including direct radiation exposure from operating facilities. Radiological impacts are expressed in terms of radiation exposures. Numerous samples were collected and analyzed according to a schedule.

Table 2.1 summarizes the geographic distribution of sample types and measurement locations. Schedules, records, and data were maintained in a computer system. In addition, unscheduled work was conducted in response to specific needs (see "Public Information Activities," in this section).

Laboratory analyses of samples for radioactivity and chemicals were conducted by U.S. Testing Company, Inc. (UST), Richland, Washington. Analyses of environmental dosimeters for penetrating radiation were performed by PNL. Ground-water sample analyses were performed by PNL's analytical laboratories, HEHF, and UST. Water quality, temperature, and flow rates for the Columbia River were determined by the U.S. Geological Survey (USGS). Quality assurance (QA) was an integral part of the

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TABLE 2.1. Environmental Sample Types and Measurement Locations

Sample Types	Sample Locations: Total Number	Onsite	Perimeter	Nearby Communities	Distant Communities
Air	50	21	14	9	6
Ground Water	563	563	-	-	-
Columbia River	3	-	2	1	-
Irrigation Water	1	-	1	-	-
Drinking Water	8	8	-	-	-
Ponds	4	4	-	-	-
Foodstuffs	8	-	5	1	2
Wildlife	10	9	1	-	-
Soil & Vegetation	38	15	14	3	6
Dose Rate	91	31	45	9	6
Waste Site Surveys	72	72	-	-	-
Railroad/Roadway Surveys	16	16	-	-	-
Shoreline Survey	14	-	14	-	-

program. Details on sampling, analysis, measurement, dose assessments, and QA are discussed in the sections that follow.

RELATED PROGRAMS, SPECIAL STUDIES, AND REPORTS

There are a number of other programs and special studies that relate to sitewide environmental monitoring.

Operating Areas Monitoring

The Westinghouse Hanford Company, the operating and engineering contractor, measures and records the amounts of liquids, gases, and solids and the concentrations of radioactivity and hazardous substances contained in effluents released to the environment. Effluent releases reported by the operating contractor are summarized in Appendix G. The operating contractor takes environmental measurements near facilities to audit the control of environmental releases and the general conditions of the local environment around its operations. These measurements supplement the extensive onsite and offsite monitoring done by PNL. An annual environmental report is published by WHC.

Drinking Water Monitoring

Drinking water was supplied to DOE-operated facilities on the Hanford Site during 1987 by 19 separate systems. Fourteen of the systems used Columbia River water as a raw water source, four systems used ground water, and one system (Richland municipal) used a combination of the two. Monitoring of the drinking water on the Hanford Site was a joint effort between HEHF and PNL, with HEHF specializing in the areas of chemical and microbiological quality and PNL focusing on radiological quality. The primary purpose for the surveillance of Hanford Site drinking water was to determine if the quality of the water complied with federal and state drinking water standards. Results of the drinking water surveillance program are reported annually by HEHF with contributions from PNL (Somers 1988).

Resource Conservation and Recovery Act Monitoring (RCRA)

Established by the U.S. Congress in 1976, RCRA requires a comprehensive program to regulate and monitor the movement of hazardous wastes from generation to final disposal. One aspect of RCRA involves ground-water monitoring at waste facilities. Ground-water monitoring programs designed to comply with RCRA were conducted at the 183-H Solar Evaporation Basins in the 100-H Area, the 300 Area Process Trenches, and the Low-Level Waste Burial Grounds in the 200 Areas. A detection-level, ground-water monitoring program began in 1986 at the Nonradioactive Dangerous Waste (NRDW) Landfill, 3 miles southeast of the 200-East Area. Well installation at the Solid Waste Landfill immediately adjacent to the NRDW Landfill, was completed in 1987, after which a detection-level monitoring program was initiated. Monitoring activities are described in DOE (1987b).

Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Assessments

The CERCLA, as amended by the Superfund Amendments and Reauthorization Act of 1986, provides for liability, compensation, cleanup, and emergency response for hazardous substances released to the environment and the cleanup of inactive hazardous waste sites, including those sites on federal installations. CERCLA assessment activities were performed in 1987 under the Inactive Waste Site Surveillance Project. Work consisted of identifying, investigating, and ranking engineered-facility and unplanned release sites. The Hanford Inactive Site Surveillance data base was updated to reflect the current ranking of each site. Level I Remedial Investigation Work Plans were developed for the

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Strontium Semiworks, liquid-waste disposal sites, and the 300 Area Process Ponds under DOE Order 5480.1A directives.

Nonradiological Air Monitoring

Nonradiological pollutants in atmospheric releases from chemical-processing plants and fossil-fueled steam plants at Hanford consisted primarily of nitrogen oxides (NO_x). The Hanford Environmental Health Foundation operated a nine-station network to sample ambient air nitrogen dioxide (NO_2) in 1987. Total suspended particulate monitoring was conducted at the BWIP exploratory shaft site during 1987 and results are summarized in "Air Quality Monitoring," Section 3.1.

Wildlife Census

The purpose of the wildlife census was to determine the population status of a few key wildlife and fish species that inhabit the Hanford Site. Information on populations of spawning chinook salmon and nesting Canada geese has been obtained for 33 consecutive years. The American bald eagle is a "threatened" species in the state of Washington (U.S. Fish and Wildlife Service 1986). Aerial censuses of bald eagles have been obtained since the 1960s. In recent years, the status of nesting hawks, long-billed curlews, and great blue herons has been added to the wildlife census. In general, the conservative use of the land and water resources of the Hanford Site has benefited indigenous wildlife species. The number of spawning salmon has increased in recent years in response to fishery's management practices. The number of bald eagles has also increased because of the increased food supply of spawned-out, dead salmon. The population of nesting geese has remained relatively stable. Results of the wildlife census were reported recently in a scientific journal (Rickard and Watson 1985).

Public Information Activities

Environmental monitoring personnel participated in a variety of meetings during 1987 to discuss monitoring results with public interest groups, professional groups, farm business organizations, and visitors to the Hanford Site. Special meetings were held with representatives of the Washington wine industry and eastern Washington legislators concerning ^{129}I in the environment and with the Farm Bureau and local farmers concerning uranium in water from eastern Washington wells, as measured by the Washington State Department of Social and Health Services (WDSHS) and PNL.

The final Environmental Impact Statement for Disposal of Hanford Defense High-Level, Transuranic and Tank Wastes (HDW-EIS) was released in December 1987 (DOE 1987a). The five-volume, 2000-page document examines the short- and long-term risks, costs, and socioeconomic and ecological impacts of several alternatives for the disposal of defense wastes located at the Hanford Site. Completion of the HDW-EIS represents a major step forward in the decision-making process.

A cooperative effort to sample and analyze water from the Columbia River and riverbank springs was conducted again in 1987 by the states of Washington and Oregon, the EPA, the Umatilla Indian tribe, and the Hanford Education Action League of Spokane, Washington. Sufficient samples were collected from the 100-N Area Springs and the Columbia River to provide an aliquot to each of the participating agencies or groups (see "Quality Assurance," Section 5.0).

In December 1987, the Quality Assurance Task Force, which is sponsored by the WDSHS, conducted a review of the environmental monitoring programs in the Pacific Northwest. The review was conducted by a panel of three experts from university and private consulting organizations. The organizations whose programs were reviewed included the states of Washington and Oregon, the Supply System, WHC, PNL, the Nez Perce Tribe, the Confederated Tribes of the Umatilla Indian Reservation, and the Yakima Indian Nation. This review was open to the public. The panel concluded that the radiation dose to the public from current Hanford operations has been adequately assessed and is very low (less than one millirem per year).

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3.0 ENVIRONMENTAL MONITORING RESULTS

3.1 AIR MONITORING

R. K. Woodruff

The transport by wind of atmospheric releases of radioactive and nonradioactive materials from Hanford to the surrounding region represents a direct pathway for human exposure. The radioactive materials in air were sampled continuously on the Site, at the Site perimeter, and in nearby and distant communities at 50 locations. Particulates filtered from the air at all locations were analyzed for radionuclides. Air was sampled and analyzed for selected gaseous radionuclides at selected locations. Nitrogen dioxide was sampled at eight onsite locations and one offsite location. Total suspended particulates were sampled at one onsite location.[a]

Many of the radionuclides released to the environment at Hanford are also found worldwide from two other sources: those that are naturally occurring and those resulting from worldwide nuclear weapons testing fallout. Those samples collected at distant community locations within the region essentially only contained contributions from natural and fallout sources, as evidenced by comparison to data obtained before restart of the PUREX Plant and by comparison to EPA data from locations outside the region. The influence of Hanford emissions on local radionuclide levels is indicated by the difference between concentrations measured at distant community locations within the region and concentrations measured closer to the Site.

In 1987, the annual average Hanford Site perimeter concentrations of ^{85}Kr, uranium, and ^{239,240}Pu were numerically greater than levels measured at distant monitoring stations. These differences were not significantly different statistically (at the 5% significance level). Iodine-129 was numerically larger at the perimeter stations than at the distant stations and the difference was significant statistically (beyond the 0.5% significance level). However, even the maximum individual perimeter sample for any radionuclide was only 0.5% of the applicable DOE DCG. The total dose from air emissions is compared to Clean Air Act and Department of Energy dose standards in the section "Potential Radiological Doses from 1987 Hanford Operations." Annual average NO_2 concentrations at all sampling locations remained well below federal and Washington State ambient air standards.

SAMPLE COLLECTION AND ANALYSIS

Radioactivity in air was sampled by a network of continuously operating air samplers at 21 locations on the Hanford Site, 14 near the Site perimeter, 9 in nearby communities, and 6 in relatively distant communities (see Figure 3.1 and Table A.1, Appendix A). Air samplers on the Hanford Site were located primarily around the major operating areas to characterize maximum concentrations in the air from Site operations. Site perimeter samplers were located on all sides, with emphasis in the prevailing downwind directions to the south and east of the Site, to characterize concentrations at the boundaries nearest to residences. Continuous samplers located in Benton City, Connell, Eltopia, Kennewick, Mattawa, Othello, Pasco, Prosser, and Richland provided data to characterize air concentrations in the nearest population centers. Samplers at McNary Dam and in the distant communities of Moses Lake, Sunnyside, Walla Walla, Washtucna, and Yakima provided data from relatively unaffected locations for comparison.

Samples were collected according to a schedule established before each monitoring year. The distribution of air samples by types is summarized in Table 3.1. Radionuclides in airborne dust were sampled for 2 weeks by continuously drawing air at

(a) Nitrogen dioxide and total suspended particulate sampling and analysis were performed by HEHF.

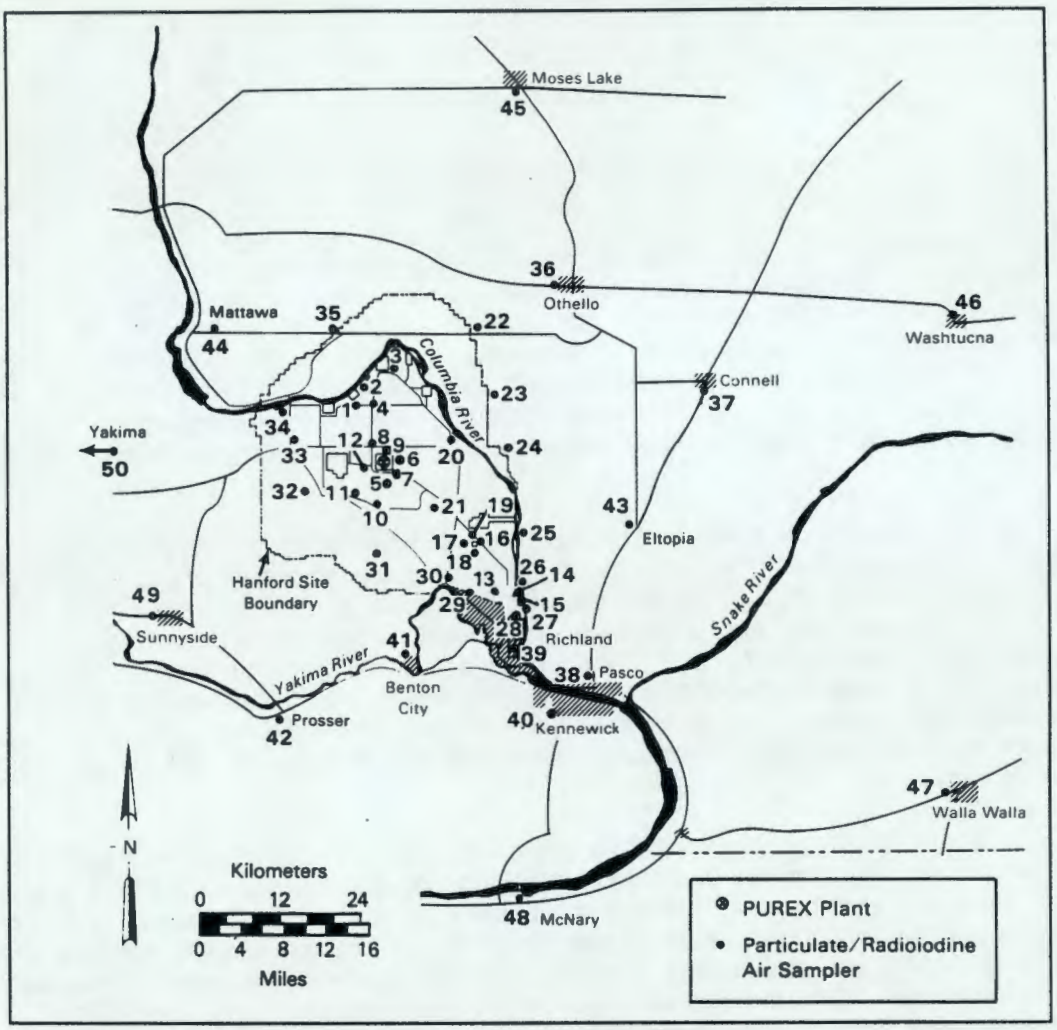

FIGURE 3.1. Air Sampling Locations (see Table A.1, Appendix A, for location key)

a flow rate of 2.6 m^3/h through a 5-cm-diameter high-efficiency, fiber glass filter.[a] (Airborne dust that has been removed from the air by rain or dry deposition to the soil or vegetation is contained in soil and vegetation samples. See "Soil and Vegetation Monitoring," Section 3.6.) The filters were collected every 2 weeks, held for 7 days, and analyzed for gross beta radioactivity. The holding period was necessary to allow for the decay of short-lived, naturally occurring radionuclides that would otherwise obscure detection of the lower levels of longer-lived radionuclides potentially present from Hanford emissions. The gross beta measurement provides a current indication of changes in environmental trends that could warrant special attention. In addition, filters from selected locations were analyzed for gross alpha radioactivity in a similar manner for the same purpose.

For most radionuclides, the amount present in the atmosphere that could have been collected on a particle filter by continuously sampling for 2 weeks was too small to be measured with the accuracy desired. Because the accuracy of sample analysis is increased when the sample contains more material, two biweekly samples were combined into monthly composite samples for each location. The monthly composites for a few nearby locations were then combined to form a geographical composite. (The 24 geographical composites used in 1987 are listed in Table A.1, Appendix A.) Each of the monthly

(a) Measured efficiencies exceed 99% for 0.3-μm particles.

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TABLE 3.1. Distribution of Air Sample Types by Location

Locations	Particulates				Gases				
	Gross Beta	Gross Alpha	^{89}Sr, ^{90}Sr ^{238}Pu, $^{239,240}Pu$[a]	Uranium[a]	^{131}I[b]	^{129}I	^{3}H	^{14}C	^{85}Kr
	Numbers of Locations Sampled								
Onsite	21	17	8/21	5/16	7/21	1	6	2	2
Perimeter	14	10	7/14	2/4	5/14	2	8	None	4
Nearby Communities	9	2	5/9	None	1/9	None	1	None	3
Distant Communities	6	2	4/6	2/2	2/6	1	2	2	2

(a) Number of location-composited samples/total number of individual locations contained in the composites. For example, 7/21 indicates 7 composite groups that are made up of 21 individual locations, or 3 individual locations per composite on the average. The individual locations making up composite groups are listed in Table A.1 and shown in Figure 3.1.

(b) Number of locations analyzed routinely/number of locations sampled routinely. (See "Sample Collection and Analysis," in this section.)

geographical composites was analyzed for 52 gamma-emitting radionuclides (listed on page D.1, Appendix D), then combined into quarterly composites and analyzed for strontium and plutonium. Selected quarterly composites were analyzed for uranium isotopes.

Gaseous ^{131}I was sampled by drawing a 2.6 m^3/h air flow through a 6.3-cm-dia by 2.5-cm-deep cartridge containing activated charcoal.[a] These cartridges were placed downstream of the particle filter at each air sampling station. Charcoal cartridges from routine sampling locations were exchanged biweekly and analyzed for ^{131}I. Routine sampling is performed near operating facilities to maximize the potential for detecting a chronic loss of control, and at distributed distant locations to determine concentrations at points of potential higher public exposure. Cartridges from additional locations were exchanged monthly to maintain fresh adsorption media, but were analyzed only if ^{131}I was identified in one of the routinely analyzed samples or if there was any other indication of an effluent release that could result in a detectable concentration.

(a) Retention efficiencies are 99% for both elemental iodine and methyl iodide.

Iodine-129 was sampled using the same technique; however, a petroleum-based charcoal was used because of its lower background concentration. Samples were collected monthly and combined to form quarterly composite samples for each of the four sample locations.

Atmospheric water vapor was collected for ^{3}H analysis by continuously passing air through cartridges of silica gel at a flow rate of 0.014 m^3/h for 4 weeks. The collected moisture was removed from the silica gel and analyzed. The silica gel cartridges were exchanged every 4 weeks. Historical ^{3}H data for air moisture at Hanford and other media have been reported in terms of activity per liter of water. Therefore, the trend of concentrations since 1982 is shown in this section in terms of pCi/L of atmospheric water. Because the DCG is stated in terms of activity per cubic meter of air, ^{3}H results for 1987 are reported in pCi/m^3 of air in the tables of Appendix A. The comparability of these two measures was demonstrated previously (Price et al. 1985).

Atmospheric carbon dioxide was collected by continuously passing air through a soda-lime collection medium for 8 weeks at a flow rate of 0.028 m^3/h. The trapped carbon dioxide (CO_2) was then analyzed for ^{14}C content and the atmospheric concentration calculated.

Samples of air were collected for ^{85}Kr analysis using a small pump that continuously filled a collection bag with air at a low flow rate. About 0.3 m^3 of air was collected over 4-week sampling periods throughout the year. The entire sample of air was analyzed for ^{85}Kr.

Nine locations were sampled for NO_2 by HEHF to assess onsite and offsite nitrogen oxide concentrations. Nitrogen oxides are primarily released by the PUREX Plant. The sample locations are depicted on the map in Figure 3.2 and identified in Table A.12, Appendix A. The NO_2 sampling was performed in accordance with EPA "Designated Equivalent Method EQN-1277-028" (EPA 1977). The NO_2 sampling unit consisted of a bubbler assembly operated to collect 24-h integrated samples. Total suspended particulate sampling was performed at location 10 in Figure 3.2. All sampling was performed in accordance with the EPA "Reference Method for the Determination of Suspended Particulate matter in the Atmosphere," (EPA 1986a) and Washington State Air Pollution Regulations "Air Pollution Standards: Suspended Particulates" (WDOE 1986a).

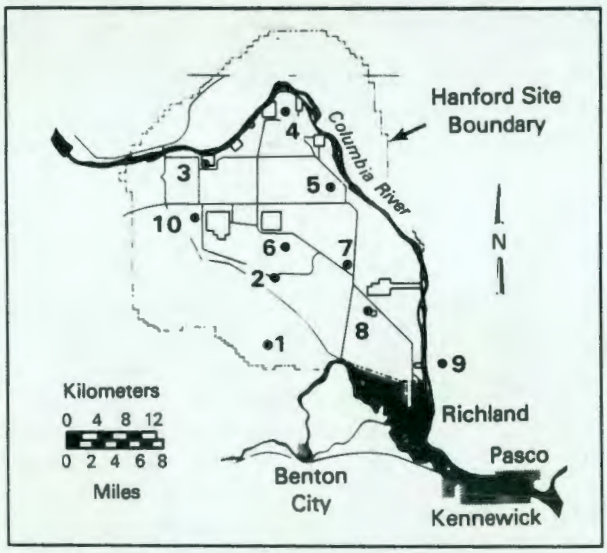

FIGURE 3.2. 1987 Nitrogen Dioxide Sampling Locations (Numbers 1 - 9) and Total Suspended Particulate Sampling Location (Number 10)

RESULTS

Onsite, perimeter, and nearby and distant community maximum, minimum, and average concentrations for gross beta and gross alpha radiation are summarized for all measurement locations in Tables A.2 and A.3, Appendix A. Maximums, minimums, and annual averages are summarized for specific detectable radionuclides, or others of special interest, in Table A.4, Appendix A. Onsite results from each sampling station near the major operating areas are summarized in Tables A.5 through A.11, Appendix A. Fifty-two radionuclides were analyzed in the monthly composite gamma energy analyses (see Page D.1, Appendix D), but none were consistently detectable.

Results of gross beta and gross alpha radioactivity in airborne particulate samples at distant and perimeter stations are given in Tables A.2 and A.3, Appendix A. Gross beta levels for 1987, as shown in Figure 3.3, peaked during winter, repeating a pattern of natural annual radioactivity fluctuations. As shown in Tables A.2 and A.3, Appendix A, gross beta and gross alpha levels were about the same on the Site, at the Site perimeter, and in nearby and distant communities, indicating that the observed levels were predominantly a result of natural sources and worldwide fallout. If Hanford operations had been an important source, concentrations would have shown a significant decrease with distance from the Hanford Site.

Measurements of ^{85}Kr continued to be a sensitive indicator of PUREX Plant plume behavior. With the resumption of PUREX Plant operations in 1983, ambient air concentrations of ^{85}Kr increased at most sampling locations above the preoperational levels of about 19 pCi/m^3. Concentrations have fluctuated annually as shown in Figure 3.4, primarily in response to changing operating levels. Concentrations in 1987 were lower on the Site and at the perimeter than in 1986 because of reduced PUREX Plant operations in 1987. The 1987 distant location measurements were similar to 1986 measurements and essentially reflect global background levels. Figure 3.5 shows the annual average ^{85}Kr concentrations for 1987 at each sampling location. The measurements close to the PUREX Plant show the effect of the prevailing northwest winds in the 200 Areas; measurements along the perimeter indicate that much of the time the stack plume turns toward Richland before it crosses the eastern Site perimeter. This pattern is also demonstrated in the historical

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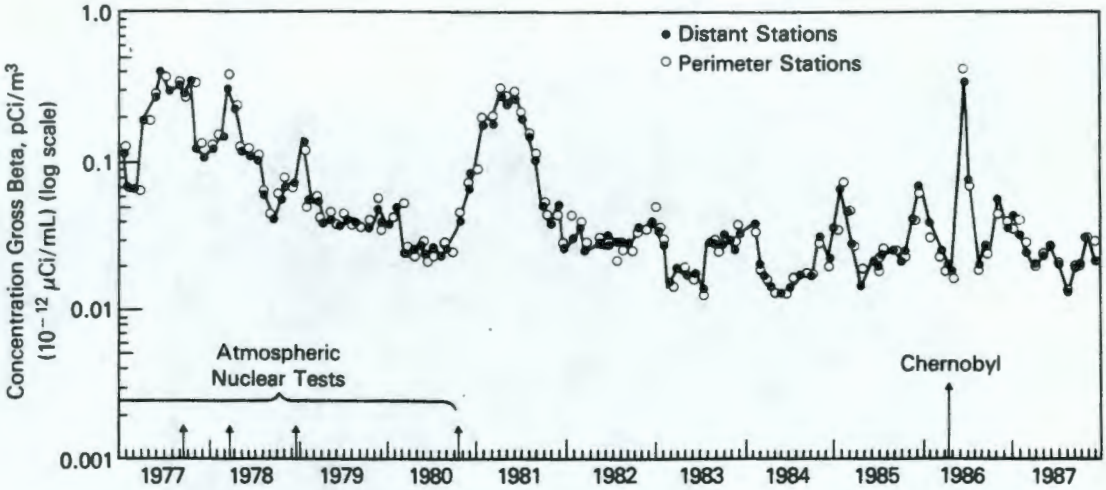

FIGURE 3.3. Monthly Average Gross Beta Radioactivity in Airborne Particulate Samples, 1977 Through 1987

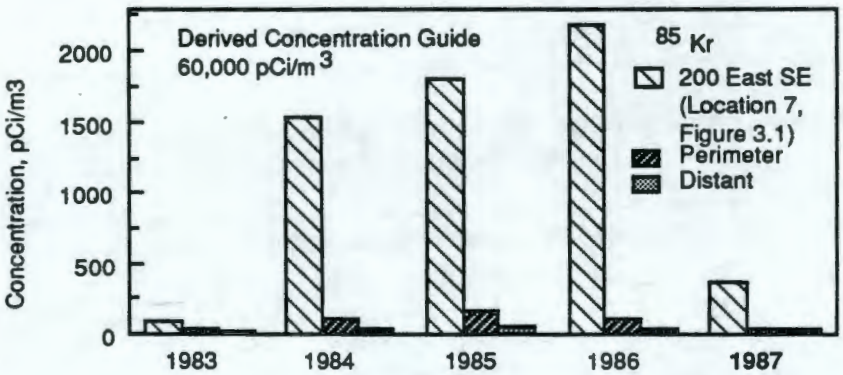

FIGURE 3.4. Annual Average Krypton-85 (^{85}K) Air Concentrations at Selected Locations, 1983 Through 1987

record (Healy et al. 1958) and is consistent with measured wind flow patterns on the Site. The perimeter annual average ^{85}Kr concentration (34 pCi/m³) was 0.06% of the proposed DCG of 60,000 pCi/m³.

Strontium-90 data for 1987 (Table A.4, Appendix A, and Figure 3.6) were similar on the Site, at the perimeter, and in nearby and distant communities. Figure 3.6 shows the variation from 1982 to 1987 for the 200-East Area sample composite, for a sample composite made up of samples from stations along the southeast perimeter of the Site and the Tri-Cities, and for a sample composite from distant communities. Concentrations in 1987 were lower than in 1986 at these locations and generally throughout the region. Also shown are the measurements for two other U.S. locations in northern latitudes (New York, New York and Beaverton, Oregon) reported by the DOE Environmental Measurements Laboratory (EML) as part of its international fallout monitoring program (Feely et al. 1985; 1988). The Environmental Measurements Laboratory discontinued ^{90}Sr analyses from their program at the end of 1985. Most of the increase noted in Figure 3.6 for the 200-East Area composite sample in 1985 was the result of an inadvertent airborne release from a liquid-waste diversion box in the C Tank Farm that occurred in

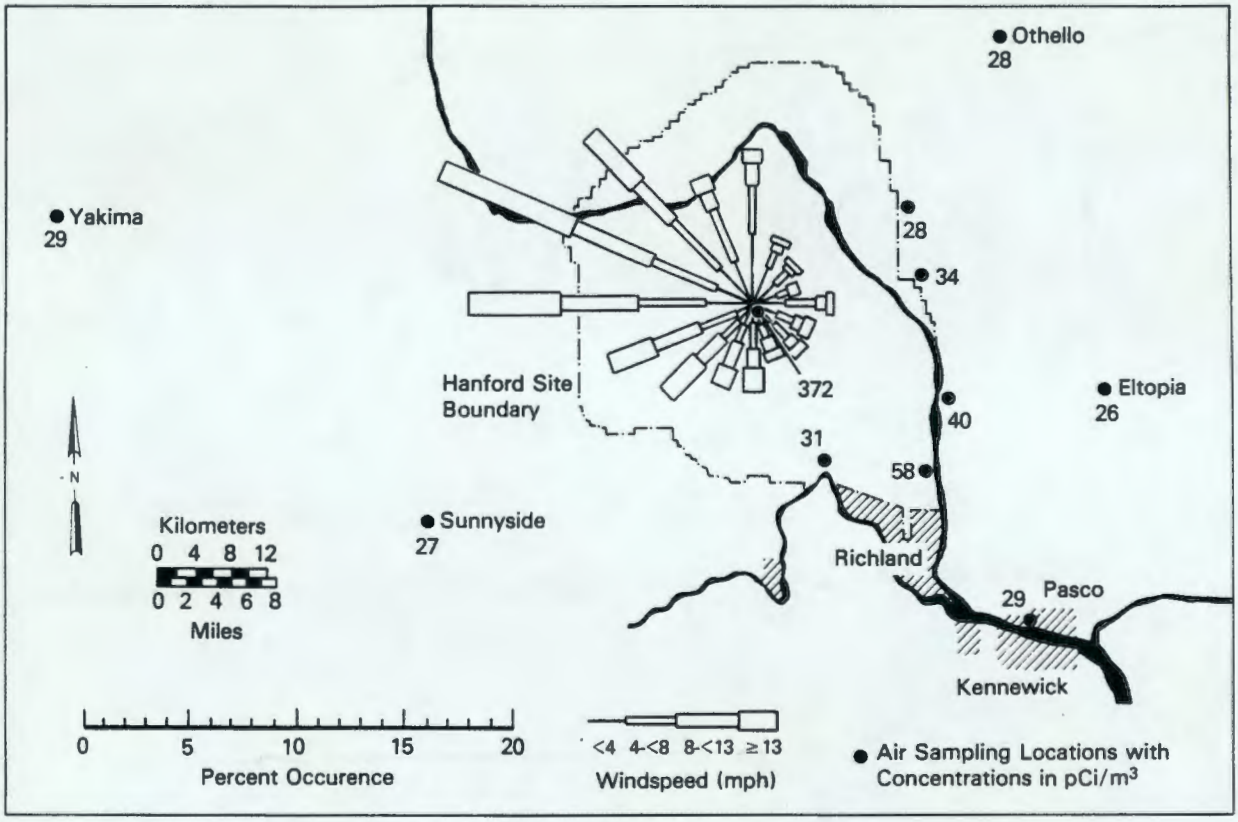

FIGURE 3.5. Annual Average Krypton-85 (^{85}K) Concentrations (pCi/m^3) in Air and the 200 Area Windrose (showing the direction from which the wind blew) for 1987

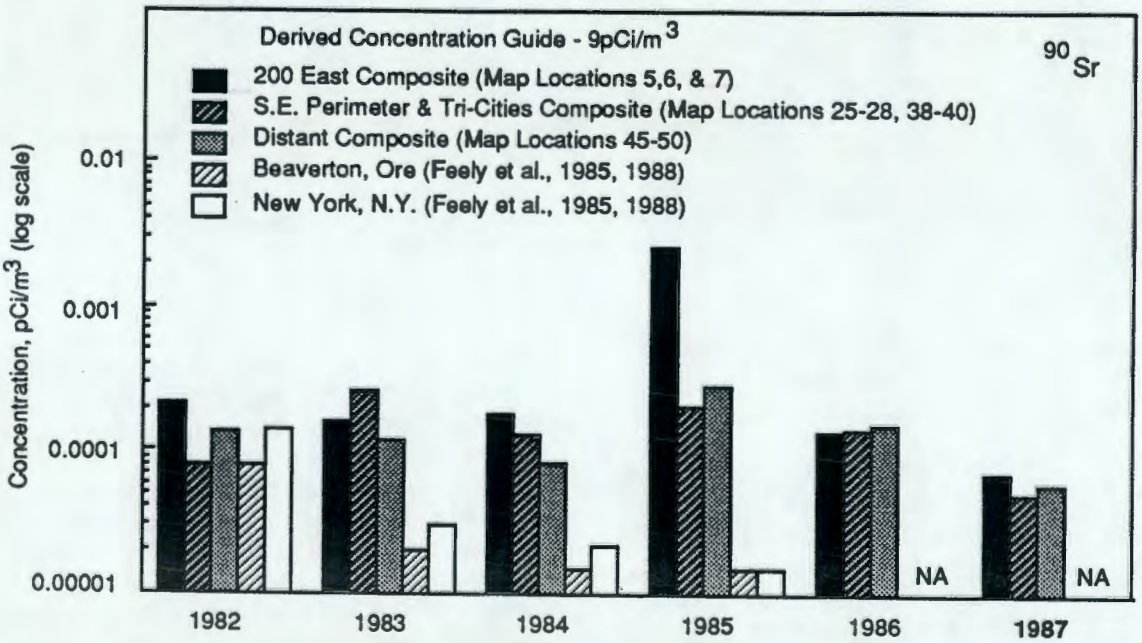

FIGURE 3.6. Annual Average Strontium-90 (^{90}Sr) Air Concentrations in the Hanford Environs Compared to Other U.S. Locations, 1982 Through 1987 (New York and Beaverton data not available after 1985)

January [see "Effluents, Waste Disposal and Unusual Occurrences," Appendix G (Price 1986)]. The annual average Site perimeter concentration in 1987 (0.00004 pCi/m^3) was only 0.0004% of the applicable DCG (9 pCi/m^3).

Quarterly air sampling for ^{129}I began in July 1984. Iodine-129 was sampled at four locations in 1987 (Figure 3.7). (Because of the low levels of ^{129}I, concentrations are reported in aCi/m^3 rather than pCi/m^3. One aCi/m^3 = 0.000001 pCi/m^3.) Concentrations at the perimeter were consistently larger than those observed at Yakima. Concentrations were variable and ranged from 157 to 714 aCi/m^3 at the 200-East SE location, and from 0.3 to 0.8 aCi/m^3 at Yakima. The average onsite concentration decreased from 1986 to 1987. The reported distant measurements were essentially unchanged from 1986 to 1987. The annual average ^{129}I concentration at the perimeter (2.7 aCi/m^3) was only 0.000004% of the DCG of 70,000,000 aCi/m^3 (70 pCi/m^3).

Average ^{3}H concentrations (expressed in pCi/m^3 of air) measured at the Site perimeter and off the Site were similar (Table A.4, Appendix A). Onsite concentrations were highest at the sampling locations

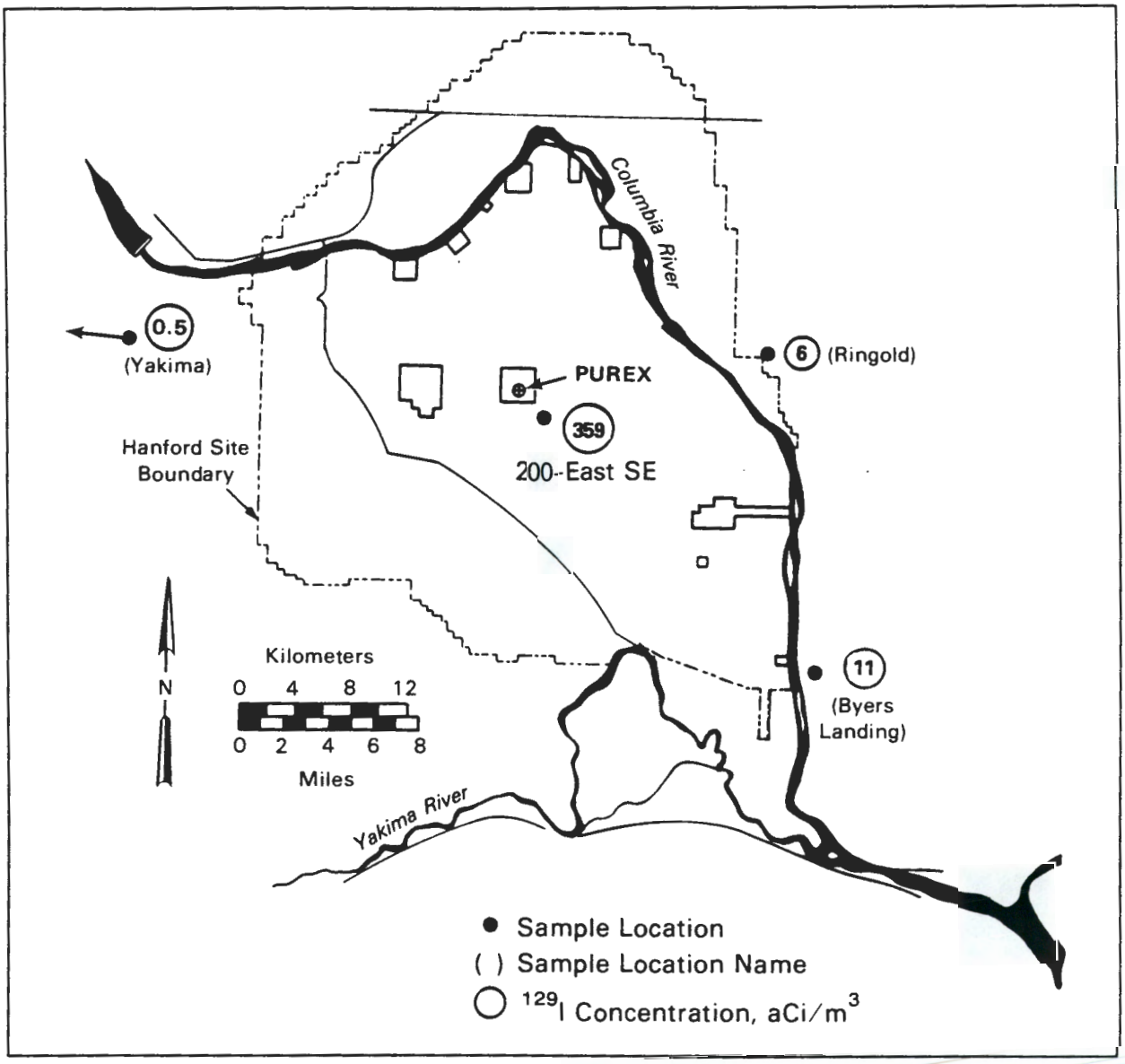

FIGURE 3.7. Annual Average Iodine-129 (^{129}I) Concentrations (aCi/m^3) in Air in the Hanford Environs for 1987 (Derived Concentration Guide 70,000,000 aCi/m^3)

immediately downwind of the PUREX Plant, and the onsite average concentration was higher than the offsite average. Figure 3.8 traces the annual trend of ^{3}H concentration in pCi/L of atmospheric water vapor for two onsite and two downwind perimeter locations, and the average of two distant community locations. The effect of the restart of the PUREX Plant in 1983 on air ^{3}H concentrations is clear at the 200-East SE sampling location. There appears to be no effect in either the distant communities or Richland. Concentrations at distant locations are comparable to concentrations in surface water across the nation (EPA 1982a-1987c). The annual average concentration at the Fir Road location on the southeast perimeter appears larger than the concentration at the 200-East SE location (nearer the source) and distant locations. The Fir Road location concentration appears greater than the 200-East SE concentration because at these low concentrations the variability and uncertainty of each of the annual averages is on the order of 100-200 pCi/m^3. The annual average perimeter concentration of ^{3}H in air (1.9 pCi/m^3) was only 0.001% of the proposed DCG of 200,000 pCi/m^3.

Air concentrations of $^{239,240}Pu$ in 1987 were similar to those measured in 1986. The annual averages of all onsite, perimeter, and near and distant community samples are shown in Table A.4, Appendix A. The 1987 perimeter and distant community averages were similar. The annual average concentration of $^{239,240}Pu$ (0.5 aCi/m^3) at the Site perimeter was less than 0.003% of the DCG (20,000 aCi/m^3).

The most recent regional data for $^{239,240}Pu$ reported by the EPA for Seattle, Spokane, and Portland for 1982 through 1986 (EPA1982a-1987c) are compared in Figure 3.9 with measurements at the Hanford southeast perimeter and Tri-Cities composite locations. Local measurements were obtained from the routine monitoring program and a special purpose 300 Area high-volume air sampler. The 300 Area high-volume air sampler has operated since 1961, independent of the routine program, to collect high-volume samples and higher-precision measurements of worldwide fallout radionuclides. This comparison indicates that the perimeter concentrations of $^{239,240}Pu$ in the predominant downwind flow direction in 1987 were similar to regional levels in recent years. The decrease in the southeast perimeter and Tri-Cities composite concentrations in 1984 and after was due in part to the implementation of a more sensitive and precise analytical technique in 1984. A further decrease in 1986 followed the installation of additional source controls at the PUREX Plant in late 1985.

Uranium concentrations in airborne particulate matter in 1987 were higher at the perimeter than at the distant communities (Table A.4, Appendix A), an increase from 1986. The perimeter and year-to-year increases resulted from increased levels north of the 300 Area. The maximum annual average concentration (0.00017 pCi/m^3) at a perimeter location (composite of map locations 25 and 26, Figure 3.1) was 0.17% of the DCG of 0.1 pCi/m^3.

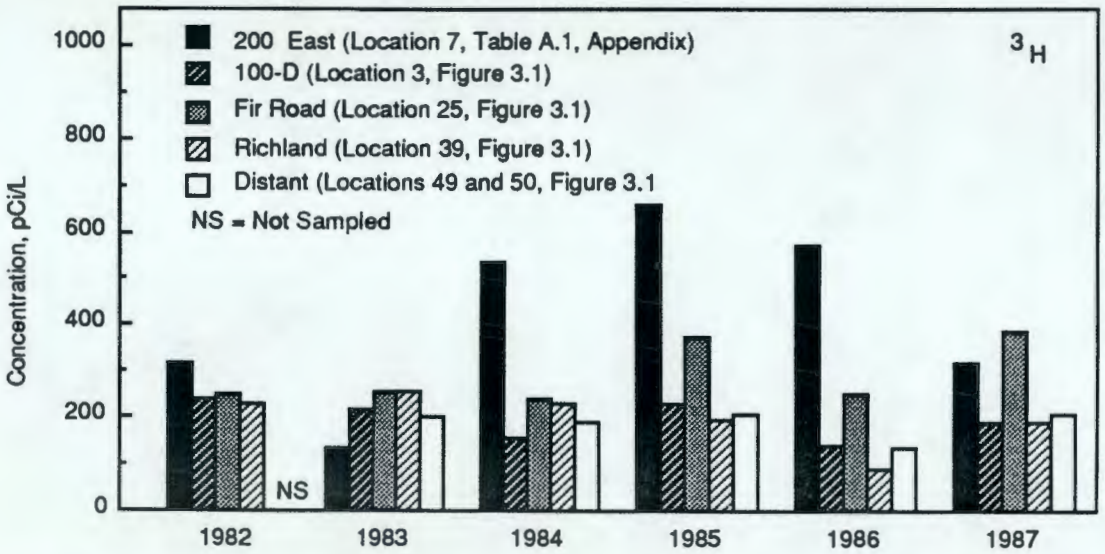

FIGURE 3.8. Annual Average Tritium (^{3}H) Concentrations (pCi/L of water) in Atmospheric Water Vapor, 1982 Through 1987

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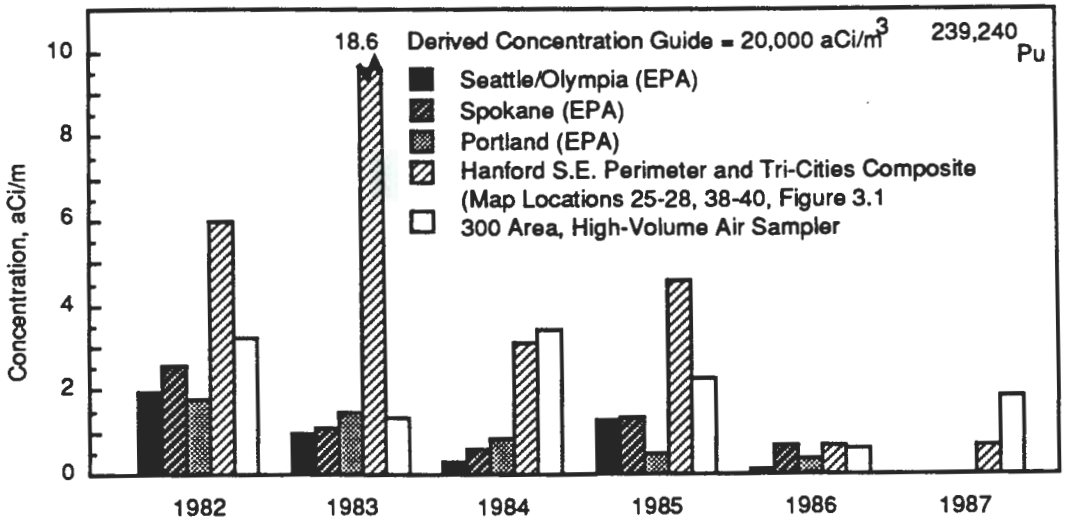

FIGURE 3.9. Annual Average Plutonium-239, 240 ($^{239,240}Pu$) Air Concentrations in the Northwest and Hanford Environs, 1982 Through 1987

Ruthenium-106, ^{131}I, and ^{137}Cs were routinely monitored through monthly composite gamma energy analyses. Detectable levels were observed in 1986 during the Chernobyl plume passage, but were detected infrequently in 1987. The results obtained for 1987 are included in Tables A.4 and A.6 through A.8, Appendix A. The annual average ^{106}Ru, ^{131}I, and ^{137}Cs concentrations at the perimeter were less than 0.01% of their DCGs.

The comparisons discussed in the above paragraphs are based on the measured numerical results without taking into account the uncertainty in the data or their averages. However, statistical analyses of the monthly and quarterly composite particulate data and the gaseous radionuclide data were conducted to take such uncertainty into account when evaluating the effect of Hanford operations on the environment. A comparison was made between the average distant community concentrations, which represent natural and worldwide fallout sources, and the average at the perimeter of the Hanford Site, which represents natural and worldwide fallout sources and any Hanford contributions. This analysis indicated that in 1987, the average Hanford Site perimeter concentrations of ^{3}H, ^{85}Kr, uranium, and $^{239,240}Pu$ were numerically greater than levels measured at distant monitoring stations. These differences were not significantly different statistically (at the 5% significance level). Iodine-129 was numerically larger at the perimeter stations than at the distant stations, and the difference was statistically significant (beyond the 0.5% significance level).

Nitrogen dioxide data collected in 1987 (Table A.12, Appendix A) indicated that the highest annual average (<0.008 ppm) was observed at the 100-D and Wye Barricade sampling locations (Figure 3.2, map location numbers 4 and 7). The Wye Barricade also had the highest average from 1984 through 1986. All locations were below the applicable federal and Washington State annual average ambient air standard for NO_2, which is 0.05 ppm.

Total suspended particulates were sampled near the 200-W Area (Figure 3.2, map location 10) during 1987. Monthly averages ranged from 7.5 to 64.0 µg/m³. The annual average was 33.0 µg/m³, well below the federal and state standards of 75 and 60 µg/m³ annual geometric mean, respectively. The monthly 24-h maximum sample ranged from 10 to 91 µg/m³; federal and Washington State 24-h maximum standards are 150 and 260 µg/m³, respectively.

3.2 GROUND-WATER MONITORING

J. C. Evans, R. W. Bryce, D. I. Dennison, and P. J. Mitchell

Radiological and chemical constituents in ground water were monitored during 1987 throughout the Hanford Site in support of the overall objectives described in "Environmental Monitoring," Section 2.2. Monitoring activities were conducted to 1) determine the distribution of mobile radionuclides and NO_3^-, 2) relate the distribution of these constituents to Site operations, and 3) identify chemicals in ground water as a result of Site operations. Additional monitoring was conducted by PNL to assess the impact that specific facilities have had on the ground-water quality to comply with RCRA (DOE 1987b). The evaluation of the quality of the ground water in the 200 Areas and surrounding region was conducted by PNL for WHC. This evaluation is to ensure compliance with DOE monitoring guidelines, to assess the performance of waste disposal and storage, and to determine the impacts of operations on the ground water (Serkowski et al. 1988). Samples from a total of 563 wells, primarily open to the unconfined (shallow) aquifer, were collected and analyzed during 1987.

Analytical results for samples were compared to EPA drinking water standards (DWS) (Tables C.2 and C.3, Appendix C) and DOE's DCG (Table C.6, Appendix C). These standards were written for drinking water and while none of the wells discussed in this section are drinking water supply wells, they provide a basis for evaluating levels of contamination. Ground water beneath the Hanford Site is used for drinking at four locations, as described in "Potential Radiological Doses from 1987 Hanford Operations," Section 4.0.

Radiological monitoring results indicate that gross alpha, gross beta, ^{3}H, ^{60}Co, ^{90}Sr, ^{99}Tc, ^{106}Ru, ^{125}Sb, ^{129}I, ^{131}I, and ^{137}Cs concentrations near operating areas were at levels above the DWS. Iodine-131 in the 100-N Area and ^{234}U and ^{238}U in the 200-West Area was above the DCG. Tritium in the 200 Areas and ^{90}Sr in the 100-N and 200-East Areas were also above the DCG. Tritium continued to move slowly with the general ground-water flow and discharge to the Columbia River. Certain chemicals regulated by the EPA and the State of Washington were also present in Hanford ground water near the operating areas. Nitrate concentrations resulting from Site operations exceeded the DWS at isolated locations in the 100, 200, and 300 Areas and in the 600 Area southwest of the old Hanford townsite. Chromium concentrations were above the DWS at 100-D, 100-H, and the surrounding area. Cyanide was detected in ground water in and north of the 200-East Area. Fluoride was above the DWS in a few wells in the 200-West Area. Carbon tetrachloride was above the DWS in wells in the 200-West Area.

The primary source of ground-water contamination is liquid waste released to the soil column by past and ongoing Site operations. Both active and inactive waste disposal sites contributed to the radionuclide and chemical contamination detected.

SAMPLE COLLECTION AND ANALYSIS

Ground-water samples were collected for radiological analysis from 563 monitoring wells during 1987. These samples were collected as part of the Site-wide ground-water monitoring program and numerous projects to assess the impact that specific facilities have had on the ground-water quality. Facility-specific monitoring was conducted at the 183-H Solar Evaporation Basins in the 100-H Area, the 1301/1325-N Liquid Waste Disposal Facility (LWDF) in the 100-N Area, the 300 Area process trenches, the NRDW Landfill, the Solid Waste Landfill (SWL), and the Transportable Grout Facility (TGF) to comply with RCRA (DOE 1987b). The NRDW Landfill and the SWL are identified as the Central Landfill in Figure 3.10. The TGF is located in the 200-East Area. Additional monitoring was conducted by WHC to evaluate the quality of the ground water in the 200 Areas and surrounding region to ensure compliance with WHC and DOE monitoring guidelines, to assess the performance of waste

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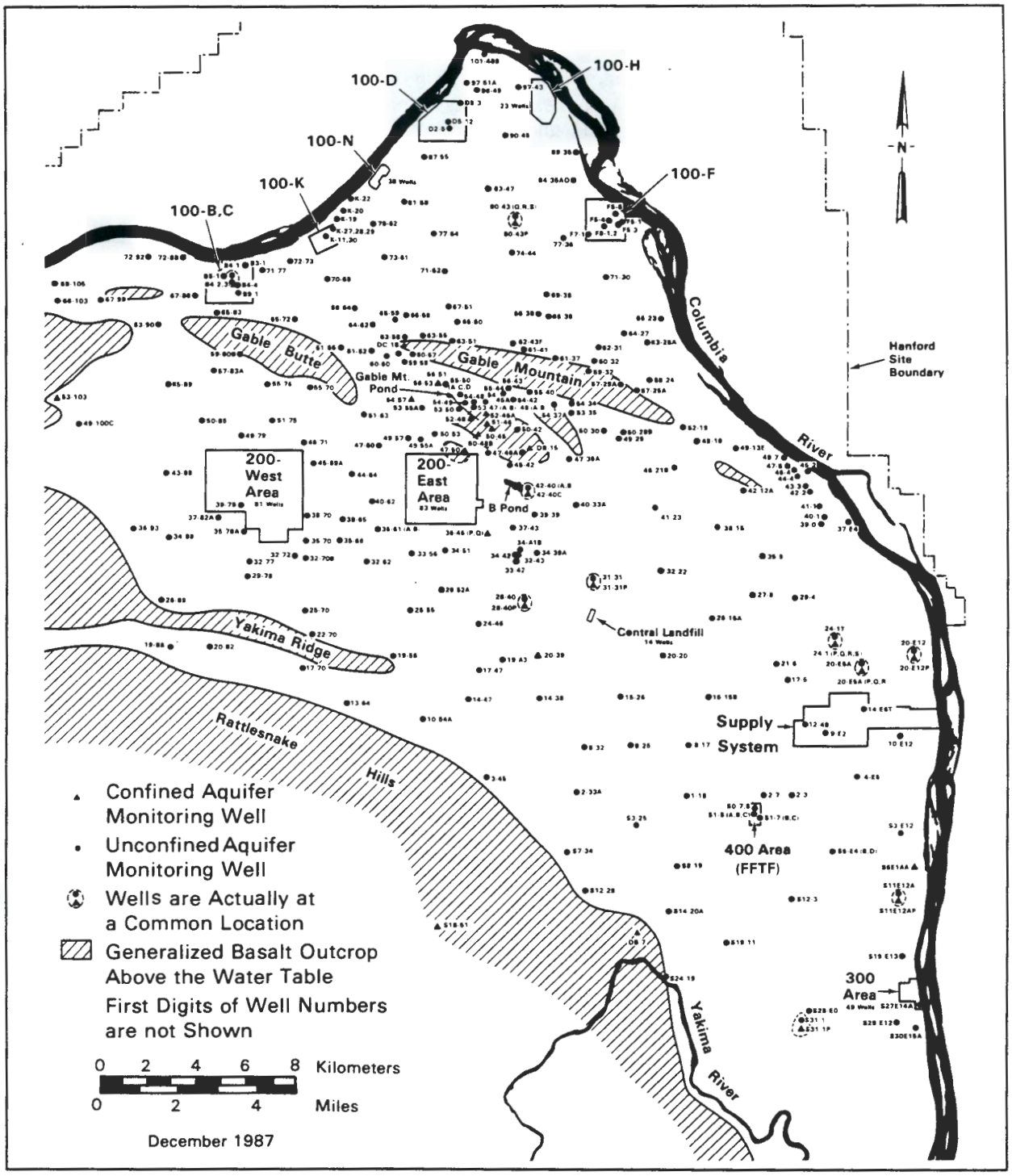

FIGURE 3.10. Hanford Site Monitoring Well Locations

disposal and storage, and to determine the impacts of operations on the ground water (Serkowski et al. 1988). Most samples were analyzed for ^3H and NO_3^-. Selected samples were subjected to more extensive radiological analysis by alpha-, beta-, and gamma-counting techniques, in many cases accompanied by selective radiochemical separations. The radiological monitoring network is shown in Figure 3.10. Well locations for the 200-East and 200-West Areas are identified in Figures 3.11 and 3.12.

A subset of the radiological monitoring network was used for Site-wide chemical monitoring. Chemical sampling wells were selected primarily for their proximity to known active and inactive chemical disposal sites in the 100, 200, 400, and 600 Areas and based on known waste inventories (DOE 1986). The 600 Area is that area inside the Hanford Site boundary but outside all other designated areas. Only wells containing submersible pumps were selected for chemical sampling to allow sufficient purging of wells prior to sample collection.

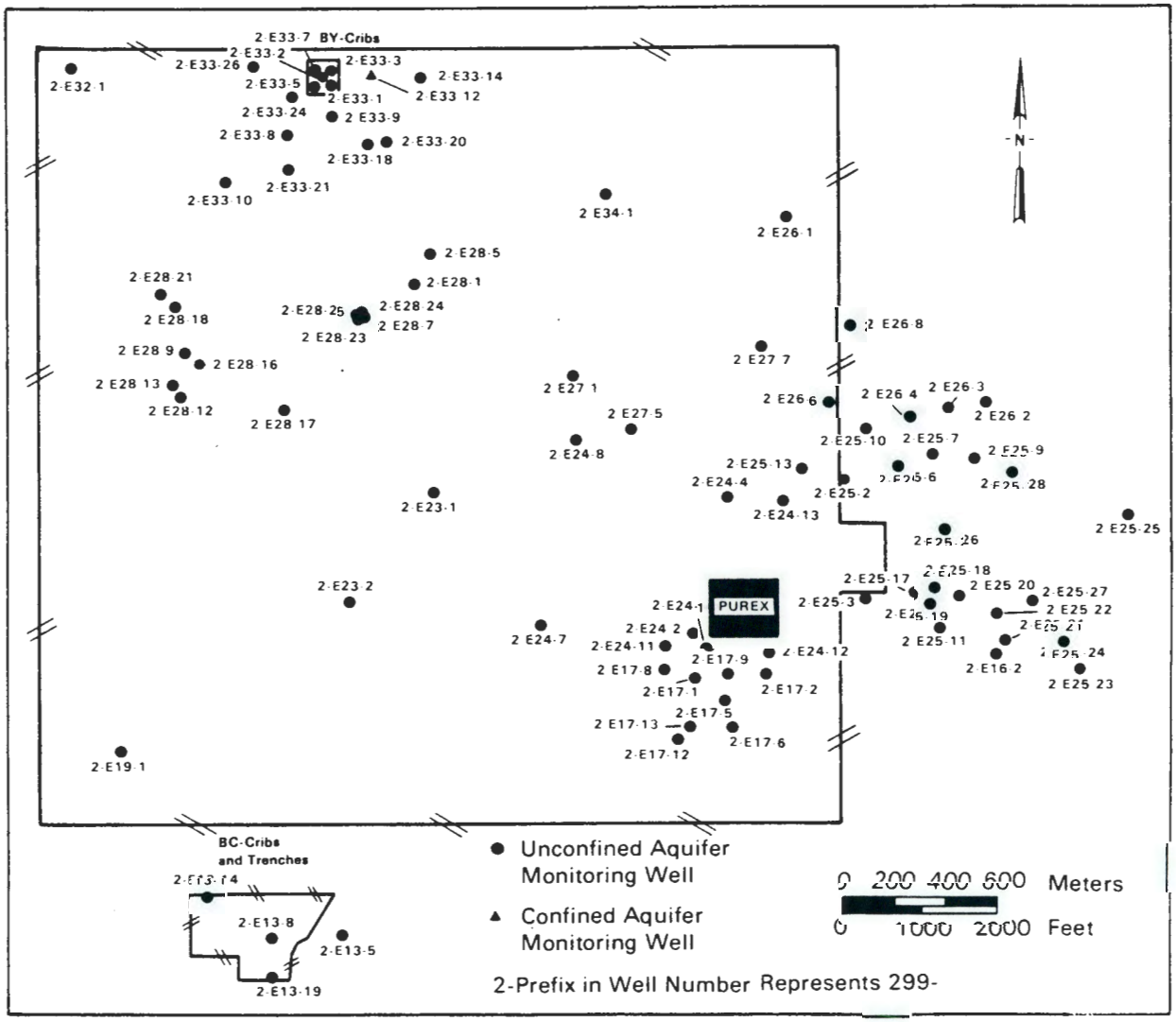

FIGURE 3.11. 200-East Area Monitoring Well Locations

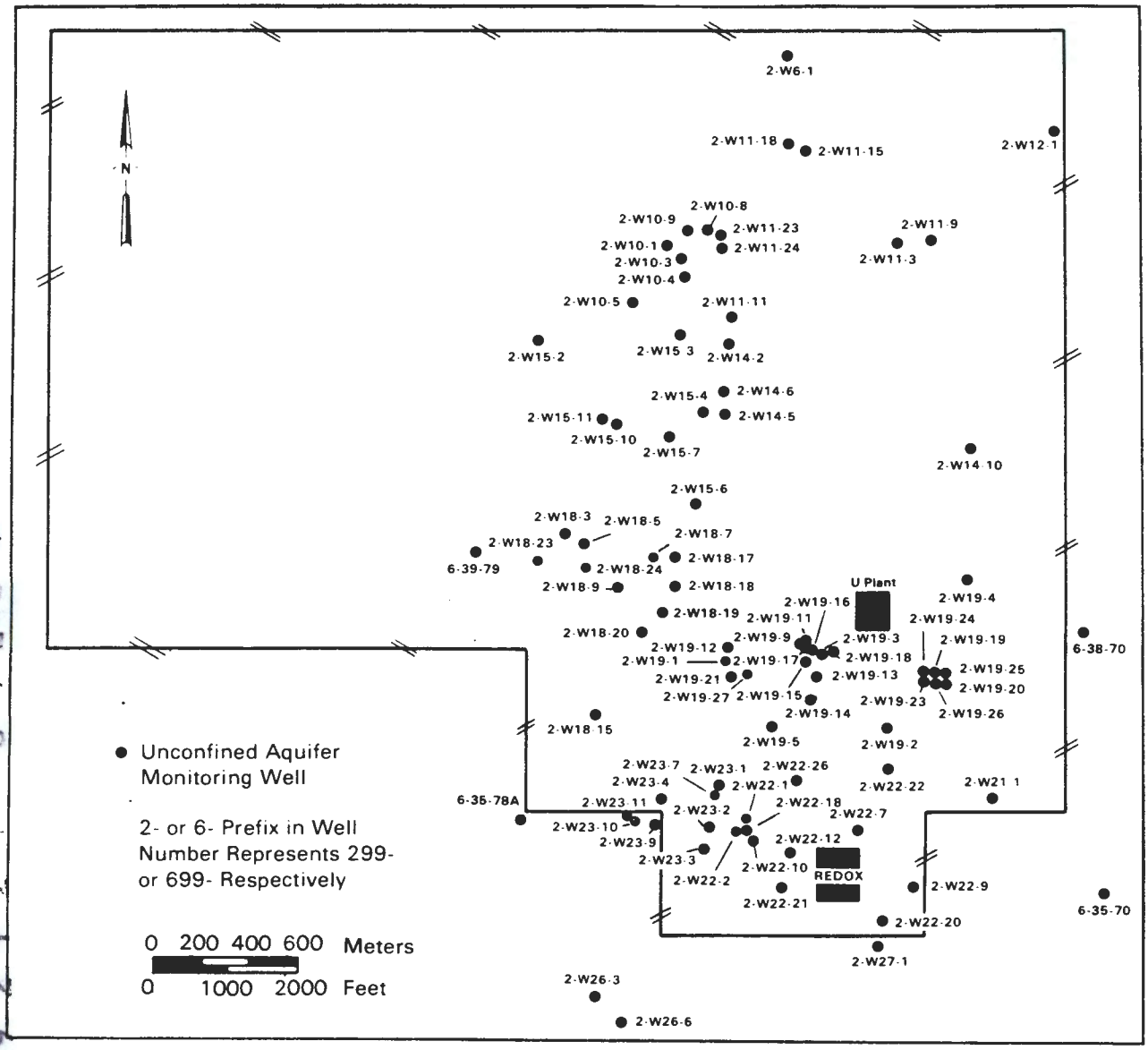

FIGURE 3.12. 200-West Area Monitoring Well Locations

In the first quarter of 1987, 46 wells were sampled for chemical constituents. This effort was expanded in the second quarter to include 132 wells, including 19 wells co-sampled on a one-time-only basis as part of the DOE-Headquarters environmental survey of the Hanford Site. During the third quarter, 121 wells were monitored; 102 wells were sampled in the fourth quarter. The sampling in the fourth quarter included some wells not previously sampled, while a number of wells that showed no significant contamination after three sampling periods were dropped from the network. To avoid redundancy, areas covered by ground-water monitoring for RCRA compliance (EPA 1986b), such as the 300 and 100-H Areas, were not included in the Site-wide chemical monitoring network. However, chemical data from all ground-water monitoring programs on the Site are included in a single data base for purposes of interpretation. Chemical data were gathered on 293 wells during 1987, including wells comprising the RCRA compliance networks. Table 3.2 summarizes the number of wells sampled, the number of samples collected, and the results obtained during 1987.

Samples from wells selected for chemical characterization were extensively analyzed. The methods

TABLE 3.2. Number of Wells Sampled, Samples Collected, and Analytical Results for Ground-Water Monitoring Programs in 1987

Area	Number of Wells Sampled	Number of Samples Collected	Number of Analytical Results
100	86	497	27,246
200	164	1,008	22,298
300	49	322	17,247
400	7	23	453
600	257	1,118	26,273
Total	563[a]	2,968	93,517

(a) Total of samples collected for Site-wide, for RCRA compliance, and for compliance with WHC and DOE monitoring guidelines.

used for chemical analysis conform to guidelines set forth by the EPA (1982). Analyses for which EPA guidelines were not available were performed in accordance with other written procedures identified in Table D.2, Appendix D. Analytical techniques used are described in "Analytical Procedures and Sampling Summary," Appendix D. All analyses were performed by UST. A list of the species covered by the analytical program is presented in Table 3.3.

Most ground-water monitoring wells on the Site are 15 or 20 cm in diameter, and are constructed of steel casing. Several small-diameter (5-cm) wells are sampled for radionuclides only. Monitoring wells for the unconfined aquifer are completed with well screens or perforated casing generally in the upper 3 to 6 m of the aquifer. Completion at the water table allows samples to be collected near the top of the aquifer where maximum concentrations for some radionuclides were measured at a few locations at the Hanford Site (Eddy, Myers, and Raymond 1978). Confined aquifer monitoring wells have screens or perforated casing within the monitored aquifer.

Samples were collected following internally documented sampling procedures based on EPA guidelines (EPA 1986b). Wells fitted with submersible pumps (0.63 L/s) were sampled after pumping for a sufficient time (at least 20 min) to allow temperature, pH, and specific conductivity to equilibrate. This purging ensured that stagnant water in the well was removed, allowing collection of a sample that was representative of the ground water near the well. Specific conductance and pH were measured in the field at the time of sample collection. Samples for volatile organic analyses were taken with zero head space and sealed immediately with a septum-sealed cap. For filtered trace metals, a disposable, 0.45-µm pore-sized filter pack was connected to a Teflon[a] sampling line. The filter was purged with 500 mL of well water, and then a sample was collected in a plastic bottle. Trace metal samples and some radiochemical samples were preserved by acidification at the time of collection. All samples were placed in ice chests immediately after sampling and transferred the same day or early the next day to the laboratory for immediate analysis of species with short holding times (e.g., for NO_3^- and volatile organic analyses). Samples were stored at 4°C from time of sampling until they were analyzed. All samples were tracked by chain-of-custody procedures from sampling through analysis and disposal.

RESULTS

Detailed discussions of monitoring results for 1987, including tables of all results for each well and constituent, are reported by Evans, Mitchell, and Dennison (1988) and Evans et al. (1988). Tables of all results for 1987 are also available for review at the DOE-RL Public Reading Room in the Federal Building, Richland, Washington. Highlights of those results are discussed below. Summary tables of selected constituents are included in Tables A.13

(a) Teflon is a registered trademark of E. I. du Pont de Nemours and Company, Wilmington, Delaware.

TABLE 3.3. Radionuclides and Chemicals Analyzed for in Site-Wide Ground-Water Monitoring Program

Radiological Parameters	Chemical Parameters
Gamma Scan	
^{60}Co	pH (field and laboratory)
^{103}Ru	Conductance (field)
^{106}Ru	Alkalinity
^{125}Sb	Total Carbon
^{131}I	Total Organic Carbon
^{137}Cs	Total Organic Halogens
^{241}Am	Be, Na, Mg, Al, K
	Ca, V, Cr, Mn, Fe
^{3}H	Ni, Cu, Zn, Sr, Ag
^{14}C	Cd, Sb, Ba
^{63}Ni	F^-, Cl^-, NO_3^-, SO_4^{2-}, PO_4^{3-}
^{89}Sr	As, Se, Pb
^{90}Sr	Hg
^{99}Tc	CN
^{129}I	NH_3
Uranium Isotopes	Volatile Organics
Uranium (total)	Semivolatile Organics
Plutonium Isotopes	

through A.23, Appendix A. Ground-water monitoring information for the 200 Areas and surrounding region is reported by Serkowski et al. (1988) and for drinking water supplies on the Hanford Site by Somers (1988). Tables presented by Serkowski et al. contain some of the same data that this report presents. Average concentrations may be different because the average of all data for a single constituent for each well is presented in tables in Appendix A and Serkowski et al. present only data collected by their program.

Concentrations of radionuclides and chemicals were compared to the EPA's DWS and DOE's DCG (Tables C.2, C.3, and C.6, Appendix C). Those standards were written for drinking water and while none of the wells discussed are drinking water supply wells, they provide a basis for evaluating levels of contamination. Drinking water supply wells are discussed in "Potential Radiological Doses from 1987 Hanford Operations," Section 4.0. The DWS are more restrictive than the DCG because the DWS are based on an annual dose to the affected organ of 4 mrem per year, while the DCG are based on an effective dose equivalent of 100 mrem per year (see "Applicable Standards and Permits and Environmental Compliance Documentation," Appendix C). DCGs are only available for radionuclides.

Radiological Monitoring Results for the Unconfined Aquifer

Selection of radiological constituents to be monitored at the Hanford Site was based on known waste management practices. Table 3.4 identifies major ground-water constituents associated with Site operations. Radiological monitoring results for ^{3}H, gross alpha, gross beta, ^{60}Co, ^{90}Sr, ^{99}Tc, ^{106}Ru, ^{125}Sb, ^{129}I, ^{131}I, ^{137}Cs, and uranium are discussed below. Results of radiological analysis are compared to the EPA's DWS and to the DOE's DCG.

Tritium is known to be present in waste streams discharged to the soil column by Site operations. Tritium also appears to be the most mobile radionuclide at the Site. As a result, ^{3}H reflects the extent of contamination in the ground water from Site operations. Figure 3.13 illustrates the 1987 distribution of ^{3}H concentrations in the unconfined aquifer, resulting from over 40 years of Site operations. Contours of ^{3}H concentrations were based on the analysis of ground-water samples collected from monitoring wells. For each well, an average value of up to 13 ^{3}H measurements was used. A summary of ^{3}H concentrations in wells sampled during 1987 is presented in Table A.13, Appendix A.

Tritium concentrations greater than the 20,000-pCi/L DWS were detected in portions of the 100-B, 100-D, 100-F, 100-K, 100-N, 200-East, 200-West, 400, and 600 Areas. Concentrations greater than the 2,000,000-pCi/L DCG were detected only in the wells in the 200-East Area and in one well in the 200-West Area. Well 199-K-30 continued to contain the highest ^{3}H concentration within the 100 Areas, with a maximum concentration of 1,300,000 pCi/L.

The highest ^{3}H concentrations in the 200-East Area, and throughout the Hanford Site, continued to be found in wells near cribs that have received effluents from the PUREX plant. Tritium concentrations greater than the DCG were present in wells near the 216-A-10, 216-A-36B, 216-A-37-1, and 216-A-45 cribs. Tritium concentrations exceeding the DWS continued to be measured in most of the other wells near these cribs.

The movement of the widespread ^{3}H plume (see Figure 3.13) that extends from the southeastern portion of the 200-East Area to the Columbia River was consistent with the patterns noted earlier (PNL 1987; Evans et al. 1988). Separate ^{3}H pulses associated with the two episodes of PUREX operations can be distinguished in the ^{3}H plume. The 200,000- to 2,000,000-pCi/L lobe east of the 200-East Area near the Columbia River is a result of discharges to ground water during the operation of PUREX from 1956 to 1972. Following an 11-year shutdown, operation of PUREX began again in 1983. Elevated ^{3}H concentrations measured in several wells (e.g., wells 699-32-43, 699-33-42, and 699-36-46) downgradient from the 200-East Area represent the formation of a second pulse of ^{3}H moving away from PUREX waste disposal facilities.

The general direction of movement of the eastern portion of the plume continues to be to the east-southeast toward the Columbia River. The migration of the plume continued farther to the south, as indicated by increased ^{3}H concentrations in wells near the 300 Area. The configuration of the western portion of the plume appears to closely match previous predictions of the direction of contaminant movement from the 200-East Area (Freshley and Graham 1988). Movement to the south may be enhanced by the spreading ground-water mound beneath B Pond. This mound is spreading as a result of increased discharge of process cooling water to B Pond since 1984.

The movement of ^{3}H plumes in the 200-West Area was also consistent with previous observations. The plume that extends from near the reduction oxidation

TABLE 3.4. Major Chemical and Radiological Ground-Water Contaminants and Their Link to Site Operations

Facilities Type	Area	Constituents
Reactor Operations	100	^{3}H, ^{60}Co, ^{90}Sr, Cr^{6+}
Irradiated Fuel Processing	200	^{3}H, ^{137}Cs, ^{129}I, ^{99}Tc, NO_3^-, CN^-
Plutonium Purification	200	CCl_4
Fuel Fabrication	300	Uranium, Cr^{6+}

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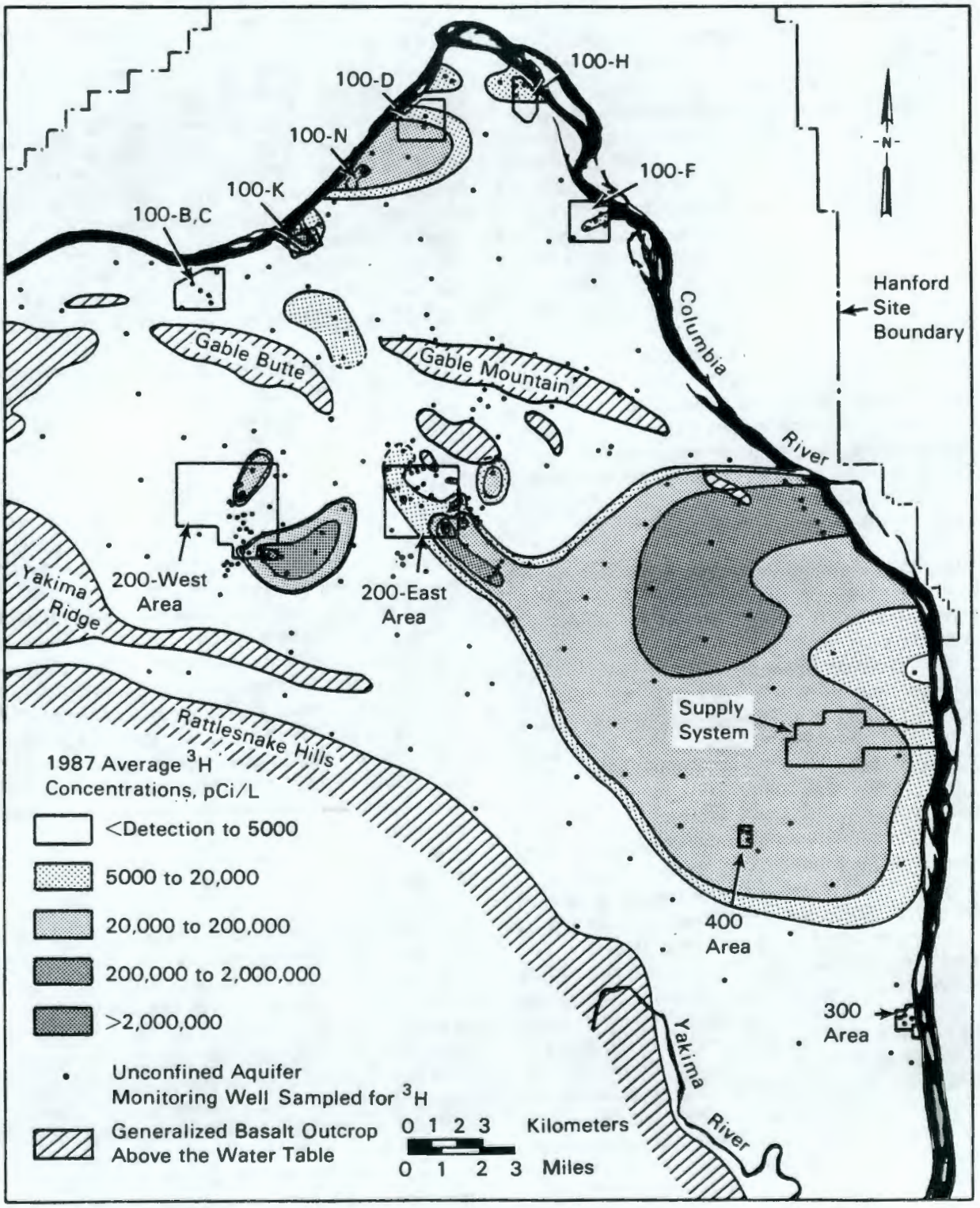

FIGURE 3.13. Tritium (^{3}H) Concentration in the Hanford Site Unconfined Aquifer in 1987

(REDOX) plant in the southern part of the 200-West Area continued to move slowly to the east and north. Well 299-W22-9 continued to be the only well in the 200-West Area with ^{3}H concentrations greater than the DCG. The maximum concentration in this well in 1987 was 8,070,000 pCi/L. Tritium concentrations in nearby wells within the 200-West Area and in the adjacent 600 Area remained above the DWS and were relatively constant throughout 1987. Movement of the ^{3}H plume that extends north and east from REDOX was indicated by changes in the ^{3}H concentrations in several wells in the plume. Concentrations in well 699-35-70 continued to decrease, indicating that peak concentrations have moved beyond this well. Concentrations in wells near the center of the plume remained relatively constant, while concentrations in well 699-40-62 continued to increase as the plume moves northward. The northernmost extent of the plume appeared to be in the vicinity of well 699-40-62. Well 699-44-64, north of well 699-40-62, continued to contain ^{3}H concentrations near the 300-pCi/L detection limit.

Gross alpha concentrations were detected in ground water from wells in several areas, and could be attributable to the presence of isotopes of plutonium and/or uranium. However, plutonium concentrations in wells sampled during the year were all below the detection limit reported by UST. The DWS for gross alpha is 15 pCi/L, not including uranium. Those wells in the 100-F, 200, and 300 Areas in which the gross alpha exceeded 15 pCi/L all contained uranium in concentrations that would account for the gross alpha concentration detected. Several wells in the 100-H and 100-N Areas also contained gross alpha concentrations exceeding the DWS. Although a few wells in the 200-East Area remained somewhat above the DWS, gross alpha concentrations in most wells in the 200-East Area were very low. The highest gross alpha concentrations measured on the Site continue to be in wells adjacent to the inactive 216-U-1 and 216-U-2 cribs. Concentrations in those wells continued to decrease slowly over the last year. All wells adjacent to the 216-U-1 and 216-U-2 cribs contained uranium concentrations that would account for the gross alpha concentrations detected. A plot of the gross alpha concentrations at well locations is shown in Figure 3.14. A summary of uranium concentrations in wells sampled during 1987 is presented in Table A.16, Appendix A.

Gross beta concentrations greater than the 50-pCi/L DWS were found in wells throughout the Site. Gross beta concentrations can commonly be attributed to the presence of one or more of the following radionuclides in the ground water: ^{60}Co, ^{90}Sr, ^{99}Tc, ^{125}Sb, ^{137}Cs, $^{234}Th + ^{234}Pa$ (uranium daughters), and to a lesser extent ^{129}I. Occasionally, some shorter lived beta emitters, such as ^{131}I, are also detectable. Tritium is not normally detected by the method used for assay of gross beta. The beta activity appears in most cases to derive from a combination of uranium and ^{99}Tc activity. The only exceptions are some of the wells in the 100-N Area and a few wells in the 200-East Area that contain ^{90}Sr at concentrations high enough to be detected with the gross beta technique.

Although gross beta concentrations greater than the DWS were widespread, the highest concentrations were found in wells near several waste disposal facilities in the 100-N, 200-East, and 200-West Areas, and in the 600 Area adjacent to the 200 Areas. Wells in the 200-East Area that contained highest gross beta during 1987 reflect past disposal of liquid waste to the inactive 216-B-5 reverse well, BY-cribs, and cribs near PUREX. Gross beta concentrations in well 299-E28-23 (15,700 pCi/L) near the 216-B-5 reverse well were the highest measured on the Site during 1987. Wells near the 216-B-5 reverse well all contained elevated concentrations of ^{90}Sr, and two wells also contained measurable ^{137}Cs. The 216-B-5 reverse well received an estimated 27.9 Ci of ^{90}Sr and 31.8 Ci of ^{137}Cs (both values decayed through April 1, 1986) during its operation from 1945 to 1947 (DOE 1986). The BY-cribs received U Plant waste. Wells monitoring the BY-cribs showed gross beta concentrations greater than the DWS, ranging from 62 to 1010 pCi/L. The BY-crib monitoring wells generally contained ^{60}Co and ^{99}Tc.

The highest gross beta concentrations in the 200-West Area were found in wells near U Plant. Gross beta concentrations in wells near the 216-U-1 and 216-U-2 cribs remained above the DWS, but are generally decreasing. Gross beta concentration in these wells is dominated by uranium daughters. Gross beta concentration remained above the DWS in several wells near Gable Mountain Pond. These wells contain relatively high concentrations of ^{90}Sr, which would account for the gross beta concentration measured. The distribution of gross beta concentration at well locations is shown in Figure 3.15

Concentrations of ^{90}Sr were above the 8 pCi/L DWS in wells in the 100-B, 100-N, 200-East, 200-West, 300, and 600 Areas. Only in the 100-N Area were

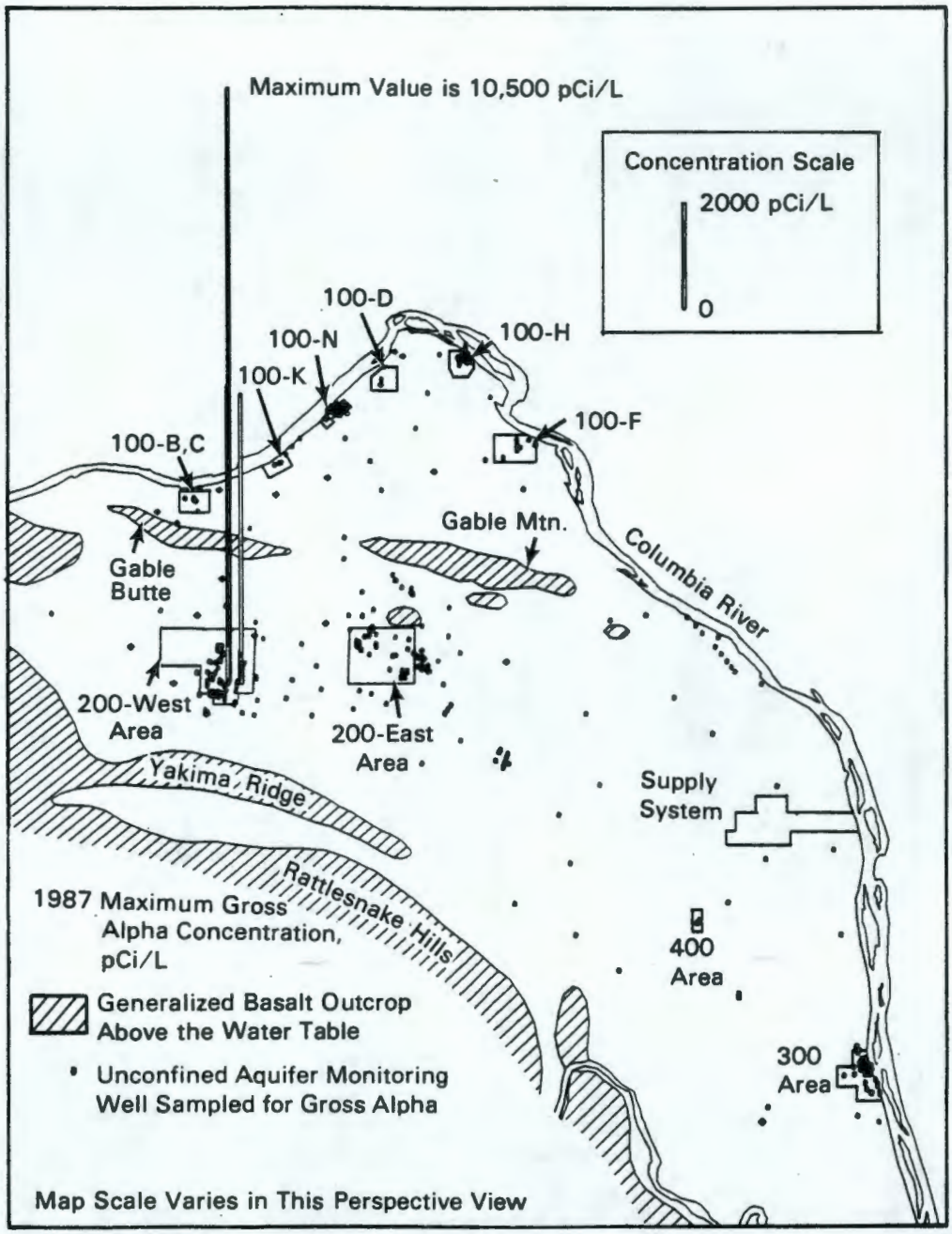

FIGURE 3.14. Maximum Gross Alpha Concentrations in Hanford Site Unconfined Aquifer Wells in 1987

concentrations of ^{90}Sr greater than the 1000-pCi/L DCG, ranging from the detection level to 10,400 pCi/L. As in past years, ^{90}Sr concentrations above the DWS but less than the DCG were detected in several wells near Gable Mountain Pond. A summary of ^{90}Sr concentrations in wells sampled during 1987 is presented in Table A.17, Appendix A.

All ^{60}Co results were near or below the detection limit (20 pCi/L), except in the 100-N Area and in isolated portions of the 200-East Area and adjacent 600 Area. Concentrations of ^{60}Co were greater than the 100-pCi/L DWS in several wells near the 1325-N LWDF; none exceeded the 5000-pCi/L DCG.

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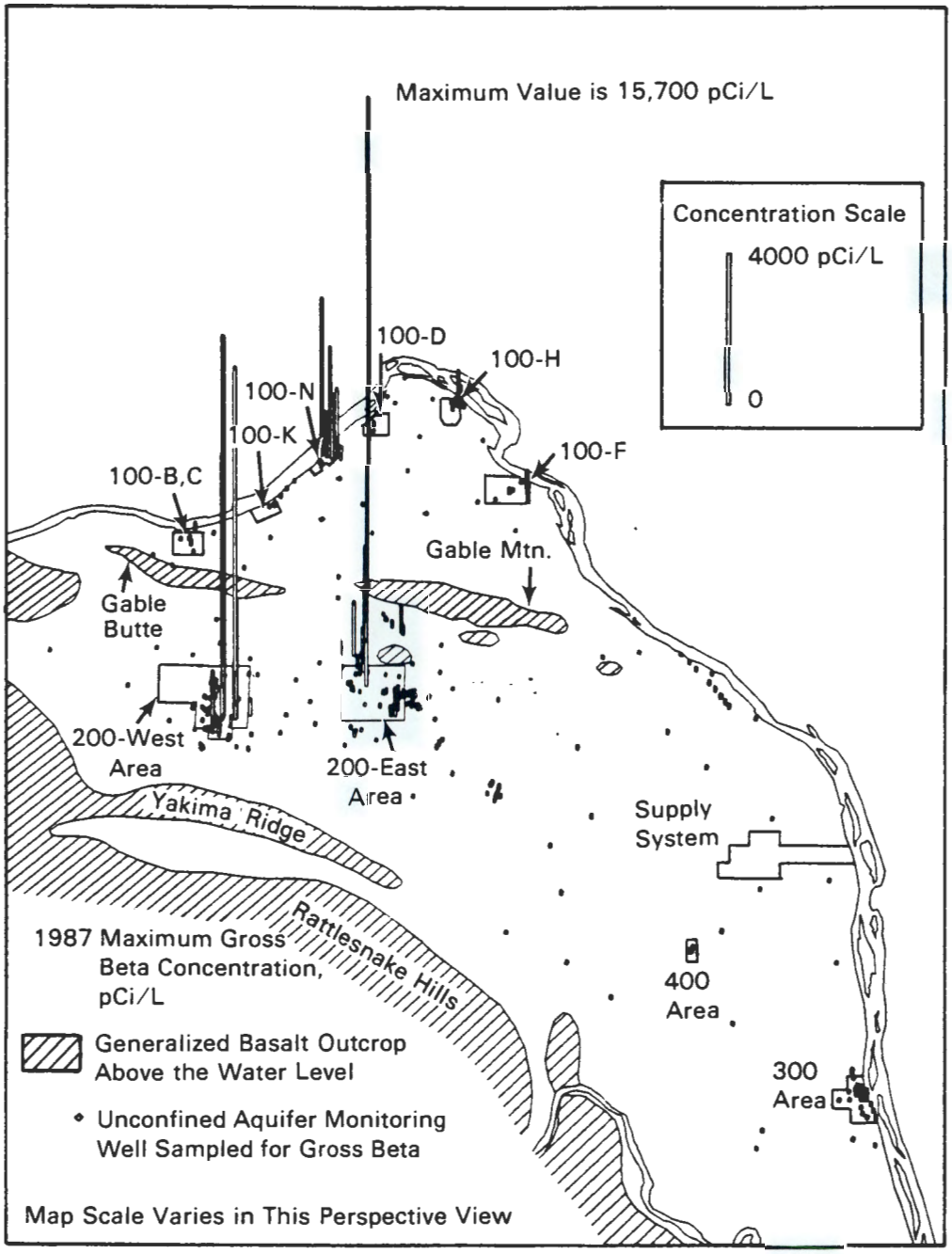

FIGURE 3.15. Maximum Gross Beta Concentration in Hanford Site Unconfined Aquifer Wells in 1987

An extensive program to analyze ground-water samples for ^{99}Tc was initiated in May 1987. Concentrations greater than the 900-pCi/L DWS were detected in wells in the 100-H, 200-East, and 200-West Areas and in portions of the 600 Area. None of the wells had concentrations exceeding the 100,000-pCi/L DCG. The highest concentrations of ^{99}Tc on the Site were measured in well 699-50-53, with a maximum concentration of 29,100 pCi/L. Well 699-50-53 is located north of the BY-cribs outside the 200-East Area. A summary of ^{99}Tc concentrations in wells sampled during 1987 is presented in Table A.18, Appendix A.

Because of its short half-life (367 days), ^{106}Ru is principally detected in wells located in areas near operating reactors or fuels reprocessing facilities, such as the 100-N Area and the 200-East Area near PUREX. Concentrations in wells in the 100-N Area generally declined in 1987, with concentrations in most wells falling below the 30-pCi/L DWS. Similarly, concentrations in wells near LWDFs receiving effluents from PUREX decreased, although wells 299-E17-5 and 299-E24-2 remained above the DWS.

Antimony-125 (^{125}Sb), a gamma emitter, was measured in 100-N Area wells near the 1325-N LWDF. Results ranged from 50 to 305 pCi/L, and were generally slightly less than those reported in 1986. The DWS for ^{125}Sb is 300 pCi/L, and the DCG is 60,000 pCi/L.

The presence of ^{129}I in ground water is significant, primarily because of its relatively long half-life (16 million years), its potential for accumulation in the environment as a result of long-term releases from nuclear fuel reprocessing facilities (Soldat 1976), its relatively low DWS (1 pCi/L),and because it is man made. On the Hanford Site, the main contributor of ^{129}I to the ground water has been liquid discharges to cribs in the 200 Areas. Samples from three wells in the 100-N Area were analyzed for ^{129}I, and all contained concentrations at least 50 times less than the DWS. Samples from 6 wells in the 200-East Area, 7 wells in the 200-West Area, and 12 wells in the 600 Area were also analyzed. Thirteen wells showed ^{129}I concentrations greater than the DWS, but less than the DCG (500 pCi/L). A summary of ^{129}I concentrations in wells sampled during 1987 is presented in Table A.19, Appendix A.

Because ^{131}I has a short half-life, it was only detected near discharge locations (100-N Area wells). Concentrations in samples taken in January 1987 in 100-N Area wells ranged from 309 to 28,600 pCi/L. The DWS for ^{131}I is 3 pCi/L, and the DCG is 3000 pCi/L. Iodine-131 was not detected in any 100-N Area wells during the latter part of 1987 because none was discharged to ground water as a result of the shutdown of N Reactor.

Concentrations of ^{137}Cs were below the detection limit (22.5 pCi/L) in all wells, except two wells located near the 216-B-5 reverse well. The 216-B-5 reverse well received an estimated 31.8 Ci of ^{137}Cs (decayed through April 1, 1986) during its operation from 1945 to 1947 (DOE 1986). The DWS for ^{137}Cs is 200 pCi/L, and the DCG is 3000 pCi/L.

A measurable plume of uranium exists in the unconfined aquifer beneath the 300 Area in the vicinity of uranium fuel fabrication facilities and near inactive waste sites known to have received uranium waste (Figure 3.16). The extent of the plume was limited to an area downgradient from active and inactive LWDFs. Average uranium concentrations in wells in and adjacent to the 300 Area ranged from 2 to 310 pCi/L (see Table A.16, Appendix A). These concentrations were similar to those measured in 1986. Samples from some wells were also analyzed for isotopic uranium (see Table A.16, Appendix A).

Chemical Monitoring Results for the Unconfined Aquifer

Chemical monitoring in 1987 revealed a number of chemical contaminants traceable to Hanford operations. While the extensive distribution of NO_3^- from Hanford operations is documented in past reports, some of the other chemical results represent new findings. Species of interest include NO_3^-, cyanide, chromium, fluoride, carbon tetrachloride, and other volatile chlorinated hydrocarbons.

Although NO_3^- is associated with process condensate liquid wastes, other liquids discharged to the ground also contain NO_3^-. Nitrate contamination in the unconfined aquifer reflects the extensive use of nitric acid in decontamination and chemical reprocessing operations. Nitrate, like ^3H, can be used to help define the extent of contamination because NO_3^- is present in many waste streams and is mobile in ground water. The distribution of NO_3^- on the Hanford Site is illustrated in Figure 3.17.

Most ground-water samples collected during 1987 were analyzed for NO_3^-. Nitrate was measured at concentrations greater than the DWS (45 ppm as NO_3^- ion) in wells in all operational areas, except for the 100-B and 400 Areas.

The highest NO_3^- concentrations in the 200-East Area continued to be found near LWDFs that received effluent from PUREX operations. A maximum concentration of 443 ppm was observed near the 241-AX tank farm. Nitrate concentrations in wells near the 216-A-10 and 216-A-36B cribs that were not used after 1987 also remained above the DWS. Wells near the 216-A-45 crib, which replaced the 216-A-10 crib and received process condensate from PUREX, contained maximum NO_3^- concentrations of 117 and 151 ppm, respectively.

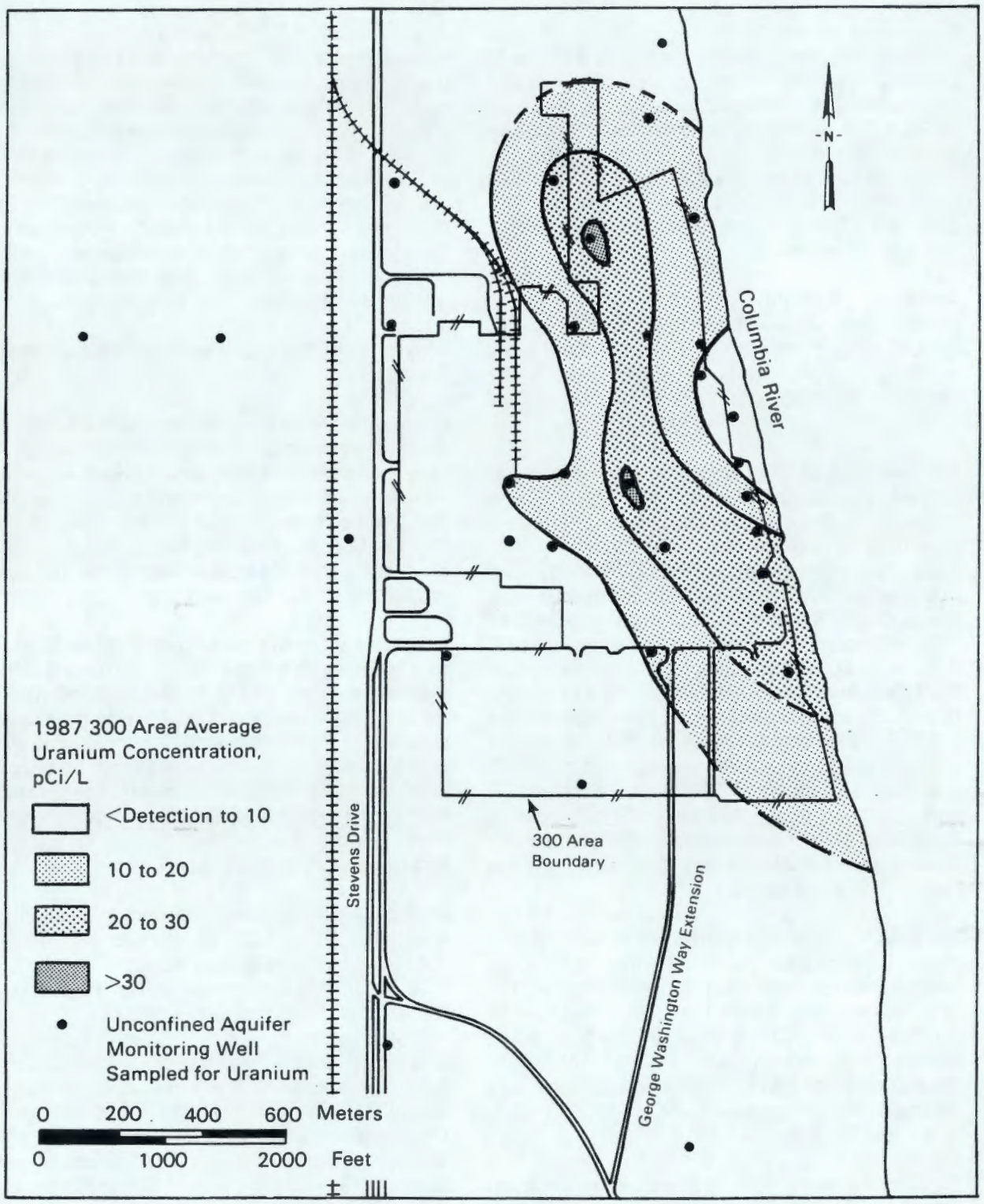

FIGURE 3.16. Uranium Concentration in the 300 Area Unconfined Aquifer for 1987 (see 300 Area location in Figure 3.10)

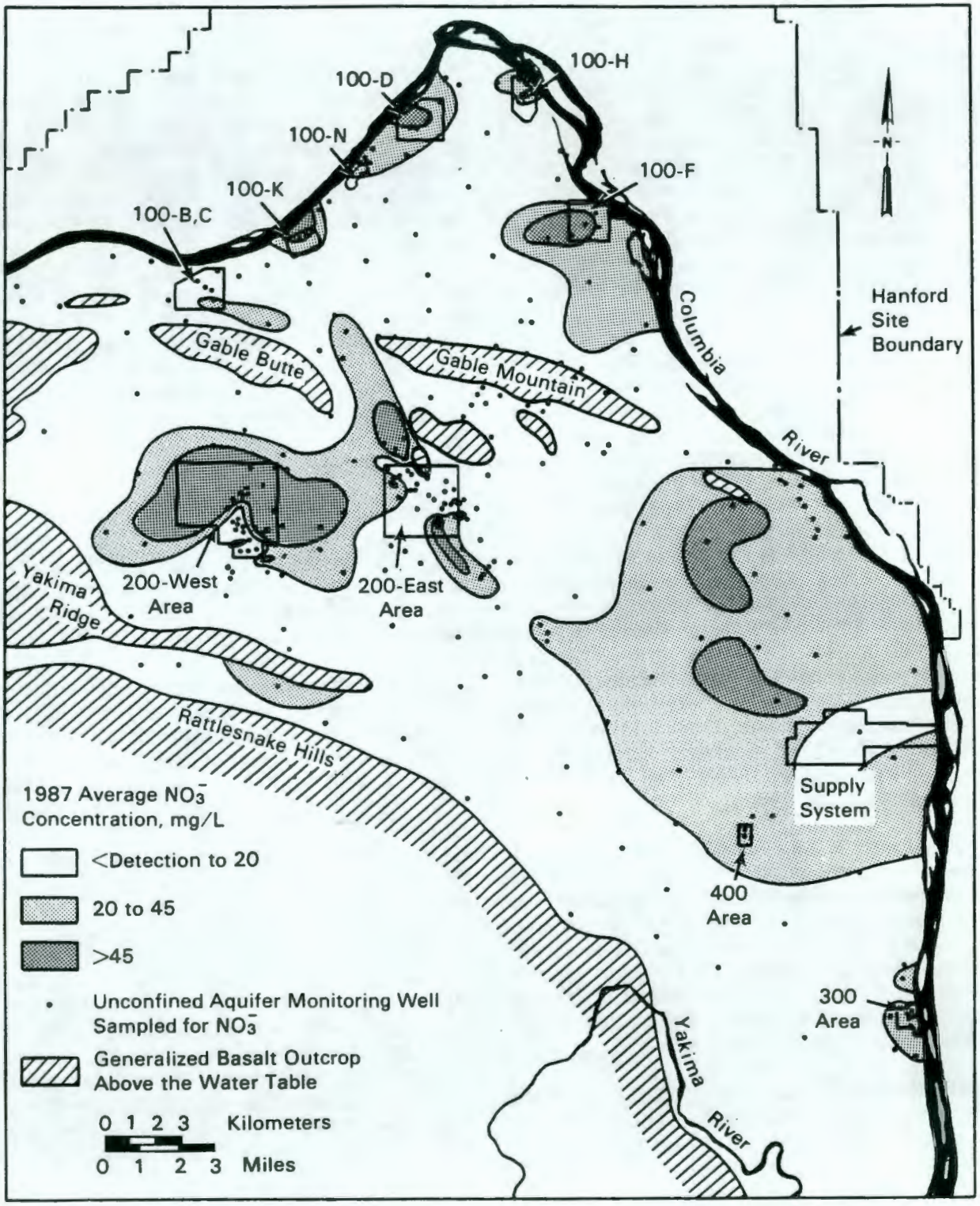

FIGURE 3.17. Nitrate (NO_3^-) Concentration in Hanford Site Unconfined Aquifer for 1987

The NO_3^- plume emanating from the southeastern corner of the 200-East Area (see Figure 3.17) was previously reported by Evans, Mitchell, and Dennison (1988). The configuration of the NO_3^- plume emanating from the 200-East Area, as with the ^3H plume mentioned above, shows the influence of two periods of PUREX operation and recent changes in the operation of B Pond. B Pond location is shown in Figure 3.10. Increases in the volume of process cooling water discharged to B Pond may have resulted in the expanding area of lower NO_3^- concentration in ground water to the east and south of that facility (see Figure 3.17).

Nitrate concentrations greater than the DWS were widespread in the ground water beneath the 200-West Area. The highest concentrations appeared to be centered in three locations: 1) wells near U Plant, 2) wells in the northwestern part of the 200-West Area; and 3) wells near the 216-S-25 crib. The highest NO_3^- concentrations measured across the Site continued to be found in wells east of U Plant near the 216-U-17 crib that has never been used. The source of NO_3^- is believed to be wastes disposed of in the 216-U-1 and 216-U-2 cribs. These cribs received over 1 million kg of NO_3^- during their operation from 1951 to 1967 (DOE 1986). A maximum NO_3^- concentration of 1500 ppm was measured in these wells and concentrations remained constant throughout 1987. Nitrate concentrations in wells located near the 216-U-1 and 216-U-2 cribs west of U Plant also remained greater than the DWS, but were generally decreasing.

Several wells in the northwestern part of the 200-West Area continued to contain NO_3^- in concentrations greater than the DWS. These wells are located near several inactive LWDFs that received waste from early T Plant operations. Average concentrations in these wells ranged from 84 ppm in well 299-W14-5 to 603 ppm in well 299-W15-4. A summary of NO_3^- concentrations in wells sampled during 1987 is presented in Table A.20, Appendix A.

Fluoride concentrations above the DWS were found in a few wells in the 200-West Area near T Plant. The maximum concentration was 12.8 ppm in well 299-W-15-4. All wells sampled outside the 200-West Area contained fluoride levels less than 1.1 ppm.

Cyanide contamination was detected in samples collected from wells in and directly north of the 200-East Area. The cyanide source is believed to be wastes containing ferrocyanide disposed of in the BY-cribs. Samples taken through December 1987 had a maximum cyanide concentration of 1120 ppb in well 699-50-53, with lesser amounts present in five other wells in or near the northern side of the 200-East Area. Wells where cyanide was detected contained unexpected concentrations of several radionuclides, including ^{60}Co. Although ^{60}Co is normally immobile in the Hanford subsurface, it appears to be chemically complexed and mobilized by cyanide.

Solutions containing ferrocyanide that were disposed of in the 200-West and 200-East Areas are likely to be the source of cyanide. The areal distribution of cyanide in the 200 Areas is shown in Figure 3.18. Cyanide has not been found in samples taken from other parts of the Site. A summary of cyanide concentrations in wells sampled during 1987 is presented in Table A.21, Appendix A.

Significant chromium contamination was found in wells in the 100-B, 100-D, 100-H, and 100-K Areas. In addition, well 199-F8-2 had detectable hexavalent chromium. The highest concentration of hexavalent chromium on the Site was found in well 199-D5-12, with a maximum of 1690 ppb in 1987.

Detectable chromium was also found in various parts of the 600 Area, particularly near the 100-D and 100-H Areas. The highest concentration was 191 ppb, four times the DWS, approximately 1 km west of the 100-H Area. Chromium contamination was also widespread in the 200-West Area. Three wells showed concentrations above the 50-ppb DWS. The distribution of chromium contamination appears to be random and may represent several independent, localized sources. A detailed delineation of the shape of the chromium plumes is not possible at this time because of inadequate well coverage for much of the affected area. A few wells in the 200-East Area also showed evidence of minor chromium contamination. The highest level found is in well 299-E13-14, with a chromium concentration of 42 ppb in December 1987. Figure 3.19 shows the concentration of chromium in Hanford Site ground water at well locations. A summary of chromium concentrations in wells sampled during 1987 is presented in Table A.22, Appendix A.

Extensive carbon tetrachloride contamination was found in the unconfined aquifer beneath much of the 200-West Area. The contamination is believed to be from waste disposal operations associated with Z Plant prior to 1973. Maximum concentrations

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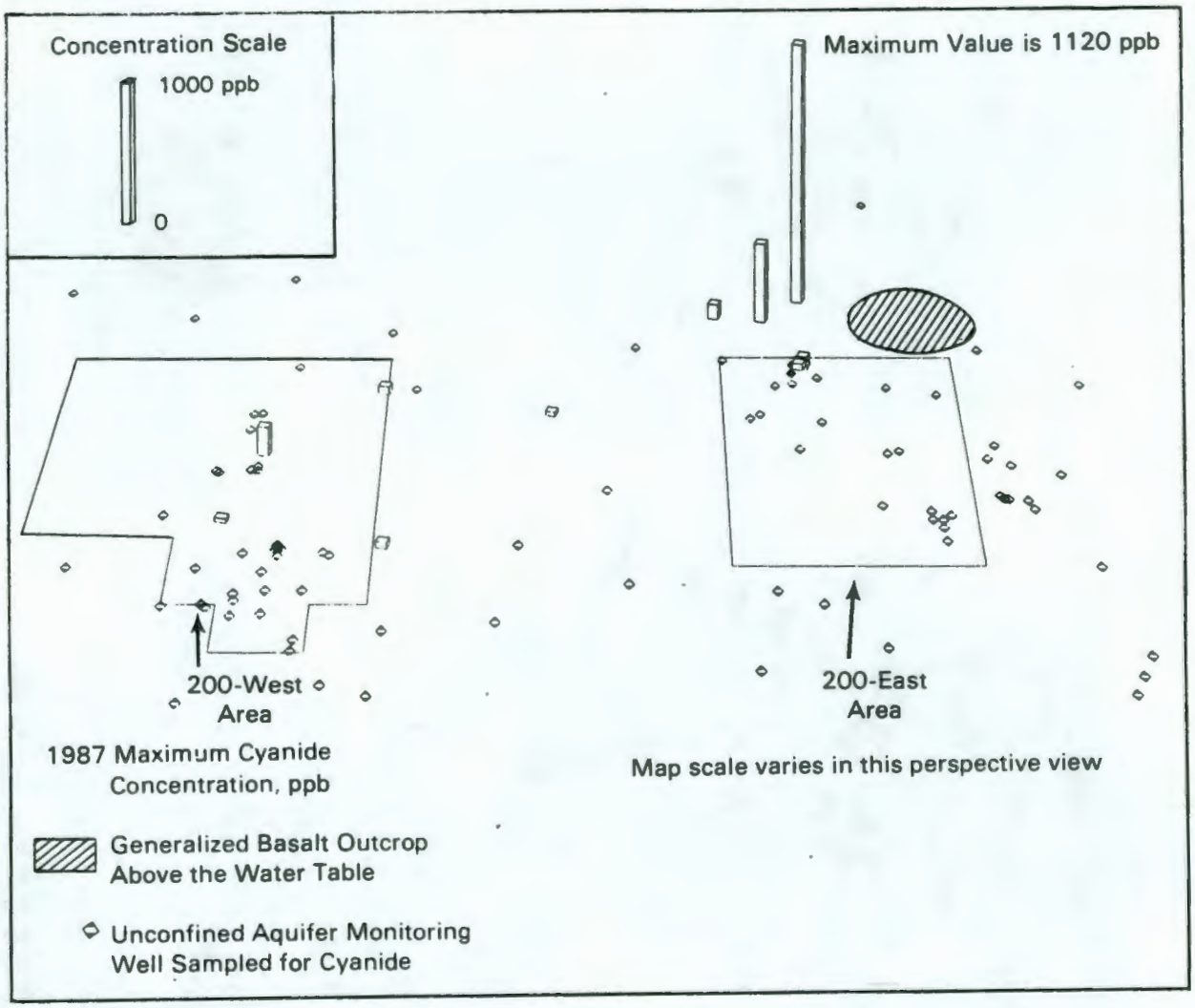

FIGURE 3.18. Maximum Cyanide Concentration in the 200 Areas Unconfined Aquifer Wells for 1987

detected in each well are shown in Figure 3.20. A maximum concentration of 4520 ppb in well 299-W15-11 was found near Z Plant in December 1987. For carbon tetrachloride, the maximum contaminant level, or target concentration, for remediation under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 and the Superfund Amendments and Reauthorization Act of 1986 is 5 ppb. The gas chromatography/mass spectrometry method detection limit shown in Figure 3.20 is also 5 ppb. In addition to carbon tetrachloride, minor amounts of other chlorinated hydrocarbon solvents were found in 200-West Area ground water, including trichloroethylene, chloroform, and methylene chloride. A summary of carbon tetrachloride concentrations in wells sampled during 1987 is presented in Table A.23, Appendix A.

Radiological and Chemical Monitoring Results for the Confined Aquifer

The uppermost (Rattlesnake Ridge) confined aquifer was monitored to determine the extent of ground-water interaction between the confined and unconfined aquifers. This intercommunication between aquifers was identified by Graham, Last, and Fecht (1984). Ground-water samples from the confined aquifer were analyzed for ^3H, NO_3^-, gamma-emitting radionuclides, and fluoride. The results are summarized in Tables A.13 through 25, Appendix A. Wells open to the confined (or a composite of the confined and unconfined) aquifer are indicated by footnotes in each table. In most cases, only background levels of constituents were detected in these wells. Detection of radionuclides in well 299-E33-12 has been

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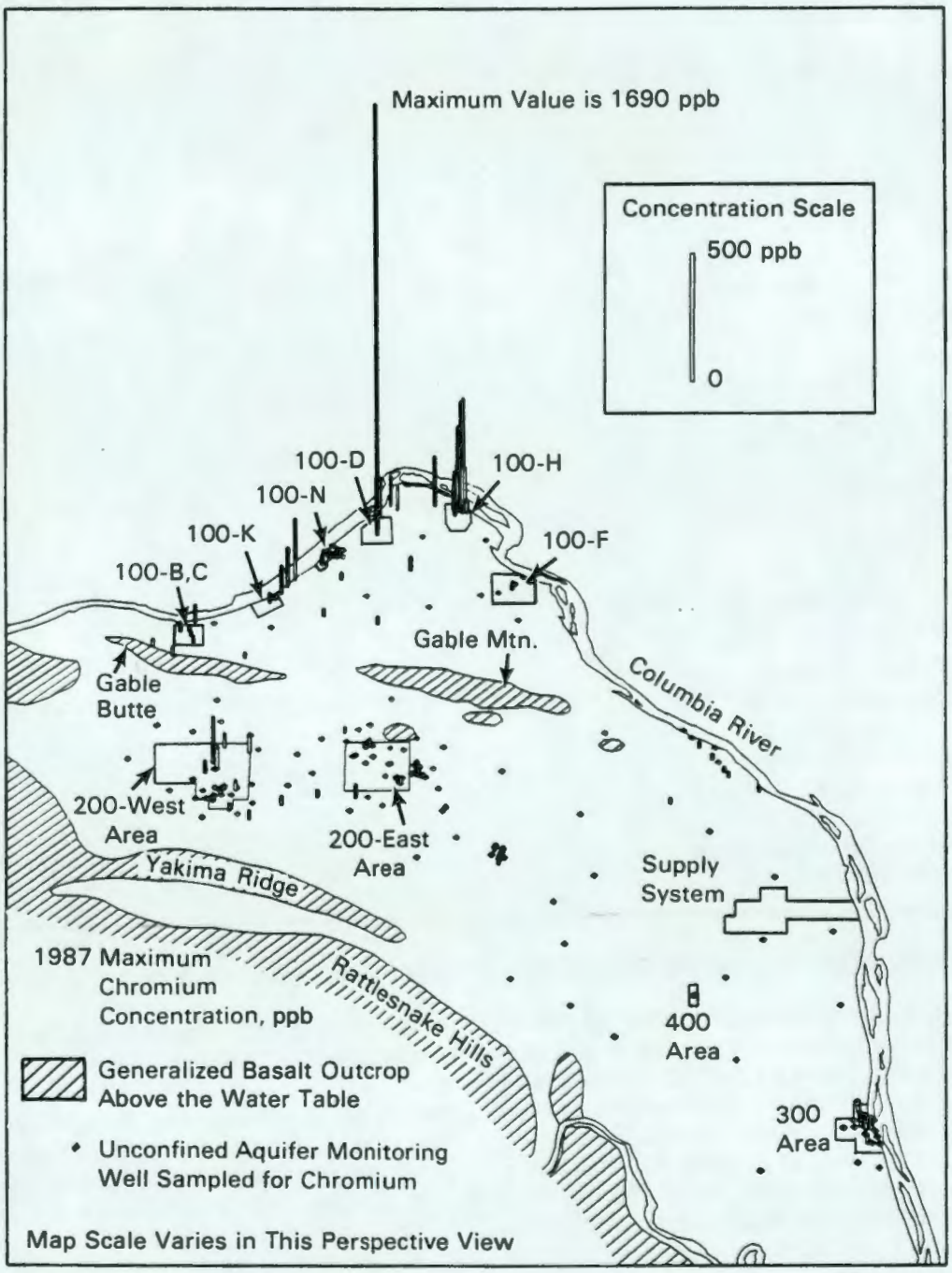

FIGURE 3.19. Maximum Chromium Concentration in Hanford Site Unconfined Aquifer Wells in 1987

attributed to contamination by high-salt waste that migrated by density flow into the borehole when it was open to both the unconfined and confined aquifers during drilling (Graham, Last, and Fecht 1984). Contaminant concentrations in this well were similar to those measured in 1986.

Intercommunication between the Rattlesnake Ridge confined aquifer and the unconfined aquifer north of the 200-East Area was indicated by the measured concentrations of NO_3^- and ^{129}I in well 699-47-50. This well is located near an erosional window (i.e., near an area where the confining layer is absent) in

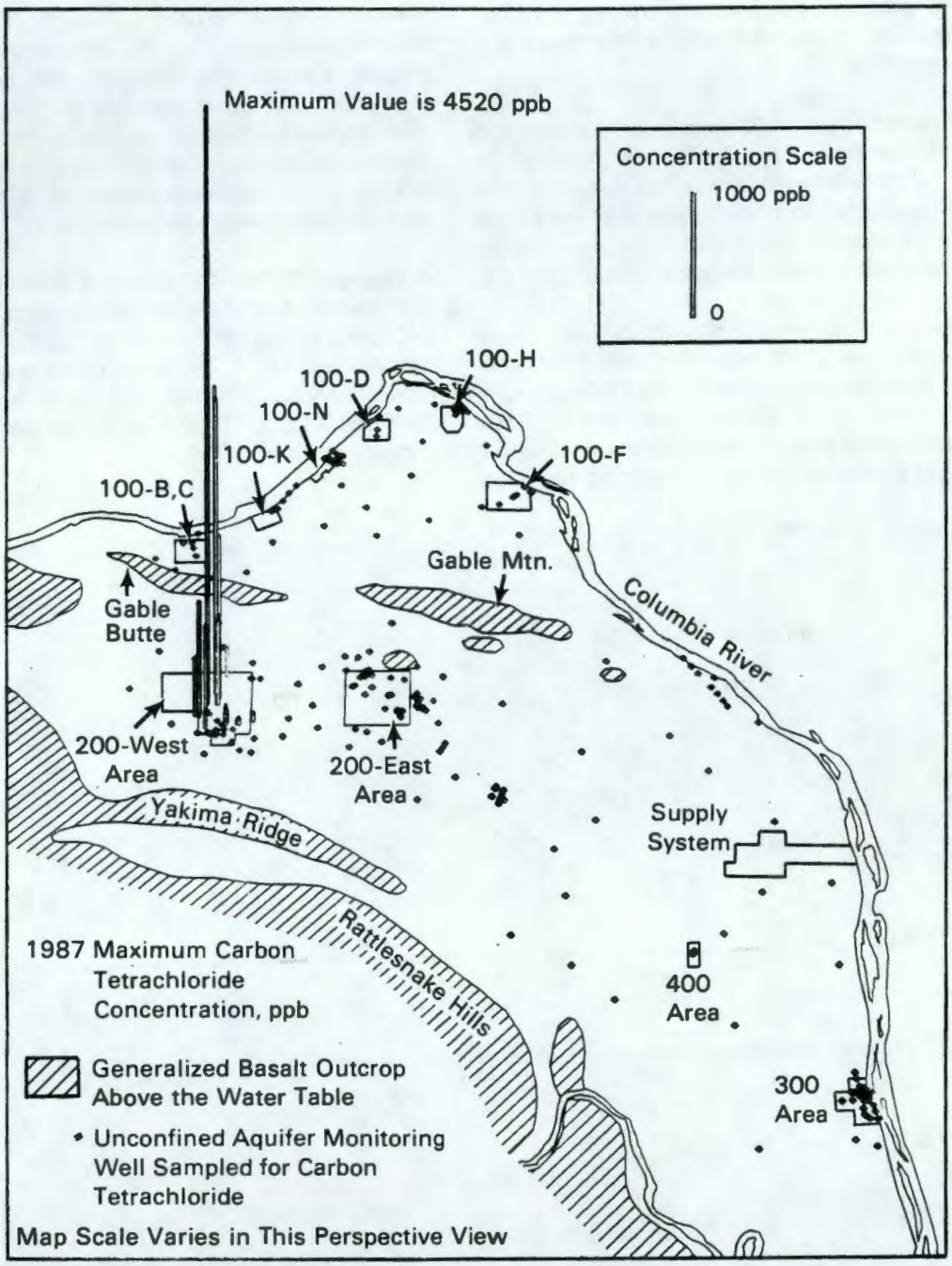

FIGURE 3.20. Maximum Carbon Tetrachloride (CCl_4) Concentration in Hanford Site Unconfined Aquifer Wells in 1987

the confining basalt flow (Graham, Last, and Fecht 1984). The ^{129}I concentration in this well was 6.07 x 10^{-3} pCi/L. Tritium was also present in ground water sampled from the Rattlesnake Ridge interbed at well 699-42-40C.

Well 699-S18-51 is open to the confined aquifer near the base of the Rattlesnake Hills. Ground water sampled from this well contained NO_3^- in concentrations above detection. The source of NO_3^- at this

location is unknown; however, it is unlikely that these concentrations are attributable to waste disposal in the 200 Areas.

Several wells completed in the confined aquifer had detectable concentrations of fluoride. An average concentration of 8 mg/L (above the 4-mg/L DWS) could be attributed to the chemistry of the basalt formations. Fluoride concentrations in some of the deeper confined aquifers routinely exceed 20 mg/L.

Three wells had elevated concentrations of a single contaminant during one sampling period in 1987. Samples collected from well 699-20-E5AP on April 26, 1987, contained an NO_3^- concentration of 18,300 ppb. Previous and subsequent samples were below the level of detection for NO_3^-. Samples collected from well 699-S11-E12AP on May 5, 1987, and well 699-51-46 on June 11, 1987, contained ^3H concentrations of 20,000 and 7790 pCi/L, respectively. Previous and subsequent samples collected at each of these wells were below detection for ^3H. The cause of elevated concentrations of these contaminants in a single sample is unknown and may reflect errors in sample collection or analysis.

Available ^{129}I data for Hanford confined aquifers (Rattlesnake Ridge and below) were assembled and published during 1987 by an intercontractor working group (WHC 1987). The document discussed background levels of ^{129}I in ground water, and identified locations where ^{129}I was found at concentrations exceeding background.

3.3 SURFACE-WATER MONITORING

R. L. Dirkes

The Columbia River was one of the primary environmental exposure pathways to the public during 1987 as a result of operations at Hanford. Radiological and nonradiological contaminants entered the river along the Hanford reach as direct effluent discharges and through the seepage of contaminated ground water. Water samples were collected from the river at various locations throughout the year to determine compliance with applicable standards.

Although radionuclides associated with Hanford operations continued to be routinely identified in Columbia River water during the year, concentrations remained extremely low at all locations, and were well below applicable standards. Nonradiological water quality constituents measured in Columbia River water during 1987 were also in compliance with applicable standards.

Four onsite ponds were also sampled to determine radionuclide concentrations. These ponds are accessible to migratory waterfowl and other animals. As a result, a potential biological pathway exists for the removal and dispersal of contaminants that may be in the ponds. Concentrations of radionuclides in water collected from these ponds during 1987 were similar to those during past years.

COLUMBIA RIVER

The Columbia River is used as a source of drinking water at onsite facilities and at communities located downstream of Hanford. In addition, the river along the Hanford Site is used for crop irrigation and a variety of recreational activities, including hunting, fishing, boating, water skiing, and swimming.

Pollutants, both radiological and nonradiological, are known to enter the river along the Hanford Site. In addition to direct discharges from Hanford facilities, contaminants in the ground water from past effluent discharges are known to seep into the river. Effluents from each direct discharge point are routinely monitored and reported by the responsible operating contractor, and are summarized in "Effluents, Waste Disposal, and Unusual Occurrences," Appendix G. Direct discharges are identified and regulated for nonradiological constituents under the NPDES. The NPDES permitted discharges at Hanford and the regulated parameters are listed in Table C.7, Appendix C.

The State of Washington has classified the stretch of the Columbia River from Grand Coulee Dam to the Washington-Oregon border, which includes the Hanford reach, as Class A (Excellent). Water quality criteria and water use guidelines have been established in conjunction with this designation and are presented in Table C.1, Appendix C. The State of Washington and EPA DWSs used in evaluating radionuclide concentrations in Columbia River water are provided in Table C.2, Appendix C.

Sample Collection and Analysis

Samples of Columbia River water were collected throughout 1987 at the locations shown in Figure 3.21. Samples were collected upstream of Hanford facilities at Priest Rapids Dam and near the Vernita Bridge to provide background data from locations unaffected by Site operations. Samples collected from the 300 Area water intake and the Richland Pumphouse provide data from locations downstream of Hanford to identify any influence on contaminant concentrations in the river from Hanford operations. The Richland Pumphouse represents the first downstream point of river water withdrawal for public use, providing an estimate of the amount of radioactivity in the water supply of population groups using Columbia River water downstream of Hanford.

Radiological analyses on water samples included gross alpha, gross beta, gamma scan, ^{3}H, ^{89}Sr, ^{90}Sr,

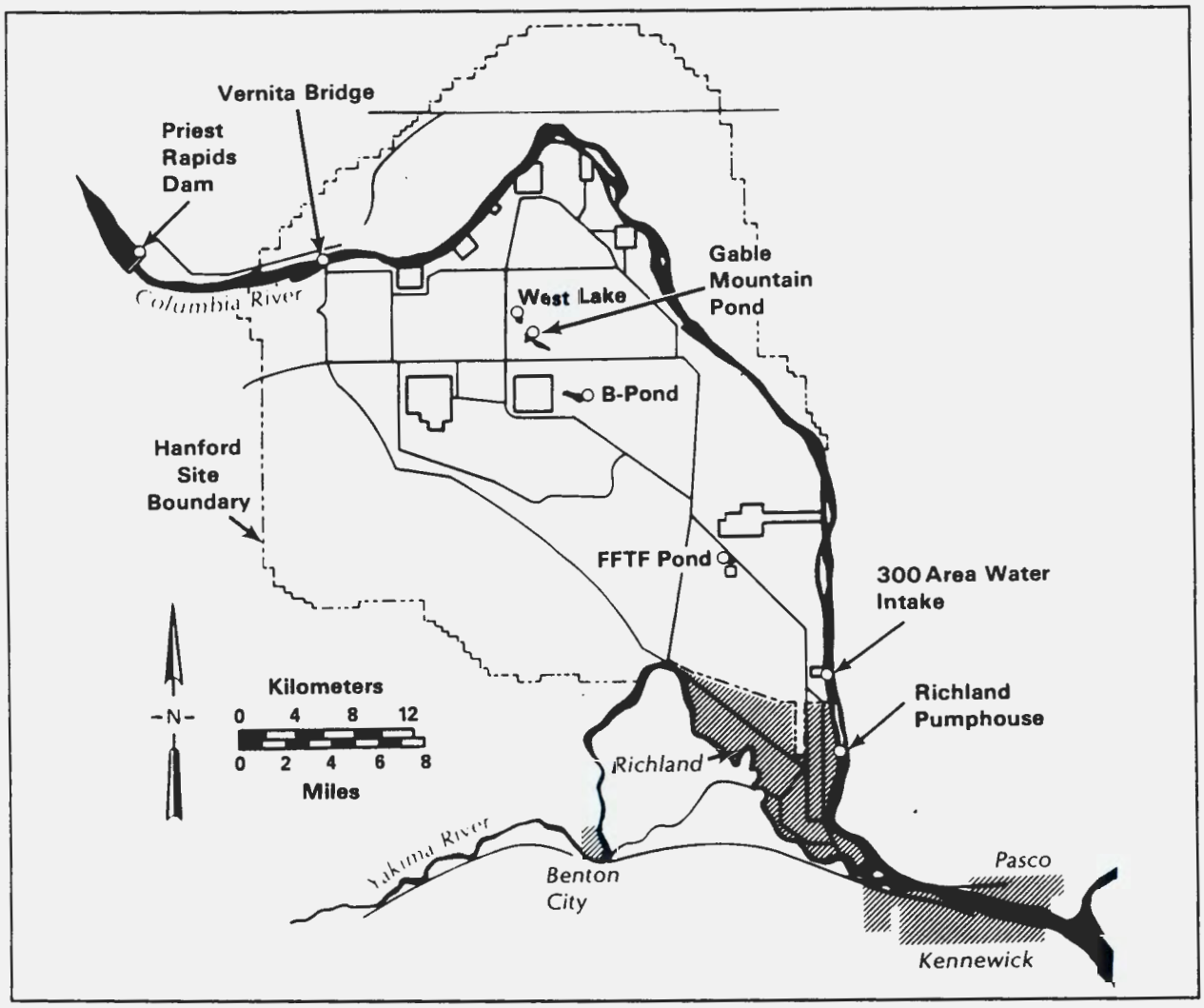

FIGURE 3.21. Columbia River Water Sampling and Onsite Pond Locations in 1987

^{129}I, $^{239,240}Pu$, and isotopic uranium. Gross alpha and gross beta measurements provided a general indication of the radioactive contamination present. Gamma scans provided concentrations of several specific radionuclides (listed on page D.1, Appendix D), primarily ^{60}Co, ^{131}I, and ^{137}Cs. Specific radiochemical analyses and, in some cases, special sampling techniques were used to determine the concentrations of ^{3}H, ^{89}Sr, ^{90}Sr, ^{129}I, ^{234}U, ^{235}U, ^{238}U, and $^{239,240}Pu$ in the river water during the year. Radionuclides of interest were selected based on their importance in determining water quality, verifying effluent control and effluent monitoring systems, and determining compliance with applicable standards that pertain to the potential exposure to the public using the river. The half-lives of specific radionuclides were considered in determining sampling and analysis frequencies.

Priest Rapids Dam is located approximately 8 km upstream of the Site boundary and 20 km upstream of the 100-B Area, the facility farthest upstream at Hanford. The water sampler at Priest Rapids Dam is positioned approximately midstream within the dam and collects water from the reservoir behind the impoundment as it passes through the dam. The Vernita Bridge sample location is approximately 6 km upstream of the 100-B Area. Samples are collected from the Benton County shoreline near the bridge for analysis of nonradiological constituents.

Analytical results for 1987 at Priest Rapids Dam are provided in Table A.24, Appendix A. Both the Priest Rapids Dam and the Vernita Bridge locations are unaffected by Site operations and provide an estimate of background contaminant concentrations in the Columbia River.

The 300 Area water intake sample location is near the southern boundary of the Site at the point of withdrawal for the 300 Area sanitary water supply. This location is a source of onsite drinking water and provides valuable time-series data for certain constituents, as it has been in existence since the early days of Hanford. Concentrations observed here are influenced by seepage of local ground water, known to contain elevated concentrations of ^{3}H and uranium (see "Ground-Water Monitoring," Section 3.2). Analytical results for 1987 at the 300 Area are provided in Table A.25, Appendix A.

The Richland Pumphouse is the primary river sampling location downstream of Hanford facilities. It is located approximately 3 km downstream of the Site boundary and nearly 6 km downstream of the effluent discharge farthest downstream. The water intake is located on the Benton County shoreline, approximately 9 m into the river. The Richland Pumphouse sampler is the first withdrawal point downstream of Hanford for a public drinking water supply. As such, an upper estimate of the amount of radioactivity in the water supply of any population using Columbia River water is provided (Corley et al. 1981). Past sampling transects near this location indicated the distribution of gross beta activity to be slightly elevated near the Benton County shoreline (Soldat 1962). A special task to evaluate the relationship between concentrations observed at the Richland Pumphouse and average river concentrations was initiated during 1987 and is continuing into 1988. Observations made when flow rates were slightly lower than the annual average showed ^{3}H concentrations to be highly variable across the river cross section. Use of the data generated at the Richland Pumphouse without careful consideration of factors potentially influencing the relationship between average river conditions and conditions at the Richland Pumphouse may be inappropriate and may lead to incorrect conclusions.

Two types of water sampling systems were used to collect radiological samples: a composite system that collected a fixed volume of water at set intervals at each location during each sample period, and a specially designed system that continuously collected waterborne radionuclides from the river on a series of filters and ion-exchange resins.

The composite sampler consisted of a timer-activated unit that periodically collected water from a continuously flowing substream of Columbia River water into a 10-L container. The sample sequence included a pre- and post-sample purge of the sample lines to preclude cross contamination between consecutive aliquots. This cycle was repeated throughout the 1-week sample period, such that approximately 55 mL of water were collected every hour. The 10-L sample container was changed every week and the sample was taken to the laboratory, where water from each location was composited over a 4-week period before analysis, resulting in a total sample size of approximately 40 L. Gross alpha, gross beta, gamma scan, ^{3}H, ^{89}Sr, ^{90}Sr, ^{234}U, ^{235}U, and ^{238}U analyses were performed on these samples. Composite sampling systems were operated at Priest Rapids Dam, the 300 Area water intake, and the Richland Pumphouse.

A special, continuously flowing system was used to separate other radionuclides from the river water before analysis. A large volume of water was required to allow the extremely small concentrations of these radionuclides in the river to be detected. River water was pumped through the collection system at a rate of approximately 50 mL/min, resulting in a total sample volume of approximately 1000 L during each 2-week sampling period. Suspended particulates greater than 0.45 µm in diameter were removed from the water on a series of filters, and soluble radionuclides, except ^{3}H, were collected on a mixed-bed, ion-exchange resin column. The filters and ion-exchange resin were exchanged every 2 weeks and analyzed for gamma-emitting radionuclides (see "Analytical Procedures and Sampling Summary," Appendix D). The filters and resin from each location were then composited on a quarterly basis for analyses of ^{129}I, ^{238}Pu, and $^{239,240}Pu$. Continuous sampling systems were located at Priest Rapids Dam, the 300 Area water intake, and for the first time, the Richland Pumphouse.

Monthly grab samples were collected from shoreline sites near the Vernita Bridge and near the Richland Pumphouse for analysis of various nonradiological water quality variables. Special care was taken to obtain water from a flowing portion of the river, avoiding stagnant backwater areas. Surface debris and bottom sediment were also avoided during the sampling process. Samples were delivered to the

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laboratory where processing was initiated to ensure sample integrity. Water quality analyses performed during 1987 included pH, NO_3^-, total coliform and fecal coliform bacteria, and biological oxygen demand. All of these parameters are indicators of the nonradiological quality of Columbia River water.

In addition to monitoring conducted by PNL, water quality measurements were also performed by the USGS at Vernita Bridge and Richland. The USGS samples consisted of cross-sectional composites of the river collected every 2 months at the Vernita Bridge and quarterly at Richland. Analyses for numerous physical, biological, and chemical constituents were performed on these samples at the USGS laboratory in Denver, Colorado. In addition to sampling, the USGS provided continuous river temperature monitoring, both upstream of the Site and at Richland, and provided flow rate measurements at Priest Rapids Dam.

Results

Results of the radiological analysis of Columbia River water samples collected at Priest Rapids Dam, the 300 Area, and the Richland Pumphouse during 1987 are summarized in Tables A.24, A.25, and A.26, Appendix A, respectively. Levels throughout the year were extremely low, being essentially undetectable without the use of special sampling techniques and analytical procedures. Significant results are discussed and illustrated below, with comparisons to previous years' provided. Radionuclides consistently in measurable quantities in river water during 1987 were ^{3}H, ^{90}Sr, ^{129}I, ^{234}U, ^{235}U, ^{238}U, and $^{239,240}Pu$. All of these radionuclides exist in worldwide fallout, as well as in effluents from Hanford facilities. In addition, ^{3}H and uranium occur naturally in the environment.

Gross alpha and gross beta measurements are useful as indicators of the general radiological quality of the river and provide an early indication of changes in the levels of radioactive contamination. The 1987 average gross alpha and gross beta concentrations in Columbia River water at Priest Rapids Dam, the 300 Area, and the Richland Pumphouse were well below the applicable DWS of 15 and 50 pCi/L, respectively. Figures 3.22 and 3.23 illustrate the annual average gross alpha and gross beta concentrations at Priest Rapids Dam and the Richland Pumphouse during the past 6 years. As is apparent in the figures, 1987 gross alpha concentrations were consistent with those of previous years, with no

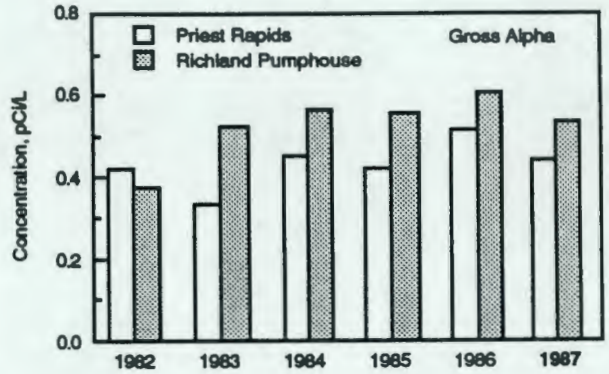

FIGURE 3.22. Annual Average Gross Alpha Concentrations in Columbia River Water, 1982 Through 1987

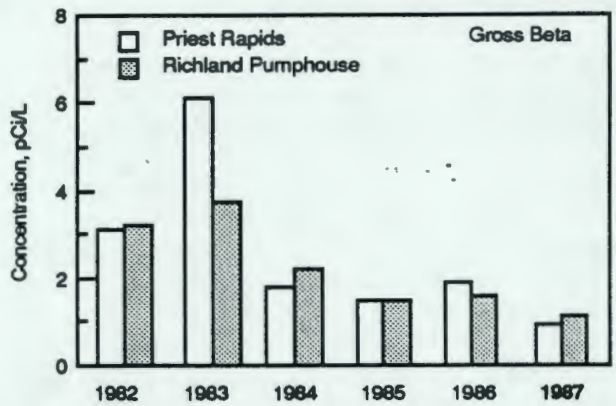

FIGURE 3.23. Annual Average Gross Beta Concentrations in Columbia River-Water, 1982 Through1987

significant increases or decreases observed. Gross beta concentrations at both locations decreased slightly in 1987.

Annual average ^{3}H concentrations measured at Priest Rapids Dam and the Richland Pumphouse during 1987 were 70 and 130 pCi/L, respectively. Figure 3.24 compares the annual average ^{3}H concentrations at Priest Rapids Dam and the Richland Pumphouse from 1982 through 1987. Tritium concentrations in Columbia River water during 1987 were similar to those during recent years and were comparable to measurements reported by the State of Washington (WDSHS 1987).

Figure 3.25 provides a comparison of monthly ^{3}H concentrations in river water during 1987, showing

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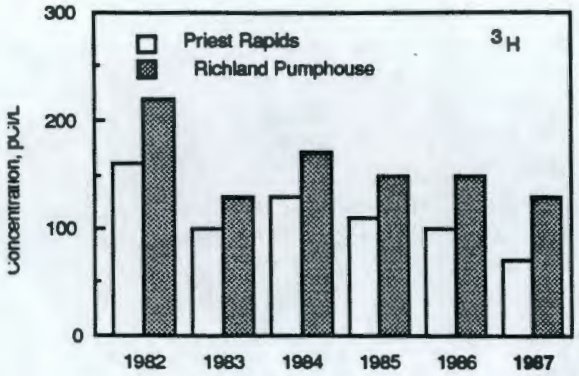

FIGURE 3.24. Annual Average Tritium (^3H) Concentrations in Columbia River Water, 1982 Through 1987

that concentrations at the Richland Pumphouse were generally higher during the year than those at Priest Rapids Dam. The variability in the monthly ^3H concentrations during 1987 was comparable to that experienced during previous years (Price 1986). Statistical analyses (paired sample comparison, t-test of differences) indicated that the difference between the ^3H concentrations at these locations was significant (Snedecor and Cochran 1980). Tritium sources entering the river were effluent releases from the N Reactor and ground water entering the river along the Site (see "Effluents, Waste Disposal, and Unusual Occurrences," Appendix G, and "Ground-Water Monitoring," Section 3.2). All ^3H concentrations were below the State of Washington and EPA DWS of 20,000 pCi/L.

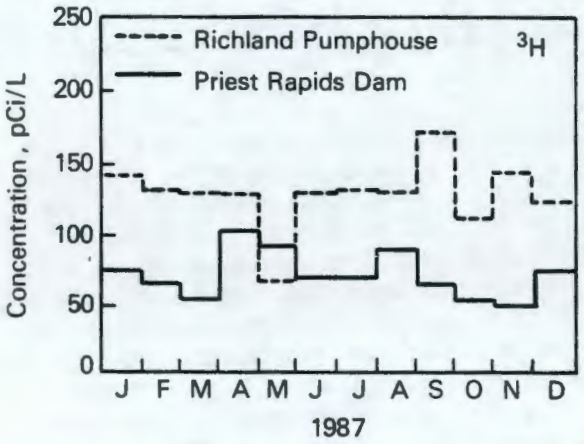

FIGURE 3.25. Monthly Tritium (^3H) Concentrations in Columbia River Water During 1987

The annual average ^{90}Sr concentrations measured at Priest Rapids Dam and the Richland Pumphouse during 1987 were essentially the same (0.14 and 0.13 pCi/L, respectively). Figure 3.26 shows the annual average ^{90}Sr concentrations at these locations from 1982 through 1987. Although the Richland Pumphouse annual average concentrations were generally slightly higher than those at Priest Rapids Dam, the differences since 1982 were slight, especially when the uncertainty associated with the averages was considered. Figure 3.27 shows monthly

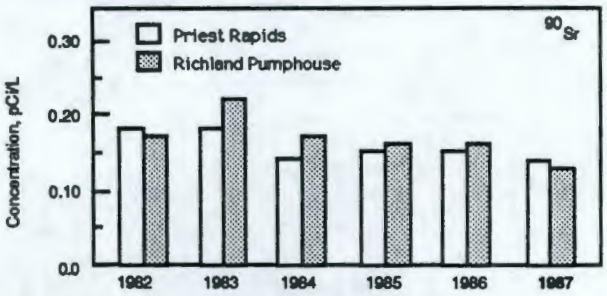

FIGURE 3.26. Annual Average Strontium-90 (^{90}Sr) Concentrations in Columbia River Water, 1982 Through 1987

^{90}Sr concentrations during the year at both locations. Statistical analyses indicated that the difference between the ^{90}Sr concentrations throughout the year at these locations was insignificant. The only known

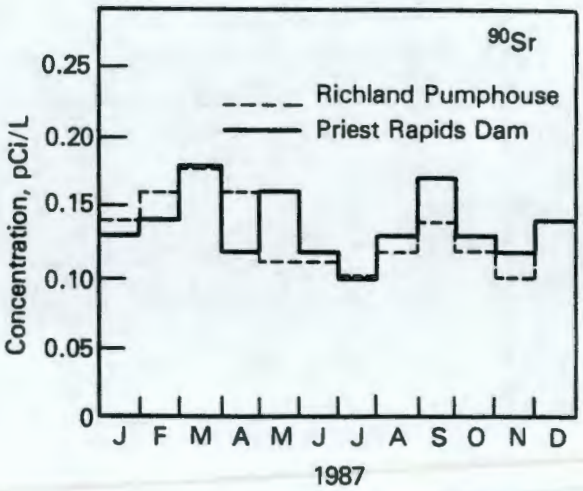

FIGURE 3.27. Monthly Strontium-90 (^{90}Sr) Concentrations in Columbia River Water During 1987

source of ^{90}Sr entering the Columbia River was the 100-N Area LWDF that discharged 2.4 Ci to the river via seepage during 1987. Observed ^{90}Sr concentrations during 1987 in Columbia River water were well below the State of Washington and EPA DWS of 8 pCi/L.

Annual average uranium concentrations in 1987 continued to be slightly higher in river water collected at the Richland Pumphouse than in samples collected at Priest Rapids Dam (Figure 3.28). The difference in annual averages (0.05 pCi/L) is small and within the degree of variability expected for this type of analysis. Monthly values during the year were not consistently higher at any one location, as shown in Figure 3.29. This figure indicates there was not a

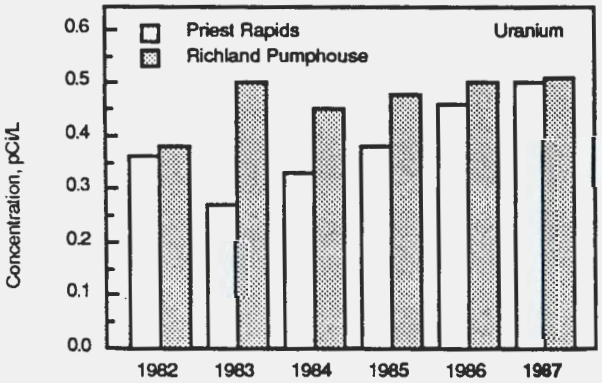

FIGURE 3.28. Annual Average Uranium Concentrations in Columbia River Water, 1982 Through 1987

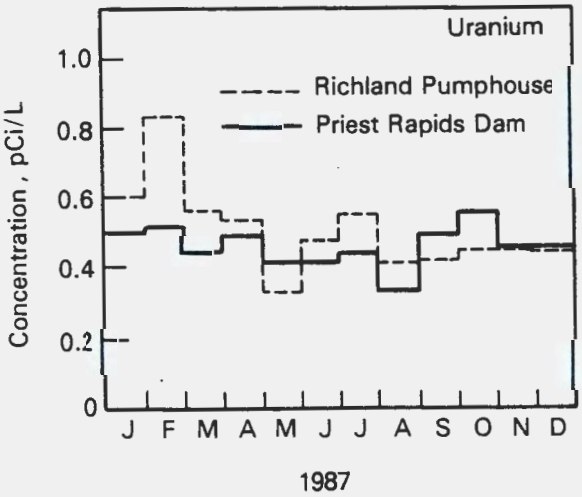

FIGURE 3.29. Monthly Uranium Concentrations in Columbia River Water During 1987

consistently measurable contribution to Columbia River water uranium concentrations attributable to Hanford operations. Statistical analyses showed that the differences during the year were insignificant. Although there is no direct discharge of uranium to the river, uranium is present in the ground water beneath the 300 Area (see "Ground-Water Monitoring," Section 3.2) and has been detected at elevated levels in riverbank springs in this area (McCormack and Carlile 1984).

As in past years, ^{129}I concentrations continue to be significantly higher at the 300 Area water intake than at Priest Rapids Dam. Average Priest Rapids Dam and 300 Area river water ^{129}I concentrations during 1987 were 7 and 106 aCi/L, respectively. During 1987, a continuous filter-resin sampling system was installed at the Richland Pumphouse to allow for the measurement of ^{129}I. Concentrations of ^{129}I at the Richland Pumphouse (103 aCi/L) were essentially the same as those at the 300 Area (106 aCi/L). Iodine-129 in the river is attributable to the flow of ground water from the unconfined aquifer into the river (McCormack and Carlile 1984). Figure 3.30 provides the annual average ^{129}I concentrations from

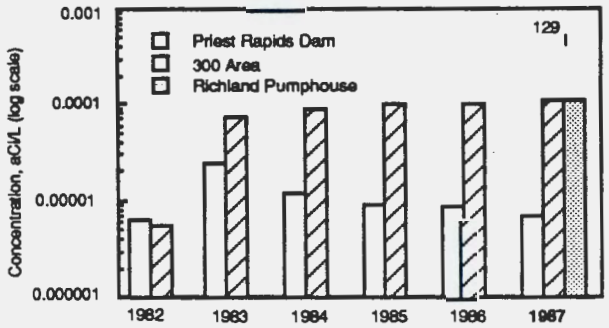

FIGURE 3.30. Annual Average Iodine-129 (^{129}I) Concentrations in Columbia River Water, 1982 Through 1987

1982 through 1987. The differences during 1987 among the Priest Rapids Dam, 300 Area, and Richland Pumphouse concentrations were similar to the differences in past years. Figure 3.31 illustrates the quarterly ^{129}I concentrations at Priest Rapids Dam and the Richland Pumphouse. As for other radionuclides, ^{129}I concentrations in Columbia River water during 1987 at those locations were below concentrations that would result in doses exceeding the State of Washington and EPA DWS of 4 mrem/yr.

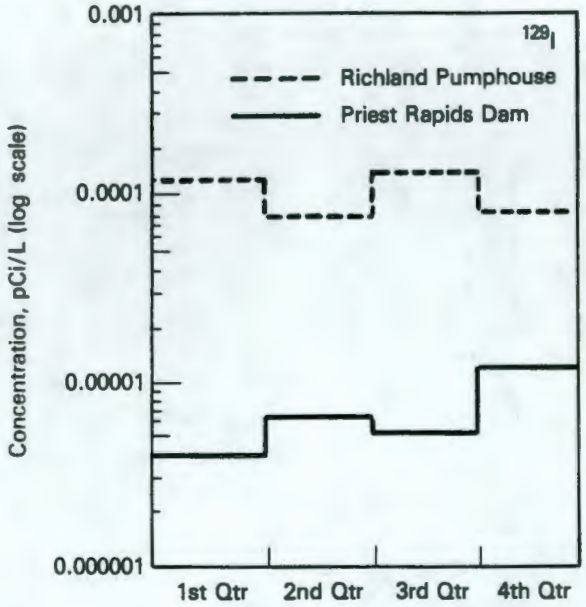

FIGURE 3.31. Quarterly Iodine-129 (^{129}I) Concentrations in Columbia River Water During 1987

During 1987, ^{60}Co and ^{131}I were not consistently in measurable quantities in the Columbia River at Priest Rapids Dam, 300 Area water intake, or the Richland Pumphouse. Likewise, ^{89}Sr, ^{134}Cs, and ^{137}Cs were generally below the detection level throughout the year. Concentrations of $^{239,240}Pu$ were extremely low with respect to the detection limit and were similar at these locations, indicating no measurable effect due to Hanford operations. All ^{60}Co, ^{89}Sr, ^{131}I, ^{134}Cs, ^{137}Cs, and $^{239,240}Pu$ concentrations during the year were below the State of Washington and EPA DWS (Tables A.24, A.25, and A.26, Appendix A).

Nonradiological water quality data compiled by PNL and the USGS during 1987 are summarized in Table A.27, Appendix A. The data include a number of parameters for which no regulatory limit exists. The parameters are, however, useful as indicators of water quality. The PNL and USGS results, where duplicated, were in general agreement and were comparable to levels in recent years. In all cases, applicable standards for Class A-designated water were met at both sampling locations. There was no indication during 1987 of any significant deterioration of the water quality along this stretch of the Columbia River resulting from Hanford operations. Potential sources of nonradiological pollutants not associated with Hanford include irrigation return water canals and seepage associated with extensive irrigation practices north and east of the Columbia River.

Figure 3.32 shows results during 1982 through 1987 for several water quality parameters with respect to the applicable standard. The pH measurements above and below the Site throughout the year were generally in close agreement and were within the

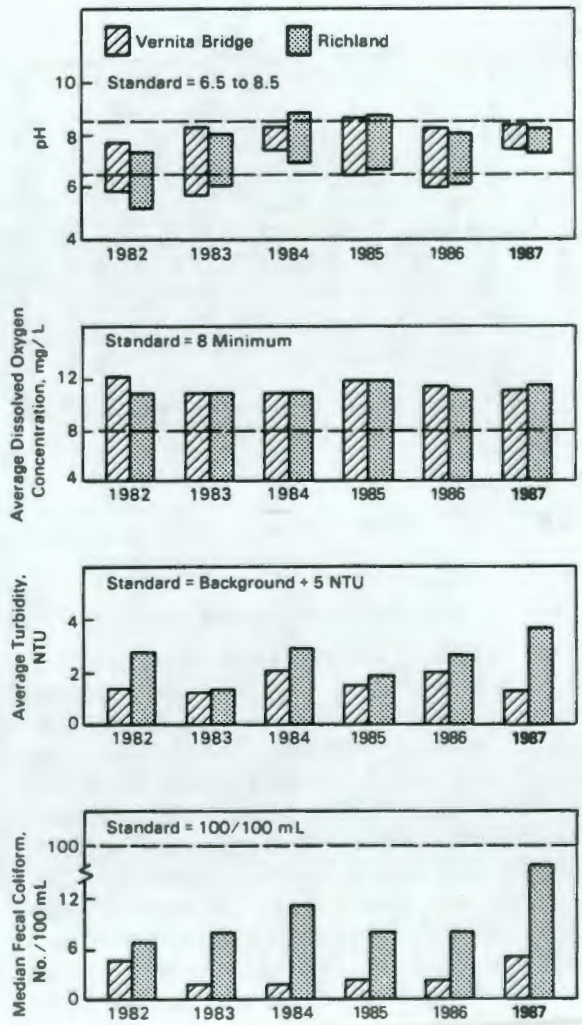

FIGURE 3.32. Columbia River Water Quality Measurements, 1982 Through 1987

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acceptable range for Class A waters. Turbidity, median fecal coliform and dissolved oxygen concentrations at both locations during 1987 were below Class A requirements.

The annual average flow rate of the Columbia River was 101,000 cfs during 1987, slightly lower than recent years. The monthly average flow rates at Priest Rapids Dam during the year are shown in Figure 3.33, illustrating a pattern similar to recent years. The peak monthly average flow occurred during May (153,000 cfs) and the lowest flow occurred during September (81,000 cfs). Daily average flow rates varied from 183,000 to 46,000 cfs during 1987.

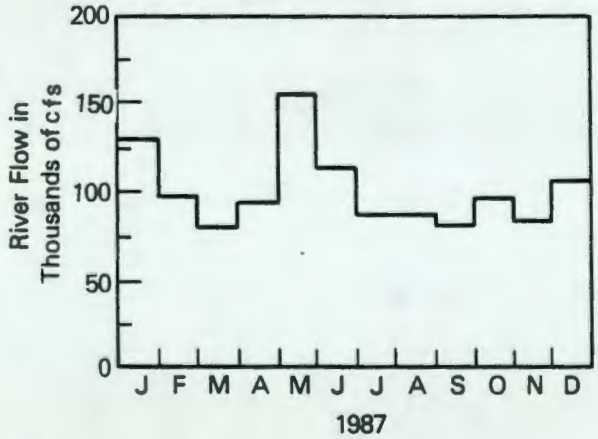

FIGURE 3.33. Monthly Average Flow Rates of the Columbia River During 1987

Average monthly Columbia River water temperatures at Priest Rapids Dam and the Richland Pumphouse are shown in Figure 3.34. The N Reactor operated January 1 through 7 in 1987. The major source of heat to the Columbia River in the Hanford reach is solar radiation (Dauble et al. 1987). Thermal discharges from N Reactor operations are also definable sources of heat to the river; however, incremental increases incurred by reactor operations are largely dissipated and masked by temperature fluctuations that result from solar radiation and convective cooling. River temperatures and the differences between Priest Rapids Dam and Richland Pumphouse temperatures during 1987, in the absence of reactor operations, were similar to those in the past (Price 1986). Monthly average temperatures were higher at the Richland Pumphouse than

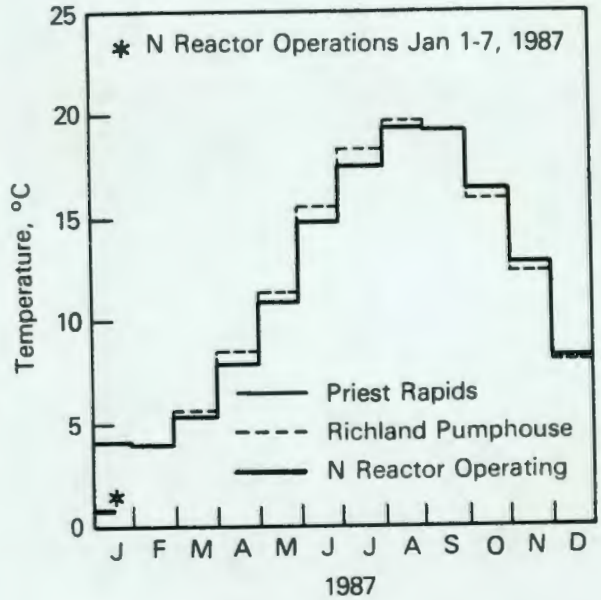

FIGURE 3.34. Monthly Average Temperatures in the Columbia River Water During 1987

at Priest Rapids Dam during March through August 1987. During January, February, and September, monthly average temperatures were the same at these locations. Cooler temperatures were observed at the Richland Pumphouse during October, November, and December.

ONSITE PONDS

Four onsite ponds (see Figure 3.21) located near operating areas were sampled periodically during 1987. Two of the ponds located near the 200-East Area (Gable Mountain Pond and B Pond) were excavated in the mid-1950s for disposal of process cooling water and other liquid wastes occasionally containing low levels of radionuclides. A third pond (West Lake), also located near the 200-East Area, is a natural body of water recharged from the ground water. This pond has not received planned direct-effluent discharges from Site facilities. The fourth onsite pond (FFTF Pond) located near the 400 Area, was excavated in 1978 for the disposal of cooling water from various facilities in the 400 Area.

Operating contractors are responsible for monitoring effluents discharged to the ponds and for operational surveillance of the ponds. During 1987, decommissioning activities on Gable Mountain Pond were

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completed, eliminating this pond and subsequently increasing the volume of B Pond as a result of the diversion of water previously discharged to Gable Mountain Pond.

Although the ponds were inaccessible to the public and did not constitute a direct offsite environmental impact during 1987, they were accessible to migratory waterfowl, creating a potential biological pathway for the dispersion of contaminants. Periodic sampling of the ponds also provided an independent check on effluent control and monitoring systems.

Sample Collection and Analysis

During 1987, 10-L grab samples were collected every 3 months from each pond. Care was taken to avoid surface debris and resuspension and inadvertent collection of bottom sediments during sampling. Unfiltered aliquots of the samples were analyzed for gross alpha and gross beta activities, gamma-emitting radionuclides, ^{3}H, and ^{90}Sr. Sodium-22 analyses were performed on the FFTF Pond samples to detect indications of process failure.

Results

Analytical results from pond samples collected during 1987 are summarized in Table A.28, Appendix A. Maximum, minimum, and average values are provided for various radionuclides at each pond. Further discussion of individual constituents and comparisons with results observed during previous years are provided below for each pond.

Radionuclide concentrations in Gable Mountain Pond during 1987, prior to its elimination, were similar to those observed in the previous 5 years (Figure 3.35). Figure 3.36 shows annual average concentrations of various radionuclides in B Pond water from 1982 through 1987. Concentrations of gross beta and ^{90}Sr have decreased since 1984. Gross alpha and ^{137}Cs concentrations remained in the range previously observed at this pond. Tritium concentrations in B Pond dropped considerably in 1987, probably associated with the short operating time of PUREX during the year.

Radionuclide concentrations in water collected from the FFTF Pond have remained relatively stable over the years (Figure 3.37), except for ^{3}H, which decreased during 1986. This decrease was attributed to a change in the source of the water supply serving the 400 Area. A new well, completed in a deeper

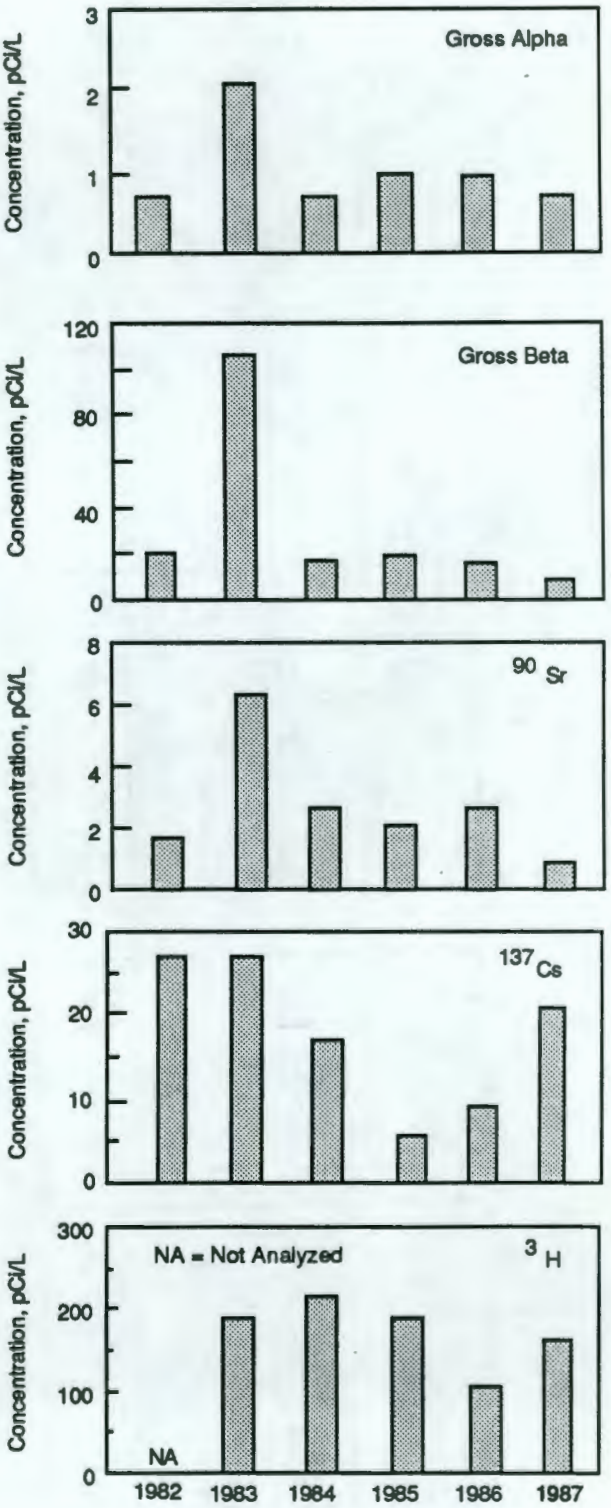

FIGURE 3.35. Annual Average Radionuclide Concentrations in Gable Mountain Pond, 1982 Through 1987

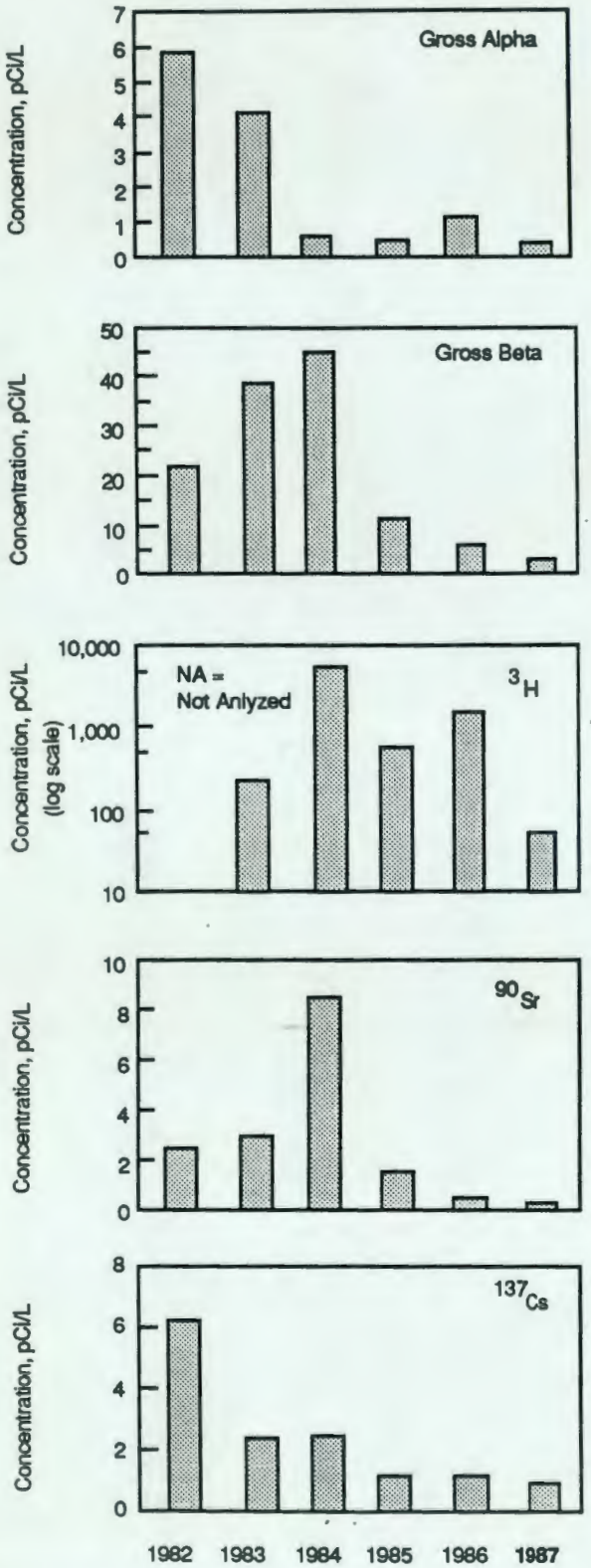

FIGURE 3.36. Annual Average Radionuclide Concentrations in B Pond, 1982 Through 1987

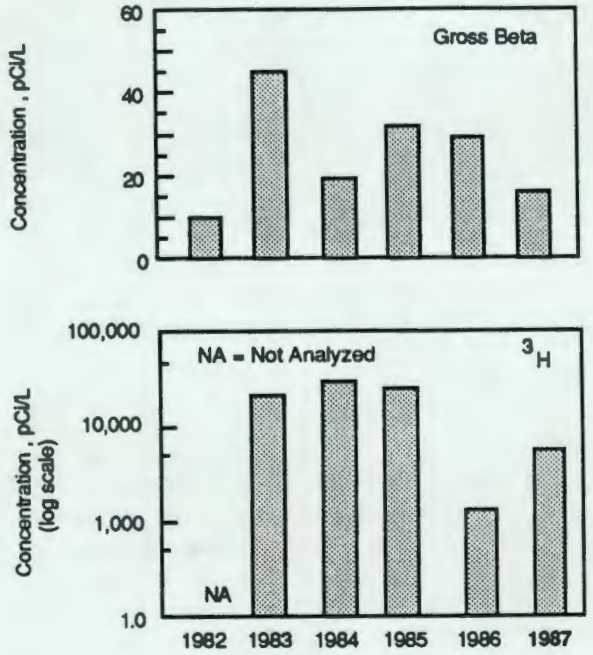

FIGURE 3.37. Annual Average Radionuclide Concentrations in FFTF Pond, 1982 Through 1987

aquifer with significantly lower ^3H concentrations, was put into service during February 1986. The 1987 average ^3H concentration was higher than that in 1986; however, it remained below the concentrations observed during the years prior to the completion of the new well. This reflects the periodic use of the old wells during periods of high water usage. As in the past, gross alpha, ^{90}Sr, and ^{22}Na were generally below the detection level during 1987 and, thus, were omitted from the figure.

Radionuclide concentrations in West Lake during 1987 were comparable to those reported in past years (Figure 3.38). Gross alpha and gross beta concentrations in West Lake, which is recharged from the ground water (Gephart et al. 1976), were higher than gross alpha and gross beta levels found in other onsite ponds. This is believed to result from high concentrations of naturally occurring uranium (Speer, Fix, and Blumer 1976). Strontium-90 concentrations have remained relatively stable over the past 6 years. Tritium concentrations, which appeared to decrease since 1983, were similar to those in the unconfined aquifer beneath West Lake (see Table A.13, Appendix A).

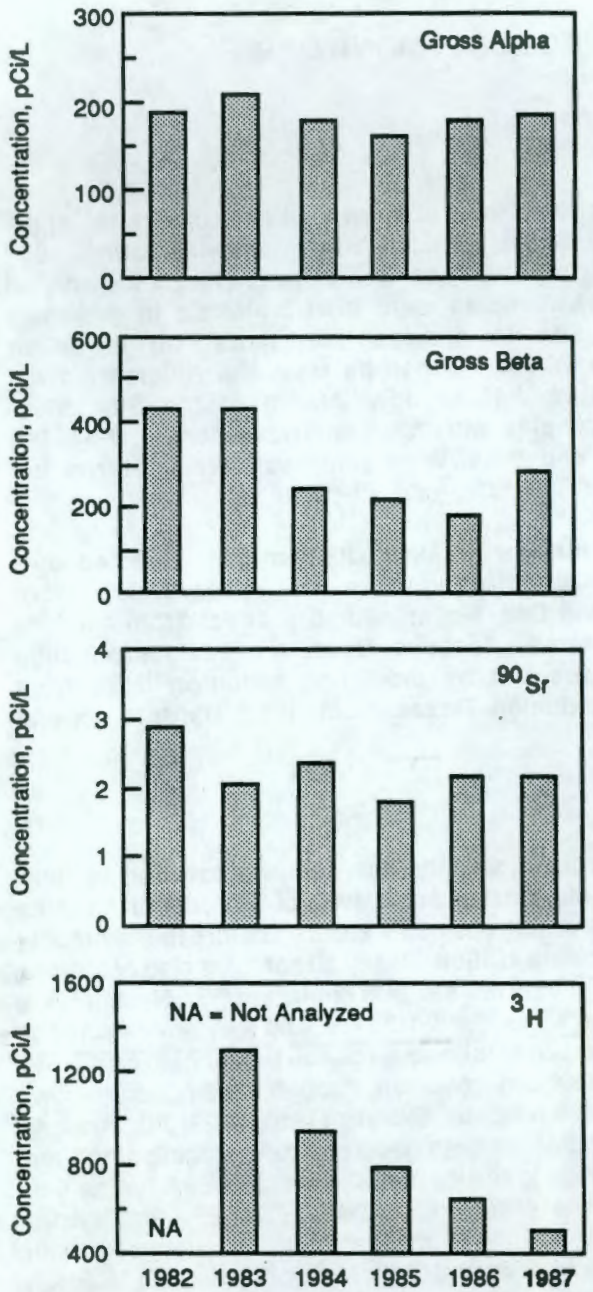

FIGURE 3.38. Annual Average Radionuclide Concentrations in West Lake, 1982 Through 1987

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3.4 FOOD AND FARM PRODUCT MONITORING

K. R. Price

Alfalfa and several foodstuffs, including milk, vegetables, fruits, wine, beef, chickens, eggs, and wheat, were collected at several locations in the Hanford Site environs during 1987 (Figure 3.39). Samples were collected primarily from locations in the prevailingly downwind directions (i.e., to the south and east of the Site). Samples were also collected in generally upwind directions somewhat distant from the Site to provide information on levels of radioactivity that could be attributed to worldwide fallout. Foodstuffs from the Riverview Area were irrigated with water pumped from the Columbia River downstream of the Site. Most samples were analyzed for ^{90}Sr and ^{137}Cs. Milk samples were also analyzed for ^{3}H, ^{89}Sr, ^{129}I, and ^{131}I. Fruit samples were analyzed for ^{3}H, ^{90}Sr, and ^{137}Cs. Wine samples were analyzed for ^{3}H and ^{137}Cs. Wheat samples were analyzed for ^{90}Sr, ^{137}Cs, and ^{239,240}Pu.

Low levels of ^{3}H, ^{90}Sr, and ^{137}Cs were found in a number of foodstuff samples collected during 1987; however, the concentrations in samples collected near the Hanford Site were similar to those in samples collected away from the Site. No measurable effect from the use of Columbia River water for irrigation was detected. Because there are no radionuclide concentration limits for foodstuffs, impact was assessed by predicting radiation dose from food consumption (as discussed in "Potential Radiation Doses from 1987 Hanford Operations," Section 4.0).

MILK

Samples of raw, whole milk were collected from several dairy farms near the Site perimeter and in the prevailingly downwind directions to evaluate possible Hanford impacts. Samples were also collected from dairy farms near Sunnyside and Moses Lake to provide indications of the general concentrations of radionuclides in milk attributable to worldwide fallout. The general areas of sampling are shown as stippled areas in Figure 3.39, and results are listed in Table A.29, Appendix A. Samples were routinely collected every other week throughout the year from the Sagemoor and Sunnyside areas, and monthly from other areas. All samples were analyzed for ^{131}I and ^{137}Cs. Tritium analyses were conducted on one sample per month, ^{89}Sr and ^{90}Sr analyses were conducted on one sample per quarter, and ^{129}I analyses were conducted on one sample every 6 months.

A total of 103 samples of milk were collected and analyzed for ^{131}I during 1987. Only two of the samples tested positive. Both results were slightly above the detection level and may or may not represent true identification. One of these samples was collected from Moses Lake, the other from Sagemoor. No residual ^{131}I attributable to the Chernobyl incident of 1986 was detected during 1987.

About 30% of the milk samples collected in 1987 contained detectable levels of ^{137}Cs, about the same percentage as was measured before the Chernobyl incident in 1986. Nearly all samples also contained ^{90}Sr. Very few samples contained ^{89}Sr. Neither ^{137}Cs nor ^{90}Sr is found naturally, and they are detected in milk samples because of their presence in worldwide fallout and movement through the air-pasture-cow-milk food chain. Results (Table A.29, Appendix A) indicate an even geographical distribution and are similar to results published by the EPA for the first quarter of 1987 (EPA 1987b). (The EPA data are discussed in "Comparison of Measurements with Calculations and Other Monitoring Results," Section 3.8.) Figure 3.40 shows the 6-year record for ^{90}Sr and ^{137}Cs in milk samples collected from the Hanford environs. The influence of the Chernobyl incident on ^{137}Cs in milk in 1986 is evident; otherwise, the levels of both radionuclides have remained relatively constant.

Some milk samples were analyzed for ^{3}H and ^{129}I in 1987. Tritium was identified in a little less than half of the samples. Iodine-129 was identified in all 11 samples tested. Concentrations were very low and similar to those obtained in recent years. No

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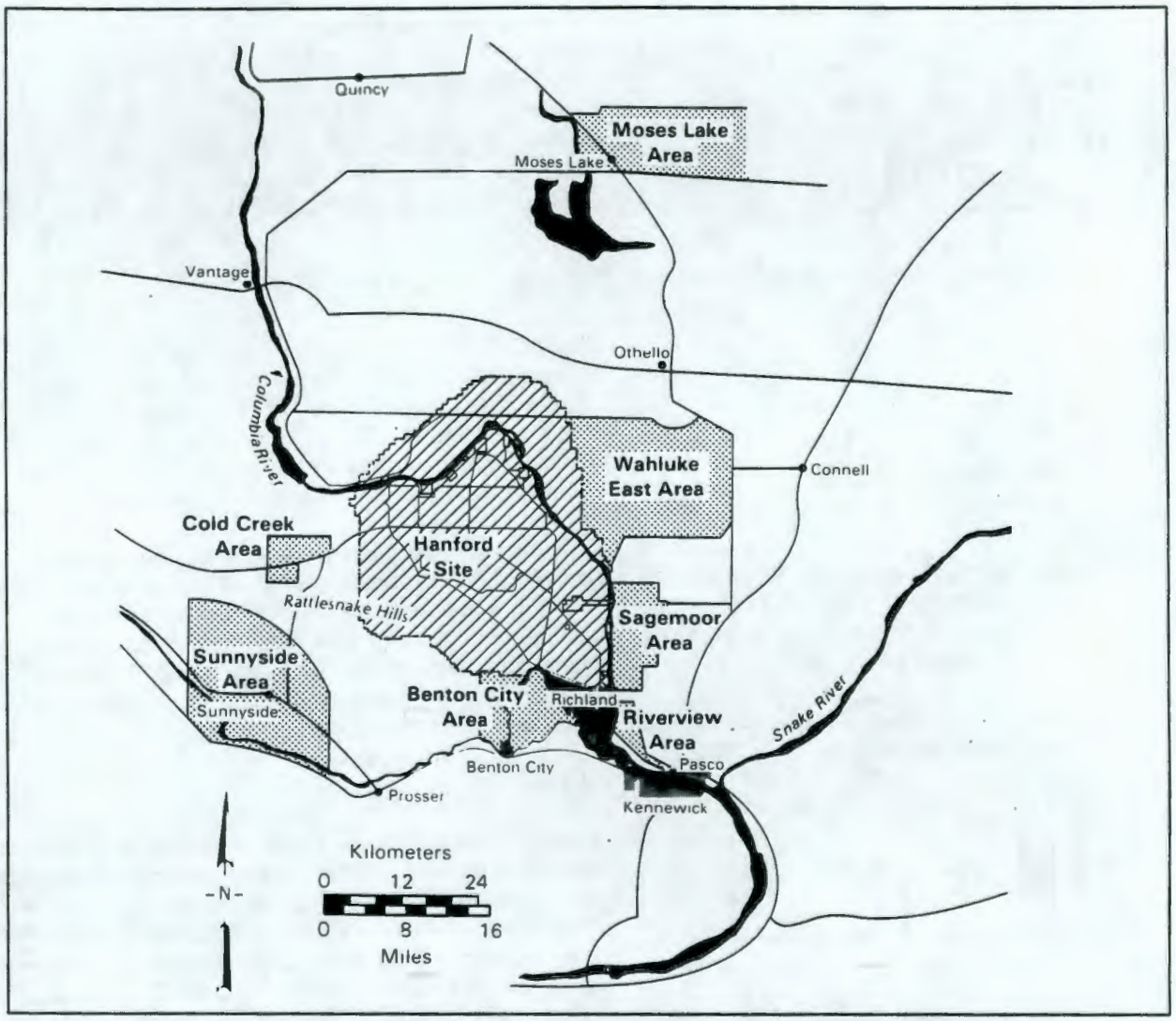

FIGURE 3.39. Foodstuffs Sampling Areas in 1987 (stippling indicates areas sampled)

differences were apparent between near-site and distant sampling locations, except that, as in past years, samples from Moses Lake show levels of ^{129}I about one-twentieth the level of samples from most other locations.

VEGETABLES

Samples of leafy vegetables (i.e., spinach, leaf lettuce, or cabbage) were obtained once during the summer from gardens located within the sampling areas listed in Table A.30, Appendix A. The leafy vegetables provided an indication of radionuclides present in locally grown produce. Three replicate samples, each composed of mixtures of the edible portions of the various leafy vegetables grown at the sampling locations, were analyzed for ^{90}Sr and ^{137}Cs. Results are provided in Table A.30, Appendix A. Strontium-90 and ^{137}Cs were identified in most samples but with no apparent difference between distant and nearby locations. The concentrations of ^{90}Sr and ^{137}Cs at all locations are comparable to those of recent years (Figure 3.41) and are attributed to worldwide fallout.

The potential radiation dose to the hypothetical maximally exposed individual was calculated for an individual who was a long-term resident of the Riverview area (see "Potential Radiological Doses from 1987 Hanford Operations," Section 4.0). A major

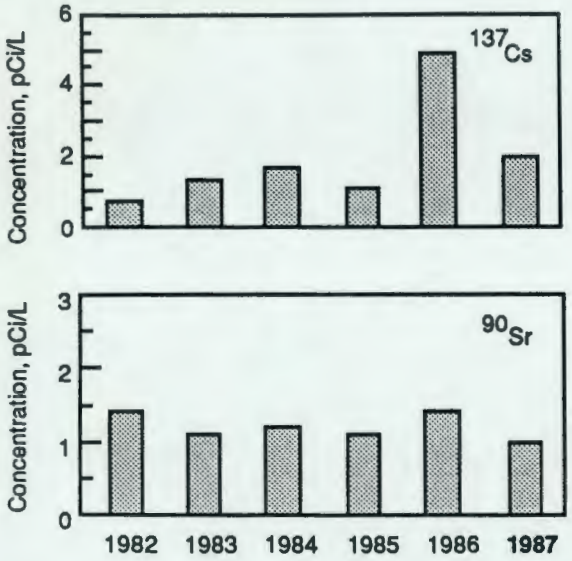

FIGURE 3.40. Annual Average Strontium-90 (^{90}Sr) and Cesium-137 (^{137}Cs) Concentrations in Milk, 1982 Through 1987

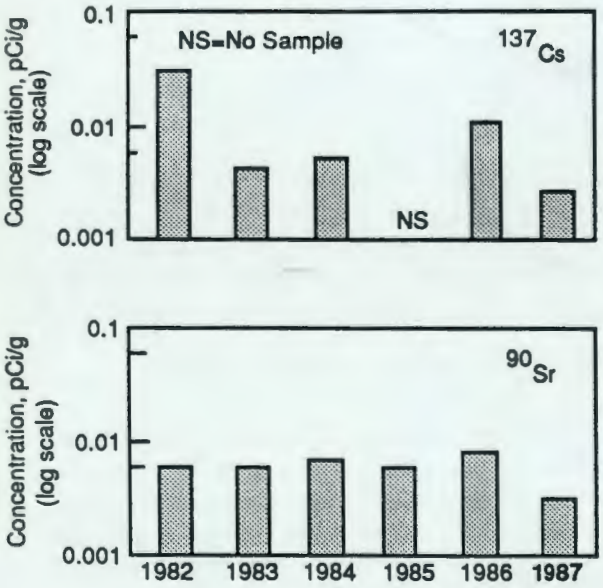

FIGURE 3.41. Annual Average Strontium-90 (^{90}Sr) and Cesium-137 (^{137}Cs) Concentrations in Leafy Vegetables, 1982 Through 1987

contributor to the potential dose was ^{90}Sr from Columbia River water used to irrigate foodstuffs grown in the Riverview area. Important commercially grown crops of tomatoes, carrots, and potatoes from the Riverview area were analyzed for ^{3}H, ^{90}Sr, and gamma-emitting radionuclides (^{137}Cs). Results in potatoes were similar to concentrations found from other sampling areas, and no effect from the use of Columbia River water for irrigation could be detected. Results are shown in Table A.31, Appendix A.

FRUIT

Samples of apples, cherries, grapes, and melons were collected during harvest from the areas listed in Table A.32, Appendix A. Three replicate samples were collected at each sampling location, and the edible portions were analyzed for ^{3}H, ^{90}Sr, and ^{137}Cs. Results are provided in Table A.32, Appendix A.

Tritium was identified in a few of the samples analyzed, ^{90}Sr in about one-third of the samples, and ^{137}Cs in a few samples. There were no detectable differences between fruit types or sampling locations. The concentration of ^{3}H, ^{90}Sr, and ^{137}Cs were similar at all locations indicating a minimum contribution from Hanford.

WINE

Locally produced wine (1986 vintage) was purchased and analyzed for ^{3}H and gamma-emitting radionuclides. Both red and white wines were analyzed. The wines were made from grapes grown in the Sagemoor area and, for comparison, in the Sunnyside area. Results of the ^{3}H and ^{137}Cs analyses are given in Table A.33, Appendix A. Most samples contained trace amounts of ^{3}H, but only one sample of the 12 analyzed contained a detectable level of ^{137}Cs. Concentrations detected in wine samples were about the same as those commonly found in milk. The low concentration of radionuclides indicates a minimal contribution from Hanford.

WHEAT AND ALFALFA

Samples of ripened wheat and mature alfalfa were collected from the areas listed in Table A.34, Appendix A. Three replicate samples of wheat and alfalfa were collected at each location and analyzed for ^{90}Sr and ^{137}Cs. Three wheat samples from the Sagemoor area were also analyzed for $^{239,240}Pu$. Results are shown in Table A.34, Appendix A.

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Strontium-90 was identified in all samples. Cesium-137 was identified in a few samples. Plutonium was not detected in any wheat sample. No distinct difference in radionuclide concentrations was apparent between samples collected near the Site and those collected at a distance. Measured concentrations are attributed to worldwide fallout.

BEEF, CHICKEN, AND EGGS

A few samples of locally produced beef, chicken, and eggs were collected from the areas listed in Table A.35, Appendix A. Table A.35 provides results of analyses for ^{90}Sr and ^{137}Cs. Results were all low, generally near detection levels, and are attributed to worldwide fallout. Strontium-90 and ^{137}Cs concentrations in beef for 1987 and the previous 5 years are shown in Figure 3.42.

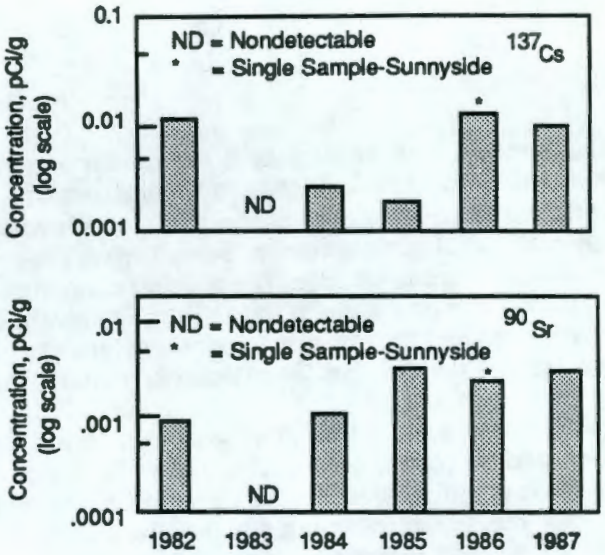

FIGURE 3.42. Annual Average Strontium-90 (^{90}Sr) and Cesium-137 (^{137}Cs) Concentrations in Beef, 1982 Through 1987

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3.5 WILDLIFE MONITORING

K. R. Price

The Hanford Site serves as a refuge for waterfowl, upland game birds, and various terrestrial animals. Wildlife have access to several areas near facilities that contain low levels of radionuclides attributable to Site operations (e.g., waste-water ponds) and serve as biological indicators of environmental contamination. Sampling was performed in areas where the potential existed for wildlife to ingest radionuclides. The number of animals that visited these areas was small compared to the total wildlife population in the region. Fish were collected from the Hanford reach of the Columbia River. Analyses provided an indication of the radionuclide concentrations in local game fish and were used to evaluate the potential dose to humans from this pathway.

Analytical results of wildlife and fish samples collected during 1987 were similar to those observed in recent years. There are no radionuclide concentration limits for wildlife samples. The dose that a person who consumed any of the wildlife sampled could have received, even at the maximum radionuclide concentrations measured in 1987, was well below applicable standards for radiation dose.

DEER

Samples taken from road kills (Figure 3.43) were used to provide an indication of the general levels of radionuclides in Hanford Site deer. Four deer were sampled and analyzed for ^{137}Cs in muscle and $^{239,240}Pu$ in liver. Muscle tissue is analyzed for ^{137}Cs because it is used for human consumption and it is most likely to contain ^{137}Cs when that is present in the diet of the deer. The liver is also used for human consumption and is the organ most likely to retain $^{239,240}Pu$ from the diet of the deer. Results indicated the presence of detectable levels of ^{137}Cs (0.019 pCi/g) in two deer. The liver of one animal contained detectable levels of $^{239,240}Pu$ at 0.0003 pCi/g. These concentrations were in the range generally attributed to worldwide fallout, and the median (middle) values were consistent with those observed in previous years (Figure 3.44). The median values rather than averages are plotted to illustrate the central tendency of the data when there is a small number of samples with highly variable results. Results for 1987 showing the maximum and average values are given in Table A.36, Appendix A.

FISH

Fish were collected at various locations along the Columbia River (see Figure 3.43). Boneless fillets were analyzed for ^{60}Co, ^{90}Sr, and ^{137}Cs. The remaining carcasses were analyzed to estimate ^{90}Sr in bone. Median concentrations for ^{60}Co and ^{137}Cs in whitefish and bass in 1987 and recent years are shown in Figure 3.45. Whitefish were collected near the 100-D Area and upstream of Hanford near Priest Rapids Dam. Bass were collected near the 100-F Area. Individual results for ^{60}Co, ^{90}Sr, and ^{137}Cs for 1987 are shown in Table A.37, Appendix A.

Cobalt-60, ^{90}Sr, and ^{137}Cs were detected in a few whitefish muscle samples collected along the Hanford reach of the river near the 100-D Area, as well as upstream of the Site near Priest Rapids Dam. However, there were no quantifiable differences between the two locations. Strontium-90 levels in whitefish carcasses in samples collected from the 100-D Area were similar to those in samples collected upstream of the Site. Samples of bass muscle and carcass collected from the slough near the 100-F Area showed ^{60}Co, ^{90}Sr, and ^{137}Cs concentrations slightly higher than those for whitefish. The 100-F Area slough has sediments slightly contaminated from past Hanford operations (Fix 1976).

UPLAND GAME BIRDS

Pheasants were collected from the 100 and 300 Areas (Figure 3.43). Samples of breast meat were analyzed for ^{60}Co and ^{137}Cs. A slightly greater number of the birds showed detectable concentrations of ^{137}Cs than of ^{60}Co. Median concentrations for ^{137}Cs in the 100 Areas are shown in Figure 3.46 and are within the ranges observed during previous years for the 100 and 200 Areas. Cobalt-60 and ^{137}Cs were not

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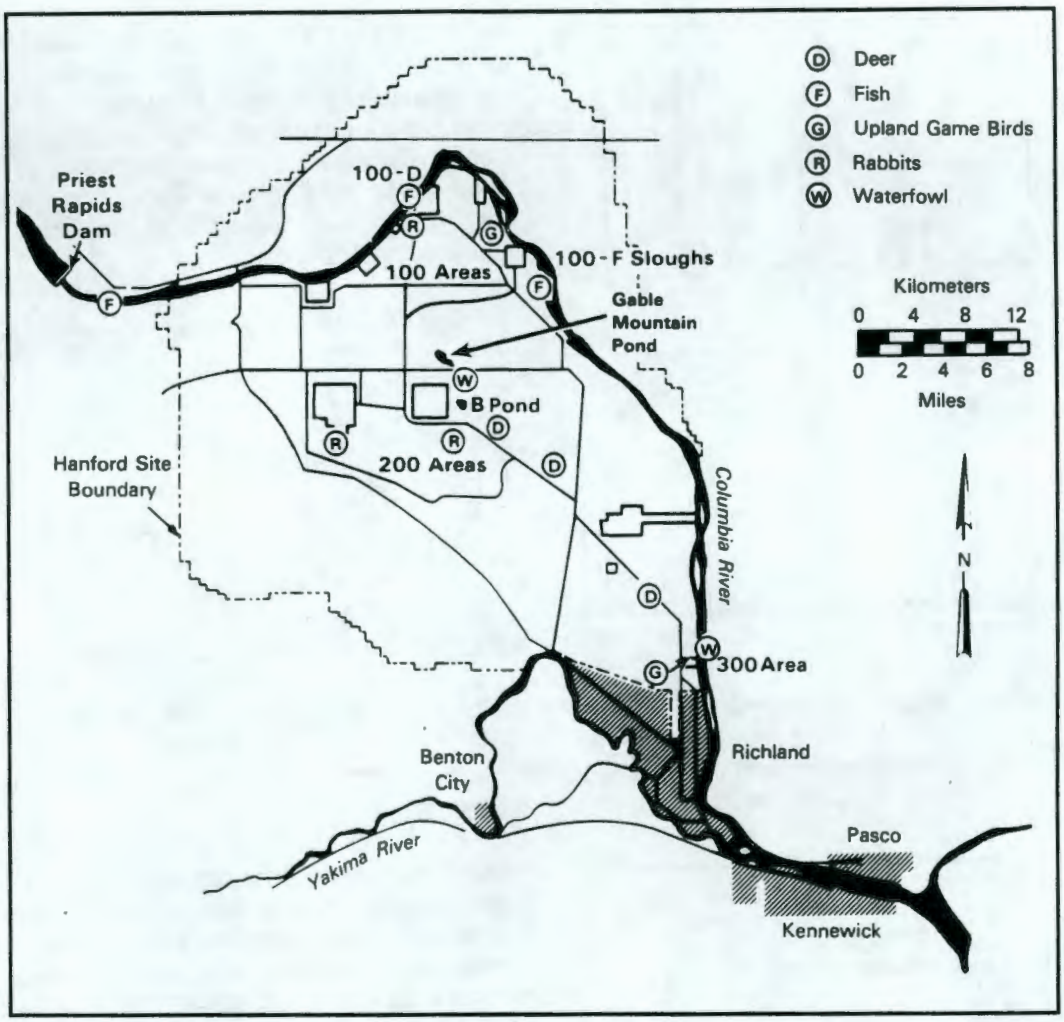

FIGURE 3.43. Wildlife Sampling Areas. (Two deer samples were collected at the same location near the 200 Areas.)

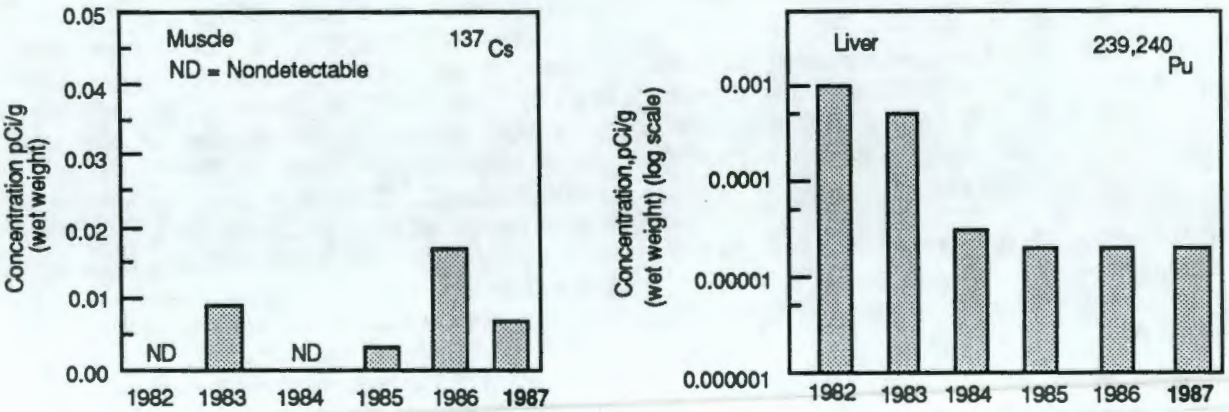

FIGURE 3.44. Median Concentrations of Cesium-137 (^{137}Cs) in Deer Muscle and Plutonium-239, 240 ($^{239,240}Pu$) in Deer Liver, 1982 Through 1987

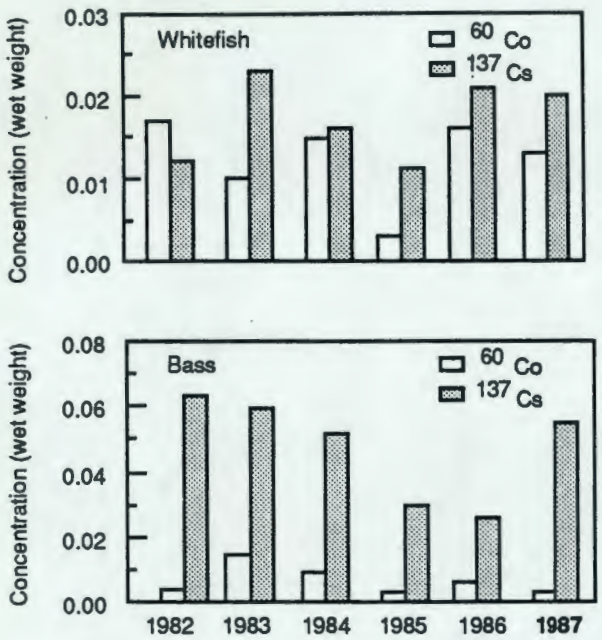

FIGURE 3.45. Median Concentrations of Cobalt-60 (^{60}Co) and Cesium-137 (^{137}Cs) in Whitefish and Bass, 1982 Through 1987

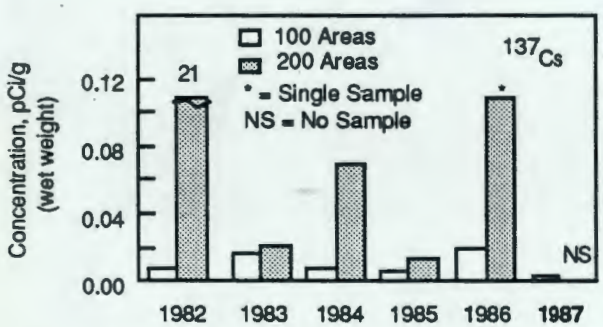

FIGURE 3.46. Median Concentrations of Cesium-137 (^{137}Cs) in Game Birds in the 100 Area in 1987 and in the 100 and 200 Areas, 1982 Through 1986

detectable in the single bird collected from the 300 Area. Maximum and average concentrations for 1987 for both nuclides are shown in Table A.38, Appendix A.

WATERFOWL

Mallard ducks were collected from B Pond in the 200 Area and from the 300 Area trench (Figure 3.43). Approximately 0.5-kg of breast meat was analyzed for ^{137}Cs. Results (Figure 3.47) continue to show concentrations decreasing in ducks collected from B Pond, as they have over the last several years. Concentrations in samples collected from the 300 Area trench in 1987 were about one-third of the concentrations measured in ducks from B Pond (Table A.39, Appendix A).

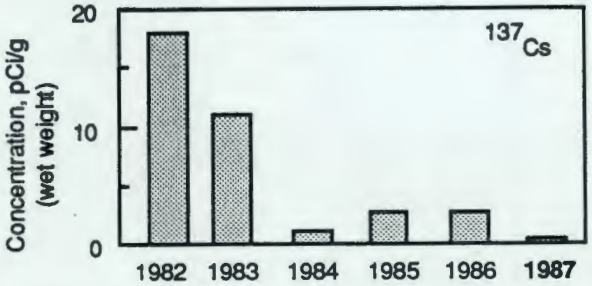

FIGURE 3.47. Median Concentrations of Cesium-137 (^{137}Cs) in Mallard Ducks from B Pond, 1982 Through 1987

RABBITS

Rabbits were collected and analyzed to evaluate the general levels of environmental contamination near operating facilities. Hanford waste materials usually contain equal quantities (activities) of ^{90}Sr and ^{137}Cs. Muscle tissue does not retain ^{137}Cs for a very long time, whereas ^{90}Sr remains incorporated in bone tissue for the lifetime of the animal. Liver tissue tends to accumulate and retain $^{239,240}Pu$ consumed by the animal.

Cottontail rabbits were collected near the 100 Area and black-tailed jack rabbits were collected near the 200 Area during 1987. Muscle samples were analyzed for ^{137}Cs and other gamma-emitting radionuclides, bone samples were analyzed for ^{90}Sr, and liver samples were analyzed for $^{239,240}Pu$. Median (middle) values of ^{90}Sr in bone and ^{137}Cs in muscle tissues measured in rabbits over the last several years are shown in Figures 3.48 and 3.49. Maximum and average concentrations for samples analyzed in 1987 are given in Table A.40, Appendix A.

The levels of ^{90}Sr in bone samples indicated that the rabbits had at some time consumed food or water contaminated with ^{90}Sr. However, the rabbits had not been eating or drinking contaminated materials recently, because muscle samples from the same

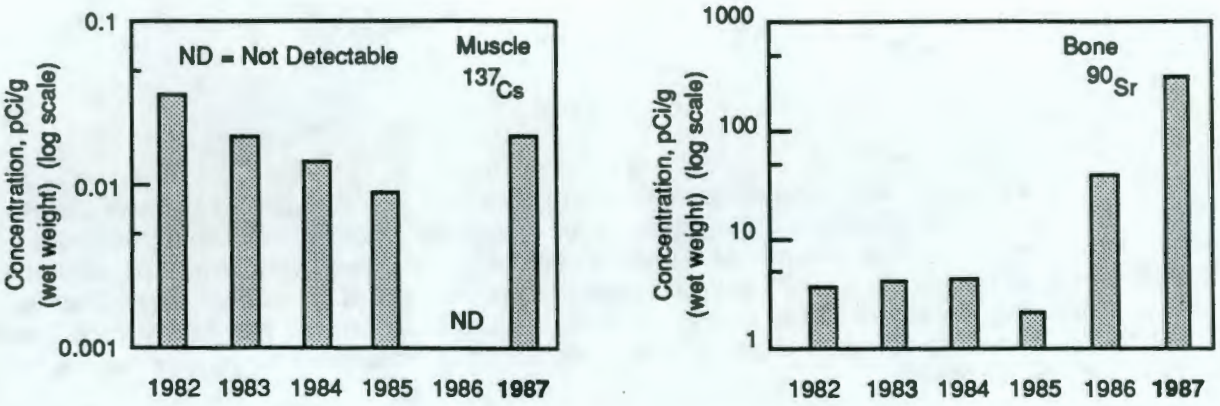

FIGURE 3.48. Median Concentrations of Strontium-90 (^{90}Sr) in Bone and Cesium-137 (^{137}Cs) in Muscle of Cottontail Rabbits in the 100 Area, 1982 Through 1987

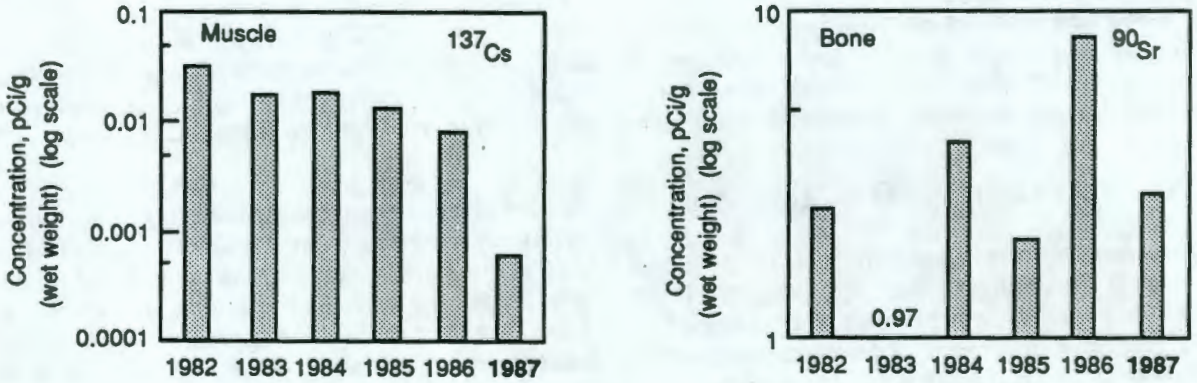

FIGURE 3.49. Median Concentrations of Strontium-90 (^{90}Sr) in Bone and Cesium-137 (^{137}Cs) in Muscle of Jack Rabbits in the 200 Areas, 1982 Through 1987

animal contained low levels of ^{137}Cs. No gamma-emitting radionuclides of Hanford origin other than ^{137}Cs were detected in any muscle sample at a level greater than expected from worldwide fallout. Concentrations of $^{239,240}Pu$ in liver samples ranged from values near the detection limit (0.0006 pCi/g) to 0.007 pCi/g for one sample. Such levels do not indicate that $^{239,240}Pu$ is present as an environmental contaminant in the areas where the animals lived.

3.6 SOIL AND VEGETATION MONITORING

K. R. Price

Surface soil and rangeland vegetation samples were collected at a number of locations during 1987, both on and off the Site. The purpose of sampling was to detect the buildup of radionuclides from the deposition of airborne effluents released from Hanford facilities. Samples were collected at nonagricultural, undisturbed sites so that natural deposition and buildup processes would be represented. Because the radionuclides of interest were present in worldwide fallout or occurred both naturally and in Hanford effluents, their presence was expected in all samples.

Assessment of radionuclide contribution from Hanford operations was made by comparing results from samples collected 1) on the Site with those collected off the Site, 2) around the Site perimeter with those collected at distant locations, and 3) downwind (primarily east and south of the Site) with those collected from generally upwind and distant locations. In addition, results obtained from each location in 1987 were compared to results obtained from the same location in previous years. Evaluations of 1987 results provided no indication of trends or increases in the concentrations of radionuclides in the offsite environment that could be attributed to Hanford operations. Results from special soil samples collected downwind from Hanford indicated no measurable buildup of Hanford-derived plutonium.

SAMPLE COLLECTION AND ANALYSIS

Soil and vegetation samples were collected at 15 onsite and 23 site perimeter and offsite locations (Figure 3.50). In addition, soil samples were collected at eight locations downwind of Hanford for special plutonium analyses (Figure 3.51). Most onsite sampling locations were adjacent to major operating areas, where the contribution of radionuclides from operations could be readily assessed. Most offsite samples were collected around the Site perimeter and in a generally downwind direction, where any Hanford contribution to radionuclide levels in soil and vegetation would be most easily detected. Samples were also collected in a generally upwind direction and at distant locations for comparison.

Single composite samples of surface soil were collected at each location. Samples were made up of five soil "plugs," each approximately 2.5 cm deep and 10 cm in diameter, obtained within a 100-m^2 area. Samples were oven-dried (105°C), sieved through a 2-mm screen, and thoroughly mixed. Aliquots of this well-mixed, composite sample were analyzed for gamma-emitting radionuclides, ^{90}Sr, $^{239,240}Pu$, and uranium.

When soil samples were collected, samples of perennial vegetation were also collected in the immediate vicinity. Vegetation samples included a mixture of rabbitbrush, sagebrush, and bitterbrush, in roughly the same proportions as occurred naturally at the sample site. A small amount of recent growth was cut from enough plants in the area to make up a sample weighing approximately 1 kg. The sample was dried and ground, and aliquots were taken for analysis. Vegetation samples were analyzed for gamma-emitting radionuclides, ^{90}Sr, $^{239,240}Pu$, and uranium.

SOIL RESULTS

Analytical results from soil samples collected on and off the Site during 1987 are reported in Tables A.41 through A.44, Appendix A. Also included in the tables are results for the previous 5 years for each location. For comparative purposes, averages of the results from all onsite and offsite locations are provided. New sample locations were established in 1985 and 1986 as a result of program revisions and expansions.

Radionuclide concentrations in onsite soil samples during 1987 were similar to those observed in previous years. Although some variability was evident between sampling locations, the averages of onsite soil sample results for specific radionuclides were similar to those observed during previous years. Locations near operating areas, the 200 Areas in particular, continued to show slightly elevated

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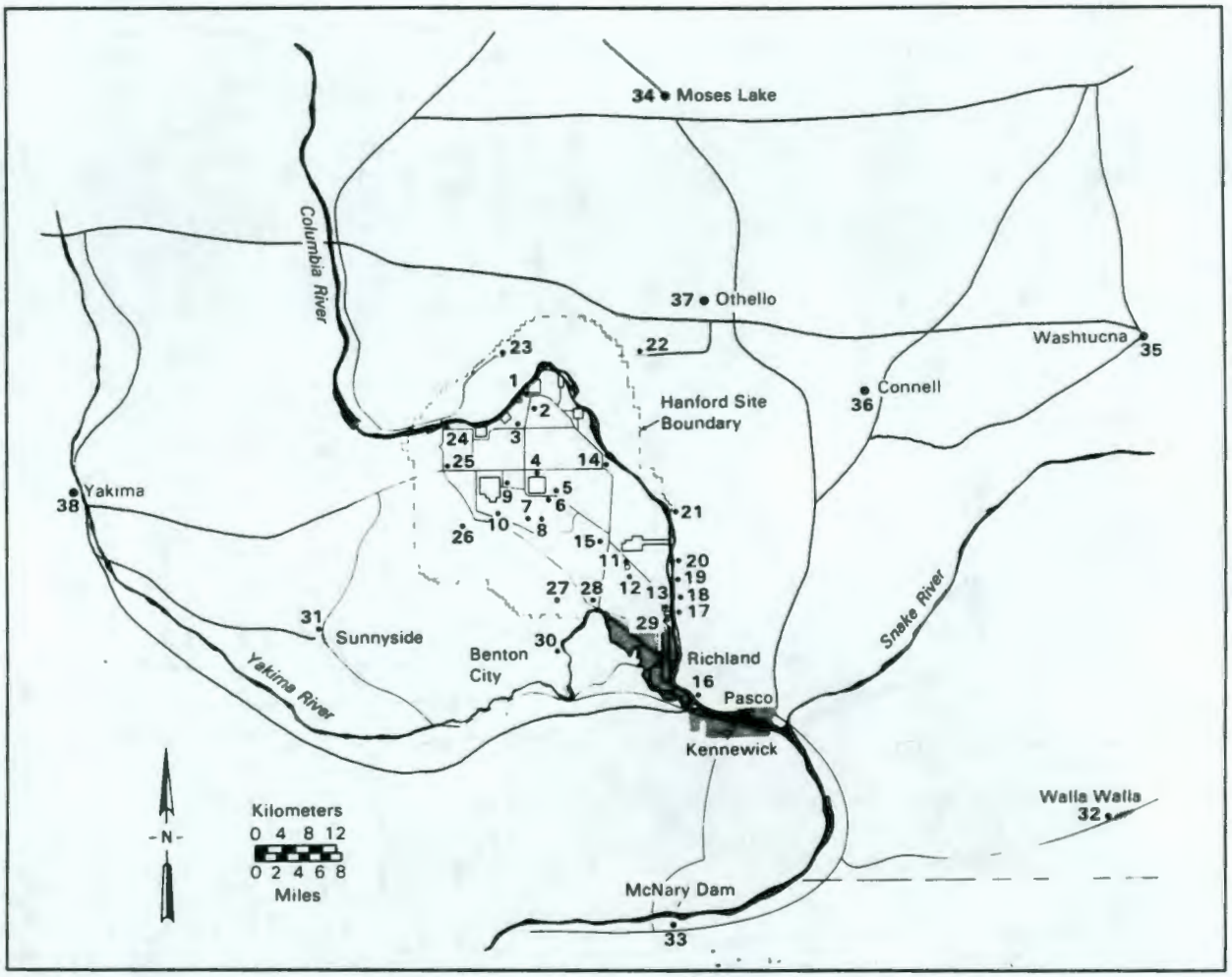

FIGURE 3.50. Onsite and Offsite Sampling Locations for Soil and Vegetation in 1987

concentrations for a few radionuclides. Specifically, the 200-East north central (Figure 3.50, Number 4) sample had elevated levels of ^{90}Sr and ^{137}Cs, and the sample taken east of the 200-West Area (Figure 3.50, Number 9) had elevated levels of $^{239,240}Pu$, as in previous years.

The offsite soil sample results were similar to those obtained during the past several years. Histograms in Figure 3.52 display median (middle) values for ^{90}Sr, ^{137}Cs, $^{239,240}Pu$, and uranium for all samples collected on and off the Site during 1987. Median values rather than averages are plotted to illustrate the central tendency of the data because of the small number of samples and the high degree of variability in results. Radionuclide concentrations tended to be slightly higher at onsite than at offsite locations.

Further evaluation of offsite samples indicated that radionuclide concentrations in soil collected at locations near the Hanford Site were similar to those collected at distant locations. Likewise, results from offsite locations generally downwind were similar to those from locations generally upwind. As in the past, radionuclide concentrations in soil were low, although they appeared to be highly variable over time at a single location.

ISOTOPIC COMPOSITION OF PLUTONIUM IN SPECIAL DOWNWIND SOIL SAMPLES

The isotopic composition of plutonium in surface soil collected from the environs of the Hanford Site was first evaluated and reported in the annual report for 1985 (Price 1986). The purpose was to estimate the

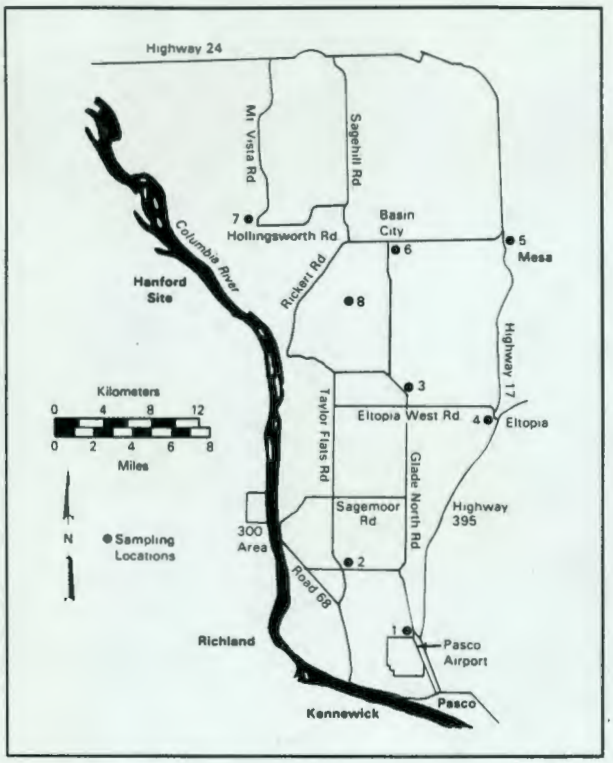

FIGURE 3.51. Locations of Special Soil Samples Collected Downwind of Hanford During 1987

amount of plutonium that may have accumulated in soil from past operations at Hanford. Additional samples were collected off the Site during 1986 and 1987 and analyzed using the same sensitive mass-spectrographic method used before. Samples were collected from eight downwind locations sampled in 1986 (PNL 1987). Those special downwind sampling locations are shown in Figure 3.51. Samples for analysis of isotopic composition were also collected in 1987 from communities added to the sampling schedule in 1986 (i.e., Moses Lake, Connell, Othello, Washtucna, Walla Walla, McNary, and Yakima).

The individual ratios of ^{240}Pu to ^{239}Pu for each soil sample and the average ratio for all samples collected in 1986 and 1987 are listed in Table A.45, Appendix A. The overall average was calculated to be 0.176 ± 0.003. The average ^{240}Pu to ^{239}Pu ratio indicative of worldwide fallout in soil has been reported as 0.176 ± 0.014 (Krey et al. 1976). Hanford-derived plutonium has an estimated ^{240}Pu to ^{239}Pu ratio of 0.0676 based on measurements from samples of high-level waste (ERDA 1977). It was determined that the $^{239,240}Pu$ detected in the special

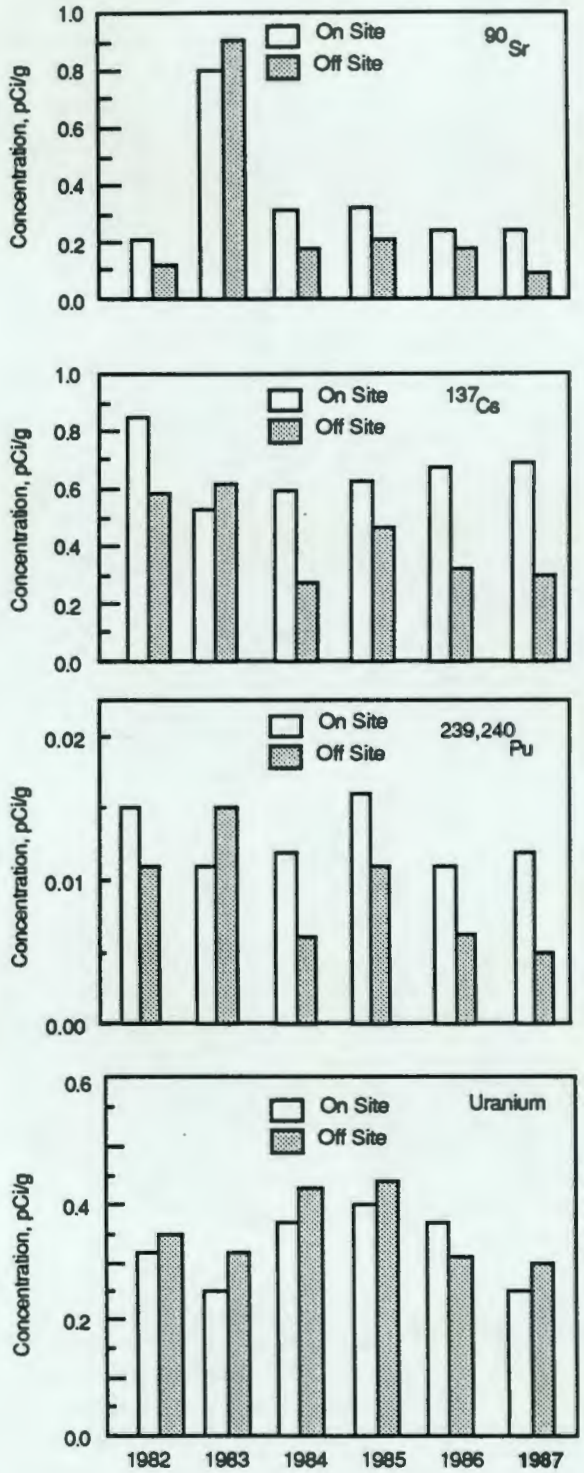

FIGURE 3.52. Median Strontium-90 (^{90}Sr), Cesium-137 (^{137}Cs), Plutonium-239, 240 ($^{239,240}Pu$), and Uranium Concentrations Measured in Soil at Onsite and Offsite Locations, 1982 Through 1987

and routine soil samples collected in 1986 and 1987 was primarily from fallout, because there was no difference between the average plutonium isotopic ratio measured and the average ratio reported for fallout. This agrees with the sampling results for other radionuclides and the conclusion reported previously on soil samples from the same locations (PNL 1987).

VEGETATION RESULTS

Analytical results from samples of mature, perennial vegetation collected during 1987 are provided in Tables A.46 through A.49, Appendix A. Individual results for the previous 5 years at each location are given in the tables, along with the average of results for the same time period. Averages of onsite and offsite sample results are also included for comparison. New sample locations were added in 1986 and 1987.

Radionuclide concentrations in vegetation samples collected on and off the Site in 1987 were similar to those observed at the same locations during previous years. Figure 3.53 provides histograms illustrating median (middle) values of ^{90}Sr, ^{137}Cs, $^{239,240}Pu$, and uranium for all samples. The high ^{137}Cs value recorded in 1986 was attributed to the Chernobyl incident. The effect of Chernobyl was not noted in the results for 1987. As with soil data, concentrations of ^{90}Sr and $^{239,240}Pu$ in onsite vegetation were slightly elevated compared with offsite concentrations. Uranium concentrations in vegetation, however, were slightly higher at offsite locations than at onsite locations.

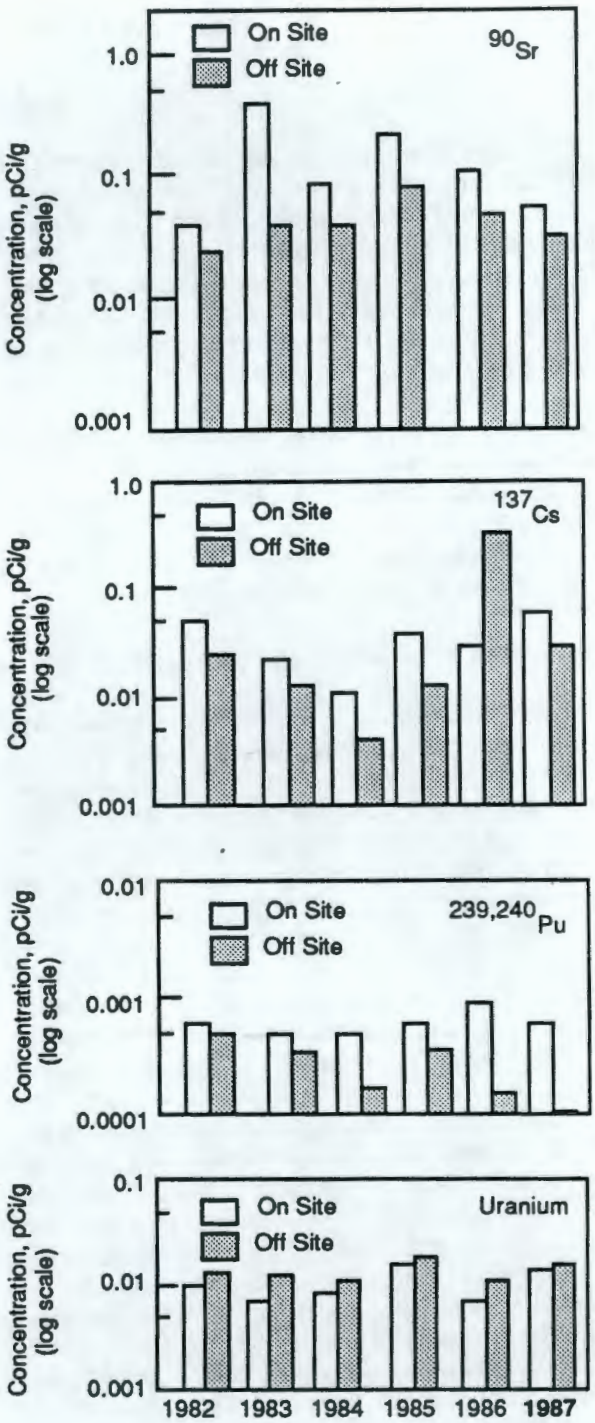

FIGURE 3.53. Median Strontium-90 (^{90}Sr), Cesium-137 (^{137}Cs), Plutonium-239,240 ($^{239,240}Pu$), and Uranium Concentrations in Vegetation at Onsite and Offsite Locations, 1982 Through 1987

3.7 PENETRATING-RADIATION MONITORING

L. A. Rathbun

Dose rates from penetrating radiation (gamma rays) were measured at a number of locations in the Hanford environs during 1987. Measurements were made using thermoluminescent dosimeters (TLDs) to provide estimates of the dose rates from external radiation sources. Penetrating radiation from naturally occurring sources, including cosmic radiation and natural radioactive materials in the air and ground, as well as worldwide fallout, was recorded at all dosimeter locations. Dosimeters also measured dose rates from exposure to radioactive materials associated with activities at Hanford. Results obtained both on and off the Site were similar to those of past years. Dose rates near operating facilities were somewhat higher than natural background rates.

Radiation surveys were conducted at numerous locations on the Hanford Site. Onsite roads, railroads, and retired waste-disposal sites located outside of operating areas were routinely surveyed during 1987. These surveys were designed to identify areas where levels of radioactivity were abnormal. Survey results for 1987 were comparable to those of past years. No unexpected or abnormal conditions were observed on Site highways or railroads.

PENETRATING-RADIATION MEASUREMENTS

External radiation measurements were made using environmental TLDs at numerous locations on the Site, around the Site perimeter, in nearby and distant communities, and along the shoreline of the Columbia River. Environmental radiation dosimeters consisted of five CaF_2:Mn thermoluminescent chips encased in a plastic capsule. The capsule contained a lead/tantalum filter to provide uniform dose response characteristics for penetrating radiation above 60 kilo electron volts (keV) (Fix and Miller 1978). Dosimeters were mounted 1 m above ground level and were exchanged every 4 weeks, with the exception of the shoreline TLDs, which were exchanged quarterly. Although they were measured in milliroentgens (mR), measured doses are reported in dose equivalent units (mrem) to allow comparison with dose standards and dose equivalents reported elsewhere in this document. The TLDs record radiation exposure from natural and fallout sources, as well as any local contribution (NCRP 1987). Because the dosimeter is used in a multienergy beta/gamma radiation field (the environment near Hanford) that differs considerably from calibration conditions (^{137}Cs photons in air), the conversion factor relating mrem to mR may not be exactly 1.0. Nonetheless, it is assumed to be 1.0 throughout this report.

Dosimeters were placed at numerous locations in the vicinity of Hanford and at several locations more distant from the Site (Figure 3.54). Dose rates measured at each location during 1987 are given in Table A.50, Appendix A. Offsite dosimeter locations were chosen to represent areas that could have been inhabited continuously. Dose measurements at these locations are reported in mrem/yr.

Results were similar to those observed in previous years for the same locations. However, new calculational methods cause dose measurements to appear about 16% higher than in previous years. The background dose rate, calculated from the annual average dose rates observed at distant locations, was 72 mrem/yr (0.008 mrem/h), in contrast to the 60 mrem/yr reported last year. Dose rates measured at Seattle and Spokane in 1985 by the WDSHS were 56 mrem/yr and 88 mrem/yr, respectively (WDSHS 1987).

Figure 3.55 shows average annual dose rates measured at perimeter and distant locations during 1987 and the previous 5 years. In this figure, some year-to-year variation is apparent. In addition to natural variability of penetrating radiation in the environs at both nearby and distant locations, the results are affected by administrative changes in the analyses of environmental TLDs. The natural variability is due to several weather and climatic factors and to solar flare activity. Thus it is difficult to quantify. Because the administrative changes (e.g., sampling period changes, background correlations) are large enough to cause the variability apparent in Figure 3.55, it is assumed that the administrative changes are more important than natural year-to-year variability.

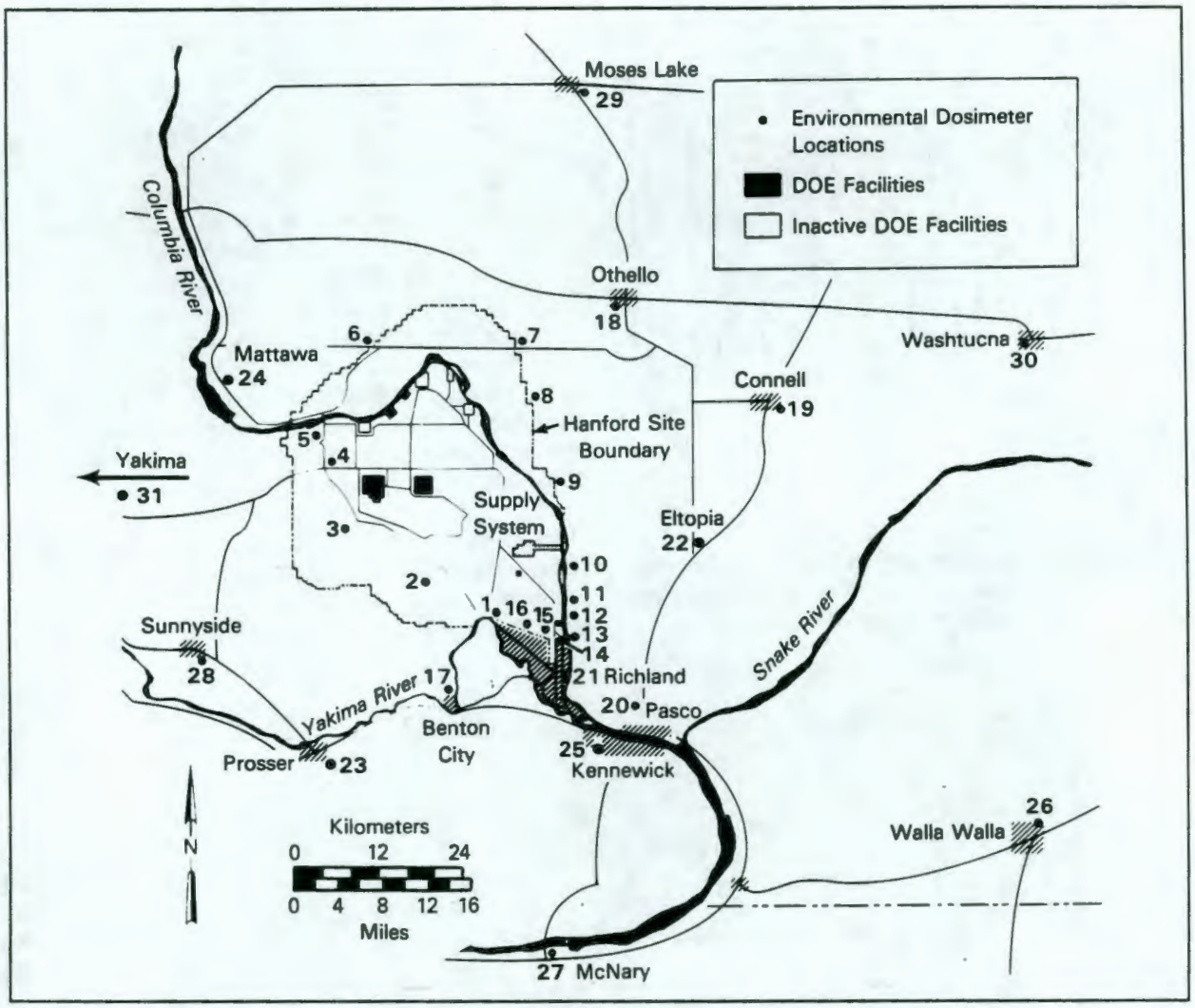

FIGURE 3.54. Environmental Dosimeter Locations at the Site Perimeter and at Nearby and Distant Communities in 1987 (see location number key in Table A.50)

In the past, some TLDs were apparently self-dosing (i.e., dose from trace radioactive material in the TLD itself was measured), requiring that a correction factor be applied. The TLDs used in 1987 did not exhibit this self-dosing characteristic, and therefore no self-dosing correction was applied. In addition, background corrections to the 1987 data were made on a different basis than had been done previously. In the past, to control for dose received in storage, control TLDs were placed in a safe when returned from the field and were read approximately 1 week later. In 1987, control TLDs were kept in storage for the entire monitoring cycle (1 to 3 months). Then the appropriate fractions of this storage dose (according to how long the TLDs were stored) were subtracted from field TLD results. This procedure provided lower but more accurate background corrections. Figure 3.55 also shows that dose rates at perimeter stations generally averaged 10 mrem/yr higher than at distant locations. The differences may have been caused by natural geographic variations in terrestrial radiation and by variations resulting from human activities such as paving of offsite monitoring locations.

Dosimeters were submerged in the Columbia River at Coyote Rapids and the Richland Pumphouse (Figure 3.56) to provide an estimate of penetrating dose rates that could be received by a person immersed in the river. The measurements, shown in Table A.51, Appendix A, indicated a dose rate less than the background dose rate of 0.009 mrem/h

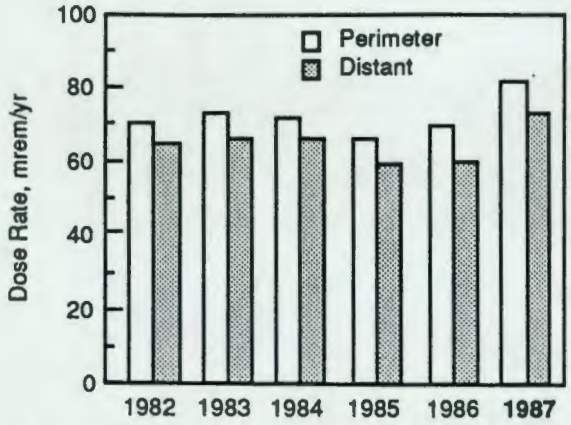

FIGURE 3.55. Annual Average External Dose Rates at Perimeter and Distant Locations, 1982 Through 1987. (The apparent increase in 1987 is due primarily to the method of calculation and does not reflect an actual increase in radiation.)

measured on land. The average dose rates at both the Coyote Rapids and the Richland Pumphouse locations were 0.006 mrem/h during 1987. These dose rates have remained low, with a range of 0.003 to 0.006 mrem/h over the years.

Dosimeters were placed at several publicly accessible locations near the perimeter of operating areas on the Hanford Site (Figure 3.57). Locations included the Columbia River shoreline near the 100-N Area, parking lots near the west perimeter of the 300 Area, and the parking lot near the Visitors Center at the 400 Area. Results for 1987 are shown in Table A.52, Appendix A. Results are reported as mrem/h (instead of mrem/yr) because the locations are not continuously occupied by the same person.

Dose rates near the 100-N Area on the river shoreline were slightly above background but were similar to those observed in previous years. The maximum dose rate recorded near the 100-N Area was 0.039

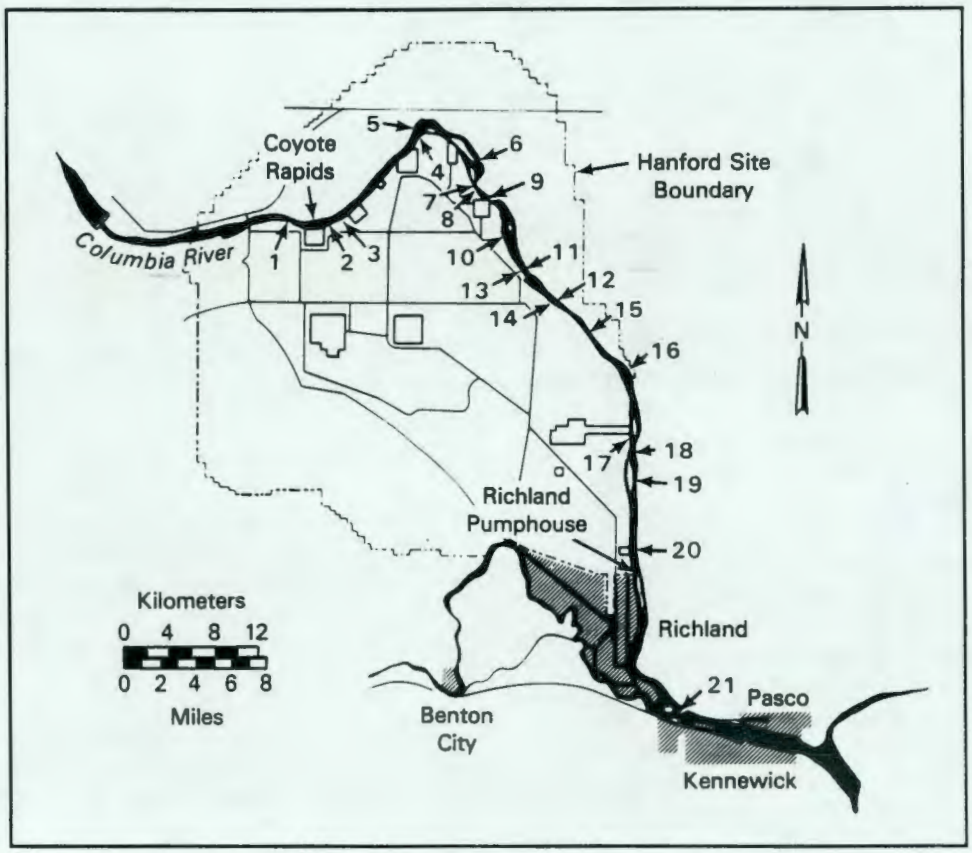

FIGURE 3.56. Environmental Dosimeter Locations Along the Hanford Reach of the Columbia River (see location number key in Table A.53)

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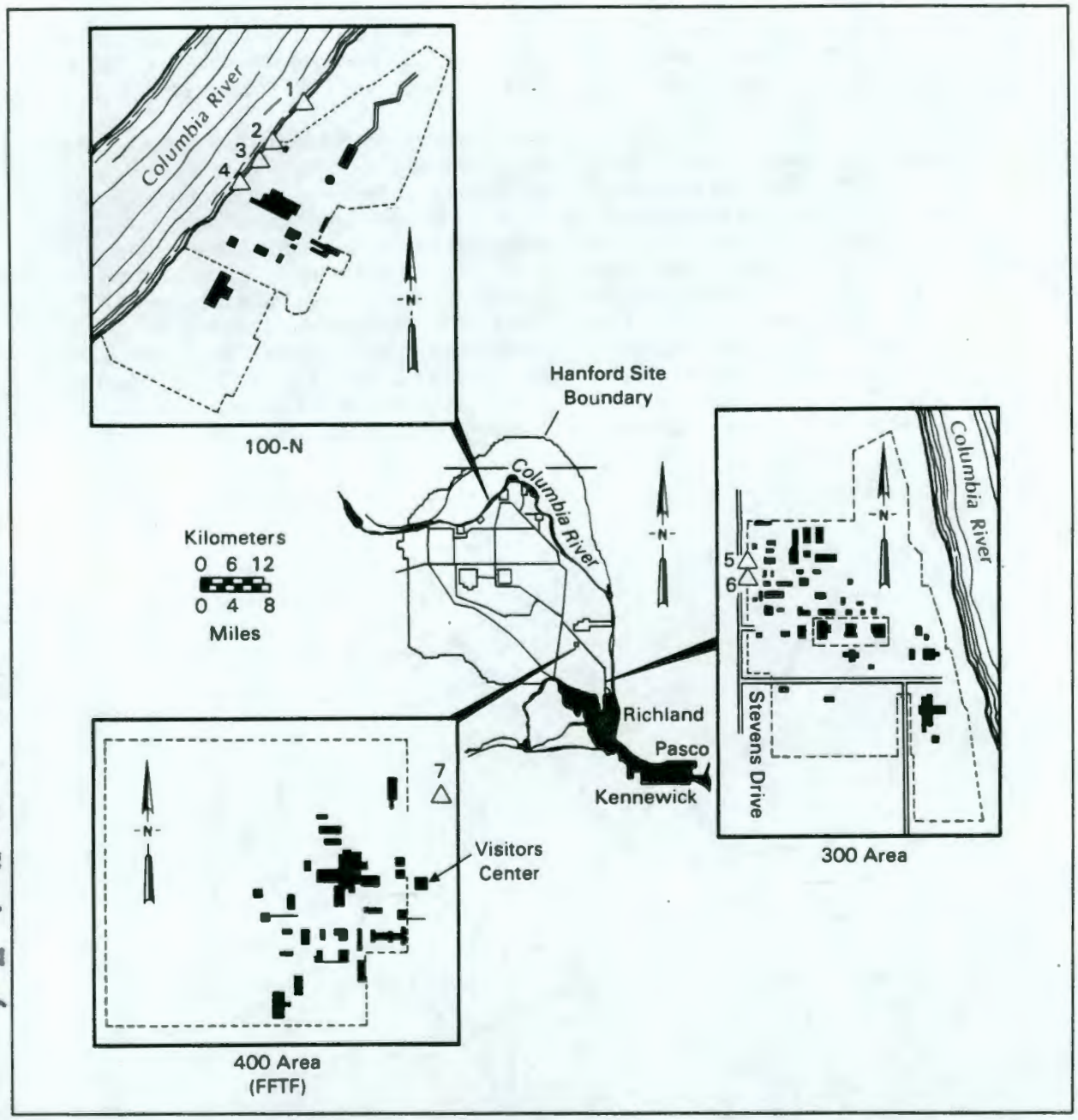

FIGURE 3.57. Environmental Dosimeter Locations at Publicly Accessible Onsite Locations in 1987 (see location number key in Table A.52)

mrem/h, while the average varied between 0.018 and 0.032 mrem/h. Dose rates in this vicinity were attributed to waste-management activities within the 100-N Area.

Dose rates at publicly accessible locations along the west perimeter of the 300 Area were slightly elevated compared to normal background levels of 0.009 mrem/h. The highest dose rate measured along the west perimeter of the 300 Area was 0.063 mrem/h, at a location near a research facility housing a radioactive steam generator that was being studied during the first half of 1987. The average dose rate at the other 300 Area perimeter location near a publicly accessible area was also higher than background (0.011 mrem/h).

9 2 1 2 5 5 6 0 2 9 5

The dose rate near the Visitors Center at the 400 Area was at background, indicating that penetrating radiation at this location could not be attributed to FFTF activities during 1987.

Low levels of radioactivity (primarily ^{60}Co and ^{154}Eu) from past reactor operations in the 100 Areas were measured at several locations along the shorelines and on islands in the Hanford reach of the Columbia River. Radiation dose rates from these radionuclides were the subject of an extensive radiological survey in 1979 (Sula 1980). In 1980, based on findings of the survey, dosimeters were placed in areas along the river (see Figure 3.56) where dose rates were determined to be slightly elevated with respect to background levels. Table A.53, Appendix A, provides results of measurements taken at these locations during 1987. Dose rates measured during 1987 were similar to those observed in recent years.

Onsite external penetrating radiation was measured at the locations shown in Figure 3.58. Results of these measurements are given in Table A.54, Appendix A. Dose rates above background levels were observed at several onsite locations during 1987. The rate in excess of background observed near the 100-N Area was attributed to short-lived, airborne noble gases and direct radiation from waste-handling and storage facilities. Dose rates at two of the 300 Area locations (locations 15 and 16 of Figure 3.58) were higher than background during 1987. These locations were near the facility where a

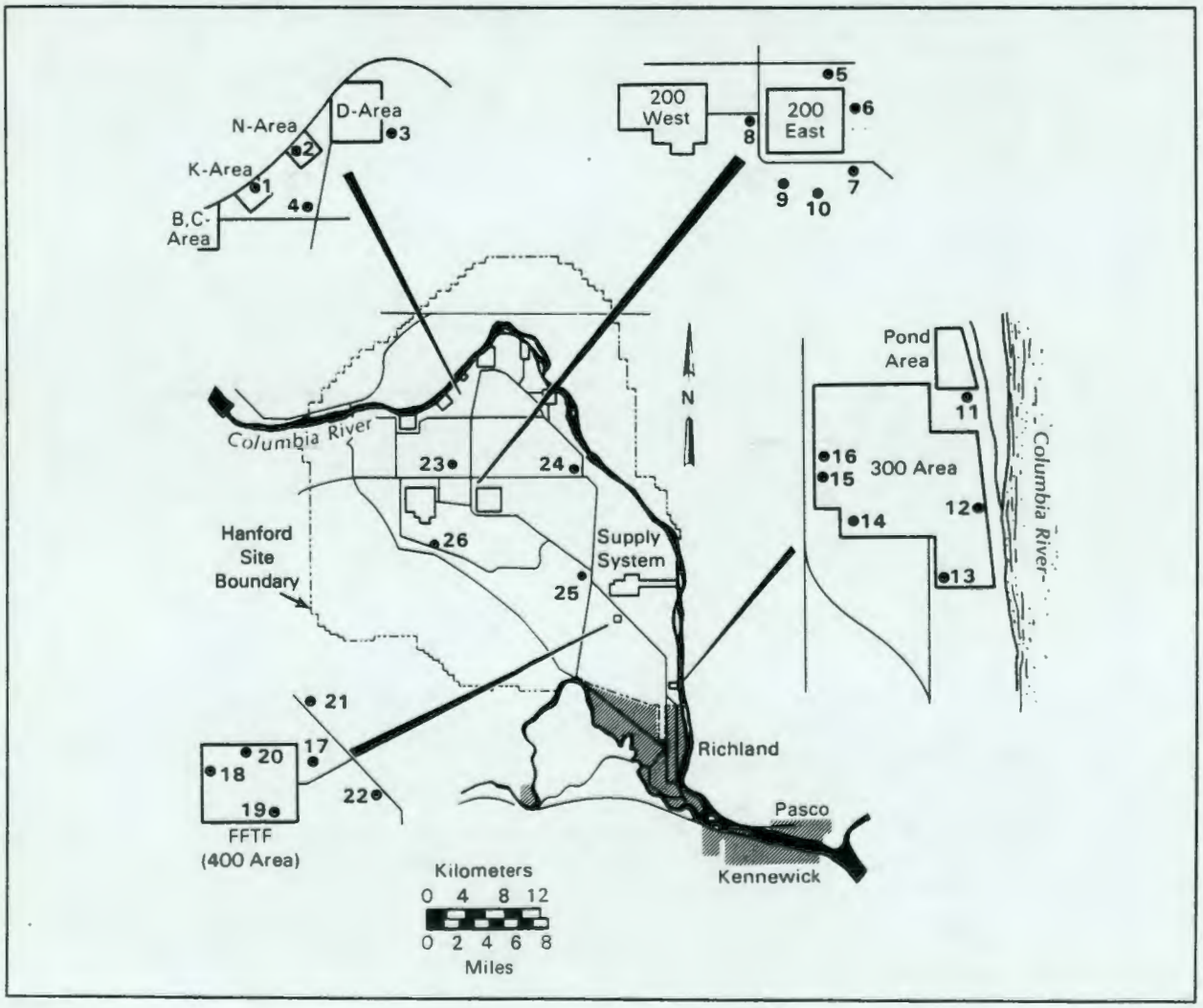

FIGURE 3.58. Environmental Dosimeter Locations on the Hanford Site (see location number key in Table A.54)

9 2 1 2 5 5 6 0 2 9 6

radioactive steam generator was being studied, which would account for the higher-than-background levels. Dose rates around the 200 and 400 Areas were within the expected background levels.

RADIATION SURVEYS

Onsite roads, railroads, and inactive radioactive-waste disposal sites outside of operating areas were routinely surveyed during 1987 to detect abnormal levels of radioactivity. The frequency of surveys on specific routes for roads and railroads was based on their use and the potential for their contamination. Most waste sites were surveyed twice during 1987. Specific routes and frequencies for surveys conducted during 1987 were defined in a master schedule developed by PNL.

Roads shown in Figure 3.59 were surveyed routinely using four scintillation detectors positioned approximately 0.5 m above the ground, evenly spaced across the width of a vehicle. No abnormal conditions were observed on Site roadways during 1987. Railroad routes (Figure 3.59) were surveyed using a small railcar with two scintillation detectors mounted approximately 0.3 m directly above the tracks. Surveys conducted during 1987 did not reveal any abnormal conditions on Site railways.

Inactive waste-disposal sites outside operating-area perimeter fences were surveyed during 1987 with portable instruments to detect changes in the levels of external radioactivity. The general physical condition of the sites was also visually inspected. In general, radiation surveys conducted during 1987 showed levels comparable to those observed in past years.

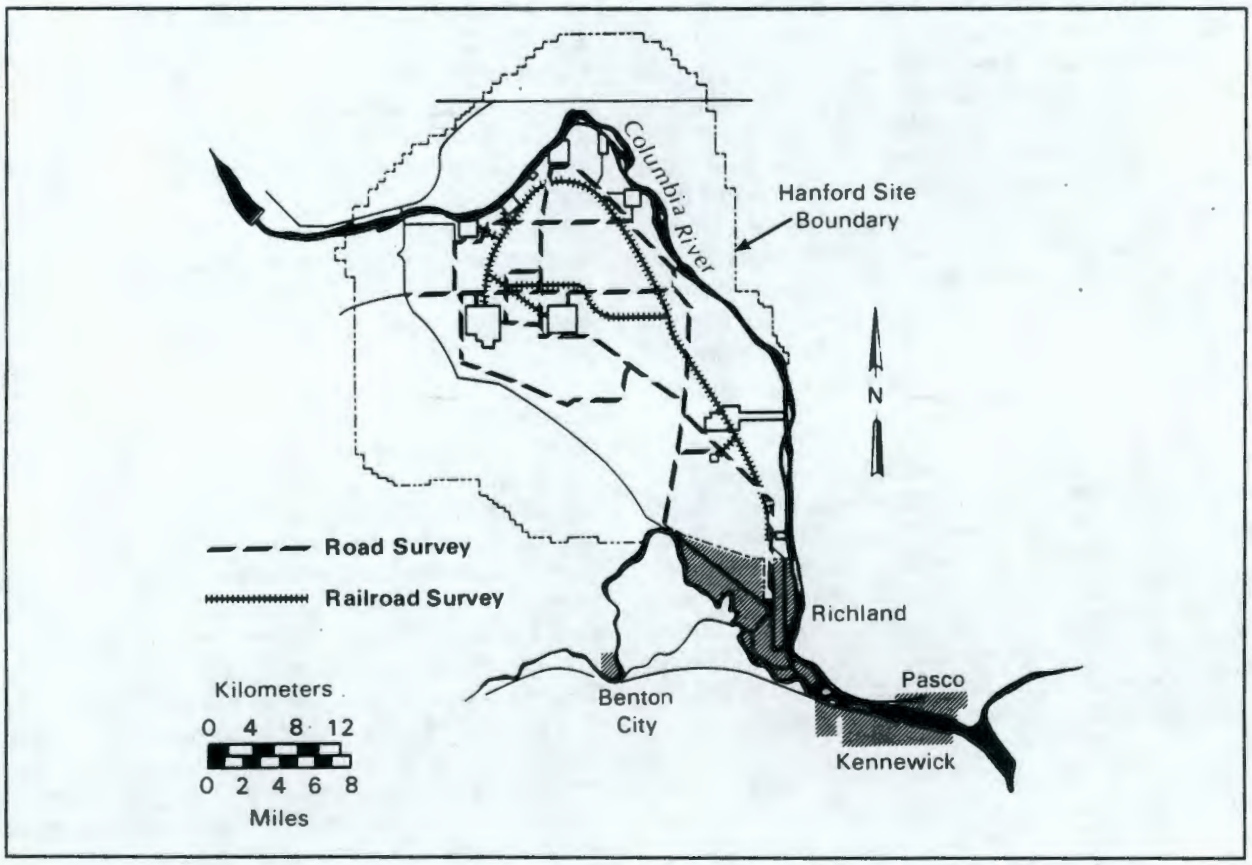

FIGURE 3.59. Road and Railroad Survey Routes in 1987

9 2 1 2 5 5 6 0 2 9 7

3.8 COMPARISON OF MEASUREMENTS WITH CALCULATIONS AND OTHER MONITORING RESULTS

R. E. Jaquish

Measurements of radiation levels and radionuclide concentrations in the environment were used to estimate the radiological impact of Hanford operations. The quantities of radionuclides released to the environment were usually small, and frequently it was not possible to measure radioactivity attributable to Hanford operations. For dose calculations, environmental concentrations of radionuclides in air, water, and other media were calculated based on the quantities released in various effluents. To verify that calculated environmental concentrations used in the dose models were reasonable, concentrations of radionuclides that could be measured in air and water were compared with calculated values. Calculated concentrations used for radiological dose assessment were verified as reasonable estimates. Monitoring results from other organizations in Washington and the Hanford vicinity were reviewed. These data did not show radionuclide concentrations to be different from national ambient radiation levels.

For most radionuclides on and around the Hanford Site, concentrations were low and indistinguishable from background. Dose estimates were based on radionuclide concentrations calculated from reported effluents using appropriate dispersion and dose models (see Appendix F). To determine whether the models had provided reasonable concentrations, measured concentrations of radionuclides in air and surface water were compared with the calculated concentrations. Most concentrations were near minimum detectable levels, but even at these levels it was possible to determine whether the calculated concentrations were in the same range as measured concentrations.

Table 3.5 lists the major nuclides contributing to the radiological dose from Hanford operations' liquid effluents to the Columbia River. The table also compares calculated concentrations with measured concentrations. The Richland Pumphouse was used as the station for comparing concentrations. Measurements taken at Priest Rapids Dam were used as the background to be subtracted to estimate the net concentration at the Richland Pumphouse.

For ^{90}Sr, ^{131}I, ^{137}Cs, and $^{239,240}Pu$, the measured concentrations were low and no increase resulting from effluents could be detected. With the exception of ^{3}H, ^{129}I, and uranium, the calculated downstream concentrations were also low, below the sensitivity of the monitoring methods. The measured concentration of ^{3}H was greater than that calculated from the monitored liquid effluents to the Columbia River. The calculated added concentration from monitored effluents was 1 pCi/L, and the measured difference was 60 pCi/L. This difference indicates an additional source of ^{3}H along the Hanford reach attributed to seepage from the Hanford shoreline (McCormack and Carlile 1984). Incomplete mixing of the ^{3}H plume at this location could also contribute to the elevated measured concentration. There was no monitored liquid effluent for ^{129}I or uranium. The small increases in these two radionuclides measured at the Richland Pumphouse are also presumed to be from ground water. (See "Ground-Water Monitoring," Section 3.2.)

A similar comparison was made for airborne radionuclides by calculating concentrations for the perimeter monitoring location nearest the Site (Ringold) and comparing these values with the measurements at this location. Average results for distant stations were used as the background level to be subtracted from the Ringold results to estimate the net concentration contributed by Hanford effluents. The 1987 average dispersion values ($\overline{X}/Q'$) were used for these calculations (see Tables F.5 to F.8, Appendix F). Table 3.6 lists the major airborne effluents from the 200 Areas and shows the calculated and net measured concentrations at the Ringold location. For ^{3}H, ^{90}Sr, ^{131}I, ^{137}Cs, and $^{239,240}Pu$, the net measured perimeter concentrations were very low or negative, indicating no detectable contribution from the Hanford effluent. This conclusion agrees with the calculated concentrations, which indicate very low levels that would be below the detection levels of the measurement techniques. The calculated ^{85}Kr concentration was 22 pCi/m^3 and the measured

TABLE 3.5. Measured and Calculated 1987 Annual Average Concentrations of Selected Radionuclides in the Columbia River

Radionuclide	100 Area Releases, Ci[a]	Calculated Concentration Added Downstream, pCi/L	Measured Concentration at Richland Pumphouse Minus Background, pCi/L
^{3}H	98	1	60
^{60}Co	0.33	0.004	0.004
^{89}Sr	0.83	0.009	0.03
^{90}Sr	2.5	0.03	-0.01[b]
^{129}I	---[c]	---	0.0001
^{131}I	0.0043	0.00005	-0.007[b]
^{137}Cs	0.08	0.0009	-0.006[b]
$^{239,240}Pu$	0.0005	0.00001	-0.0001[b]
U Total	---[c]	---	0.05

(a) From Table G.5, Appendix G.
(b) Negative concentration values indicate results less than the background value.
(c) Indicates no monitored effluent for these radionuclides.

TABLE 3.6. Measured and Calculated 1987 Annual Average Air Concentrations of Selected Radionuclides (pCi/m^3)

Radionuclide	200 Area Releases, Ci[a]	Calculated Perimeter Concentrations at Ringold	Measured Perimeter Concentrations at Ringold Minus Background[b]
^{3}H	70	0.02	-0.8
^{85}Kr	70,000	20	6
^{90}Sr	0.0002	6×10^{-7}	-0.00003
^{129}I	0.5	0.0002	0.000006
^{131}I	<0.0002	$<6 \times 10^{-8}$	-0.001
^{137}Cs	0.00004	1×10^{-8}	-0.00007
$^{239,240}Pu$	0.0004	1×10^{-7}	0.0

(a) From Table G.5, Appendix G.
(b) Negative concentration values indicate results less than the background value.

concentration was 6 pCi/m^3. This is reasonable because the straight line model tends to give results higher than observed in actual wind fields. Although the measured and calculated concentrations of ^{129}I were very low, the calculated results were greater than the measurements. Uncertainties in both the quantity released and the environmental measurements could contribute to the differences observed.

In general, the comparison of measured and calculated concentrations for a limited number of radionuclides in air and water indicated that the calculated concentrations were in the correct range, as identified by environmental monitoring measurements.

Other Monitoring Data

The states of Oregon and Washington and the EPA performed environmental monitoring in 1987; however, these organizations collected only limited amounts of data from the Hanford vicinity. The following monitoring was performed by these organizations:

Monitoring	Locations
U.S. Environmental Protection Agency	
Gross Beta in Air	Olympia and Seattle, Wash.
Tritium in surface water	Northport and Richland, Wash.
Radionuclides in pasteurized Milk	Seattle and Spokane, Wash.
Strontium-89 and -90 in pasteurized milk	Region 10 composite
State of Washington	
Radioactivity in air	Hanford Site
Radioactivity in Columbia River	Priest Rapids and Richland, Wash.
Radioactivity in springs	100-N Area Springs
Radioactivity in soil	Hanford Site
State of Oregon	
Radioactivity in springs	100-N Area Springs

Monitoring data for 1987 from the states of Washington and Oregon are not available in published form. Table A.57, Appendix A, lists the 1986 data for the joint sampling of the Columbia River and seep springs by the states and PNL.

The EPA monitoring is conducted through their Environmental Radiation Ambient Monitoring System. Monitoring results are compiled and distributed quarterly (EPA 1987b) by the Office of Radiation Programs' Eastern Environmental Radiation Facility in Montgomery, Alabama.

The EPA monitoring results for Washington State and the Hanford vicinity are similar to the ambient background levels from other parts of the United States. A summary of EPA results for 1987 is shown in Table 3.7.

TABLE 3.7. U.S. Environmental Protection Agency and PNL Results - 1987

Tritium in Surface Water, pCi/L

Northport, Wash.	EPA	Jan-March 1987	100 ± 200
Richland, Wash.	EPA	Jan-March 1987	100 ± 200
Richland, Wash.	PNL	1987 Mean	130 ± 10

Tritium in Drinking Water, pCi/L

Seattle, Wash.	EPA	Jan-March 1987	100 ± 200
Richland, Wash.	EPA	Jan-March 1987	300 ± 200
Richland, Wash.	PNL	1987 Mean	130 ± 10

Gross Beta in Air Particulates, pCi/m^3

		January	February	March	1987 Mean
Olympia, Wash.	EPA	0.00	0.00	0.00	---
Spokane, Wash.	EPA	0.02	0.01	0.01	---
Hanford Perimeter	PNL	---	---	---	0.03

Radionuclides in Pasteurized Milk, pCi/L

			^{137}Cs	^{140}Ba	^{131}I
Seattle, Wash.	Jan	EPA	10 ± 3	---	---
	Feb	EPA	20 ± 7	8 ± 8	4 ± 7
	Mar	EPA	13 ± 7	5 ± 8	5 ± 7
Spokane, Wash.	Mar	EPA	9 ± 18	-17 ± 18	1 ± 14
Riverview, Wash.	1987 Mean	PNL	3.6 ± 9.1	---	0.01 ± 0.35

Strontium in Pasteurized Milk, pCi/L

			^{89}Sr	^{90}Sr
EPA Region 10 Comp.	Jan-March	EPA	2 ± 1	0.4 ± 0.4
Riverview, Wash.	1987 Mean	PNL	2.8 ± 7.1	0.8 ± 1.0

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4.0 POTENTIAL RADIOLOGICAL DOSES FROM 1987 HANFORD OPERATIONS

J. K. Soldat

An assessment was made of the radiological dose from Hanford operations during 1987. The calculated effective dose equivalent[a] received by a hypothetical maximally exposed individual in 1987 was 0.05 mrem, less than the 0.09 mrem estimated for 1986. The effective dose to the surrounding population (adding the doses to an average individual from all sources, then multiplying by the number of people in the area) was about 4 person-rem, compared to 9 person-rem estimated for 1986. The current DOE radiation standards for protection of the public are 100 mrem/yr for prolonged exposure and 500 mrem/yr for occasional annual exposures to a maximally exposed individual.[b] All measured and calculated radiation doses were well below the applicable standards for radiation protection, and were substantially less than doses normally received from common sources of background radiation.

Radioactive materials were released to the environment as air and water effluents from Hanford operations during 1987. Potential radiation doses to the public that resulted from these releases were evaluated in detail, as required by DOE Order 5481.1 (DOE 1981b), to determine compliance with pertinent regulations and standards.

The potential radiological impacts of 1987 Hanford operations were assessed in terms of the following:

- the maximum dose rate at a publicly accessible location on or within the Site boundary (this quantity is also termed the "fence-post" dose rate)
- the dose to a hypothetical, maximally exposed individual at an offsite location, expressed as the effective dose
- the effective dose to the population residing within an 80-km radius of one or more of the onsite operating areas.

To the extent possible, radiation dose assessments should be based on direct measurements of radiation exposure rates or radionuclide concentrations in the surrounding environment. If statistically significant concentrations of radionuclides in the offsite environment attributable to Hanford operations were detected by monitoring, dose calculations were made using measured concentrations. However, the amounts of radioactive materials released during 1987 were usually too small to be measured directly once they were dispersed in the offsite environment. A few radionuclides, ^{3}H and ^{129}I in the Columbia River and ^{85}Kr in air, were detectable in the offsite environment and dose calculations were made on the basis of measured concentrations. For most radionuclides in environmental media, it was not possible to distinguish between concentrations resulting from either worldwide fallout or effluent releases from Hanford operations during 1987.

In most cases, potential offsite radiation doses were estimated using computer models that predicted concentrations of radioactive materials in the environment from effluent releases. These models are described in Appendix F, and the reported Hanford effluents for 1987 are shown in Tables G.1 through G.6, Appendix G. Measured and estimated concentrations of selected radionuclides are compared in "Environmental Monitoring Results," Sections 3.1 through 3.8.

Estimated potential offsite radiation doses to the public were small. Although the accuracy associated with the computed radiation dose calculations is not specified, maximum parameter values (i.e., plant uptake and consumption factors) were selected for use in the models. Thus, the doses calculated using these models should be viewed as maximum estimates (made using maximizing assumptions) of the potential doses resulting from 1987 Hanford operations.

(a) Hereafter referred to as "effective dose" (see Glossary, Appendix B, and Appendix F).

(b) Memo from W. A. Vaughan, Assistant Secretary for Environment Safety and Health, U.S. Department of Energy, to DOE Field Offices, August 5, 1985.

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MAXIMUM "FENCE-POST" DOSE RATE

The "fence-post" dose rate is a measure of the maximum potential external radiation dose rate at publicly accessible locations on or near the Site. The "fence-post" dose rate was determined from radiation exposure measurements using fixed environmental dosimeters placed at locations of expected maximum dose rates. It does not represent the dose actually received by any member of the public, but rather the radiation dose absorbed by the dosimeter. The reporting of maximum "fence-post" dose rates is required by DOE Order 5484.1 (DOE 1981b).

"Fence-post" dose rates were measured in the vicinity of the 100-N, 300, and 400 (FFTF) operating areas, as described in the section "Penetrating Radiation Monitoring," Section 3.7. The 200 Areas were not included because they are not accessible to the general public.

The Columbia River provides public access to an area within a few hundred meters of the N Reactor and supporting facilities. Measurements made at the 100-N Area shoreline (Table A.52, Appendix A) were consistently above background. The highest average dose rate observed along the shoreline during 1987 was 0.03 mrem/h (0.0003 mSv/h), or about four times the dose rate normally observed at offsite shoreline locations (0.007 mrem/h or 0.00007 mSv/h).

The FFTF Reactor Visitors Center, located southeast of the FFTF Reactor building, provides public access to the 400 Area. Dose rate measurements during 1987 at this location (Table A.52, Appendix A) showed essentially normal background radiation levels (0.009 mrem/h or 0.00009 mSv/h).

Dose rates along the perimeter of the 300 Area were above background levels at some locations accessible to the general public. The highest average dose rate measured was 0.06 mrem/h (0.0006 mSv/h) over a 2-day period in early 1987 near a research facility housing a radioactive steam generator. The average dose rate for other 300 Area perimeter locations accessible to the public was 0.011 mrem/h (0.00011 mSv/h).

The impact from these reported "fence-post" dose rates was negligible. They should not be used to calculate annual doses to the general public because no one resides at these "fence-post" locations.

MAXIMALLY EXPOSED INDIVIDUAL DOSE

The maximally exposed individual is a hypothetical person, living at a single location, who has a life style that results in him/her receiving the maximum calculated radiation dose using maximum assumptions with regard to location, inhalation of radioactive effluents, consumption of contaminated foods and water, and direct exposure to contaminants. This individual's characteristics were chosen to maximize the potential combined doses from all realistic, available exposure pathways from environmental releases at Hanford. The particular characteristics of the maximally exposed individual were based on factors such as the total amount, composition, and dispersion of effluents released to the air or the Columbia River.

The following exposure pathways were included in the calculation of doses to the hypothetical maximally exposed individual: inhalation of and submersion in airborne effluents, consumption of foods contaminated by radionuclides deposited on the ground from airborne materials and by irrigation with water from the Columbia River, direct exposure to radionuclides deposited on the ground, use of drinking water originating from the Columbia River, consumption of fish taken from the Columbia River, and direct exposure to radionuclides while using the Columbia River for recreation. The hypothetical maximally exposed individual for 1987 was postulated to be an individual who:

- was a resident in an area approximately 13 km south-southeast of the 300 Area
- consumed foodstuffs grown in the northwestern part of the Riverview district using Columbia River water for irrigation
- ingested drinking water obtained from the Pasco sanitary water system
- used the Columbia River extensively for boating, swimming, and fishing, and consumed the fish that were caught.

The doses to the hypothetical maximally exposed individual were calculated using the effluent data in Tables G.1 and G.5, Appendix G and monitoring data.

The calculated committed doses to specific organs and the effective doses for the maximally exposed individual are summarized in Table 4.1. These values include the doses received from exposure to liquid and airborne effluents during 1987, as well as from potential exposure beyond 1987 from radionuclides deposited in the body during 1987 via inhalation and ingestion of drinking water, fish, and farm products.

The total effective dose to the hypothetical maximally exposed individual in 1987 was calculated to be 0.05 mrem (0.0005 mSv). The primary pathways contributing to the 1987 effective dose to the maximally exposed individual were:

- consumption of food irrigated with Columbia River water (19%)
- consumption of food containing radionuclides deposited from the air (54%)
- consumption of pan fish from the Columbia River (16%).

The effective dose limits for any member of the general public from all routine DOE operations are 500 mrem/yr (5 mSv/yr) for occasional exposures and 100 mrem/yr (1 mSv/yr) for prolonged exposure periods.[a] The calculated effective dose for the hypothetical maximally exposed individual was 0.05% of the prolonged exposure limit. The dose limit for any individual organ is 5000 mrem/yr (50 mSv/yr). In the maximally exposed individual, the organ calculated to receive the highest dose was the thyroid (0.02% of the limit).

Comparison with Clean Air Act Standards

Additional limits for the air pathway are provided in 40 CFR 61, Subpart H of the Clean Air Act (EPA 1983): 25 mrem/yr (0.25 mSv/yr) whole-body committed dose and 75 mrem/yr (0.75 mSv/yr) committed dose to any organ for any member of the public. The 1987 emissions resulted in doses that were 0.1% of the

(a) Memo from W. A. Vaughan, Assistant Secretary for Environment Safety and Health, U.S. Department of Energy, to DOE Field Offices, August 5, 1985.

TABLE 4.1. Calculated Committed Doses and the Effective Dose to the Hypothetical Maximally Exposed Individual from 1987 Hanford Operations (mrem)

Pathway		50-Year Committed Dose					Effective Dose[b]
		Red Marrow	Bone Surfaces	Lung	GI[a]	Thyroid	
Air	- Direct [c]	0.003	0.009	0.004	0.001	0.008	0.002
	- Food [d]	0.001	0.001	0.001	0.001	0.8	0.03
Water[g]	- Foods[e]	0.04	0.07	0.003	0.01	0.007	0.01
	- Drinking Water	0.005	0.007	0.003	0.004	0.003	0.003
	- River Recreation[f]	0.02	0.05	0.004	0.01	0.005	0.009
	Total	0.07	0.1	0.02	0.03	0.8	0.05

(a) Gastrointestinal tract (lower large intestine).
(b) Effective dose is compiled from the product of each organ's dose and its weighting factor and includes some organs not listed here.
(c) Includes inhalation, submersion, and direct exposure to ground deposition.
(d) Includes consumption of all foodstuffs contaminated via dry deposition.
(e) Includes consumption of all foodstuffs contaminated via irrigation water.
(f) Includes consumption of fish taken from the Columbia River.
(g) Includes dose from ground-water seepage (^{3}H and ^{129}I) to the river.

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whole-body dose limit and 1% of the dose limit for the maximally exposed organ (thyroid). Thus, the calculated maximum hypothetical annual doses for 1987 Hanford releases were well below all applicable standards.

The effective dose for the maximally exposed individual from 1987 Hanford operations is compared with the doses for 1985 and 1986 in Figure 4.1. The calculated committed organ doses and effective doses for 1985, 1986, and 1987 are in Table 4.2.

POPULATION DOSE

The regional population dose from 1987 Hanford operations was estimated by calculating the radiation dose to the population residing within an 80-km radius of any of the onsite operating areas. Population doses are expressed in units of person-rem. The results are shown in Table 4.3, in terms of the committed organ dose and the effective dose. Site-specific population distribution characteristics, food pathway and dietary parameters, residency parameters, and recreational activity parameters assumed for these calculations are given in Tables F.1 to F.4 and F.9 to F.12, Appendix F.

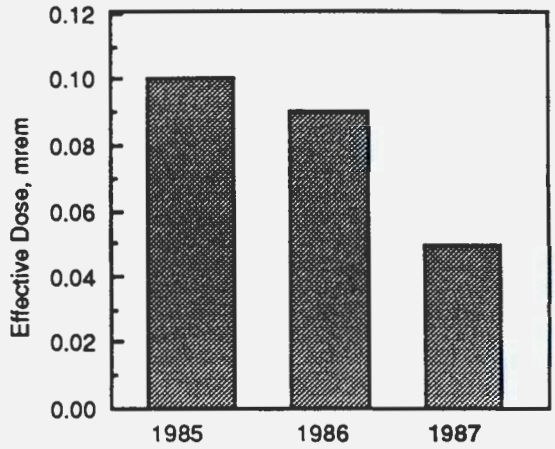

FIGURE 4.1. Calculated Effective Doses to the Maximally Exposed Individual for 1985, 1986, and 1987

The effective dose to the population was calculated to be 4 person-rem (0.04 person-Sv) in 1987, compared to 9 person-rem (0.09 person-Sv) in 1986. This dose corresponds to an average per capita effective dose of 0.01 mrem (0.0001 mSv) for individuals living within 80 km of Hanford. The decrease

TABLE 4.2. Calculated Committed Organ Doses and Effective Dose to the Hypothetical Maximally Exposed Individual from Hanford Operations, 1985 Through 1987 (person-rem)

Committed Dose[a]	1985	1986	1987
Red Marrow	0.3	0.3	0.07
Bone Surfaces	0.7	0.6	0.1
Lung	0.07	0.03	0.02
GI [b]	0.09	0.04	0.03
Thyroid	1.0	0.9	0.9
Effective Dose [c]	0.1	0.09	0.05

(a) Total 50-year committed dose to each organ from exposure to all available pathways.
(b) Gastrointestinal tract (lower large intestine).
(c) Effective dose compiled from the product of each organ's dose and its weighting factor, and includes some organs not listed here.

TABLE 4.3. Calculated Committed Organ Doses and the Effective Doses for the 80-km Population from 1987 Hanford Operations (person-rem)

Pathway		50-yr Committed Dose: Red Marrow	Bone Surfaces	Lung	GI[a]	Thyroid	Effective Dose[b]
Air	- Direct[c]	0.6	2	0.9	0.5	2	0.6
	- Foods[d]	0.1	0.1	0.08	0.09	110	3
Water[g]	- Foods[e]	0.03	0.07	0.004	0.01	0.01	0.01
	- Drinking Water	0.2	0.3	0.1	0.1	0.1	0.1
	- River Recreation[f]	0.01	0.02	0.003	0.005	0.003	0.004
	Total	0.9	2	1	0.7	110	4

(a) Gastrointestinal tract (lower large intestine).
(b) Effective dose compiled from the product of each organ's dose and its weighting factor, and includes some organs not listed here.
(c) Includes inhalation, submersion, and direct exposure to ground deposition.
(d) Includes consumption of all foodstuffs contaminated via dry deposition.
(e) Includes consumption of all foodstuffs contaminated via irrigation water.
(f) Includes consumption of fish taken from the Columbia River.
(g) Includes dose from ground-water seepage (^{3}H and ^{129}I)to the river.

in the estimated radiation doses for 1987 reflect the decrease in the release rates of radionuclides to the environment from Hanford facilities. The latter decrease, in turn, reflected curtailed operations at the N reactor and the PUREX Plant in 1987. (See "Major Activities," Section 2.1)

A comparison of the 80-km population doses attributed to 1985, 1986, and 1987 Hanford operations are given in Figure 4.2 and Table 4.4.

The primary pathways contributing to the 1987 effective dose for the population were

- air submersion in the short-lived noble gases from the N Reactor (8%)
- consumption of foodstuffs contaminated with radionuclides released with gaseous effluents from the PUREX Plant stack (81%).

The air submersion and inhalation pathways were the primary sources of radiation dose to the bone surface. The dose to the thyroid resulted primarily

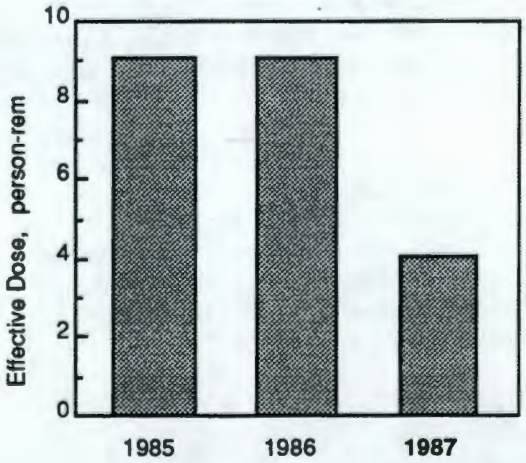

FIGURE 4.2. Calculated Effective Dose to the 80-km Population in 1987

from the consumption of food containing the long-lived radionuclide ^{129}I, released with the gaseous effluents from the PUREX Plant.

The average per capita effective dose from 1987 Hanford operations, based on a population of 340,000 within 80 km, was 0.01 mrem. This dose

TABLE 4.4. Calculated Committed Organ Doses and Effective Dose to the 80-km Population from Hanford Operations, 1985 Through 1987 (person-rem)

Committed Dose[a]	1985	1986	1987
Red Marrow	6	5	0.9
Bone Surfaces	31	12	2
Lung	13	7	1
GI[b]	4	4	0.7
Thyroid	98	120	110
Effective Dose[c]	9	9	4

(a) Total 50-year committed dose to each organ from exposure to all available pathways.
(b) Gastrointestinal tract (lower large intestine).
(c) Effective dose equivalent compiled from the product of each organ's dose and its weighting factor, and includes some organs not listed here.

estimate may be compared with doses from other routinely encountered sources of radiation, such as natural terrestrial and cosmic background radiation, medical treatment and x-rays, natural internal body radioactivity, and inhalation of radon. The average radiation doses from these sources are illustrated in Figure 4.3. The estimated per capita dose for individual members of the public is only a small fraction of the annual per capita effective radiation dose from natural background and medical sources of radiation (about 360 mrem in the Tri-Cities area of Washington State). The contribution of radon (200 mrem) to the effective dose from natural background sources has only recently been quantified by authoritative U.S. organizations (NCRP 1987).

RADIOLOGICAL IMPACT FROM PAST OPERATIONS

Columbia River

Measured levels of certain radionuclides in the Columbia River have been attributed to past operations at Hanford. (See "Surface Water Monitoring," Section 3.3) The primary environmental impacts resulting from past operations were residual radionuclides deposited along the Columbia River shoreline in river sediments and the seepage of ground water into the river from the unconfined aquifer.

Environmental radiation dose rates resulting from residual radionuclides deposited along the Columbia River shoreline were discussed in "Maximum 'Fence-Post' Dose Rates," Section 4.0. (See also "Penetrating Radiation Monitoring," Section 3.7).

Although ^{129}I was not released directly to the Columbia River from Hanford facilities in 1987 (Table G.5, Appendix G), this nuclide was measured at low concentrations in the Columbia River at the Richland Pumphouse. In addition, the measured concentration of ^{3}H at the Richland Pumphouse was higher than that predicted from measured effluents to the Columbia River. These concentrations are attributed to seepage from ground water.

The effective dose from the extra concentrations of these two radionuclides in the river is estimated to be 0.007 mrem (7×10^{-5} mSv) to the maximally exposed individual, and 0.1 person-rem (0.001 person-Sv) to the 340,000 people within 80 km. The extra contributions from ^{3}H and ^{129}I are included in the doses from individual water exposure pathways and in the total doses listed in Tables 4.1 and 4.3.

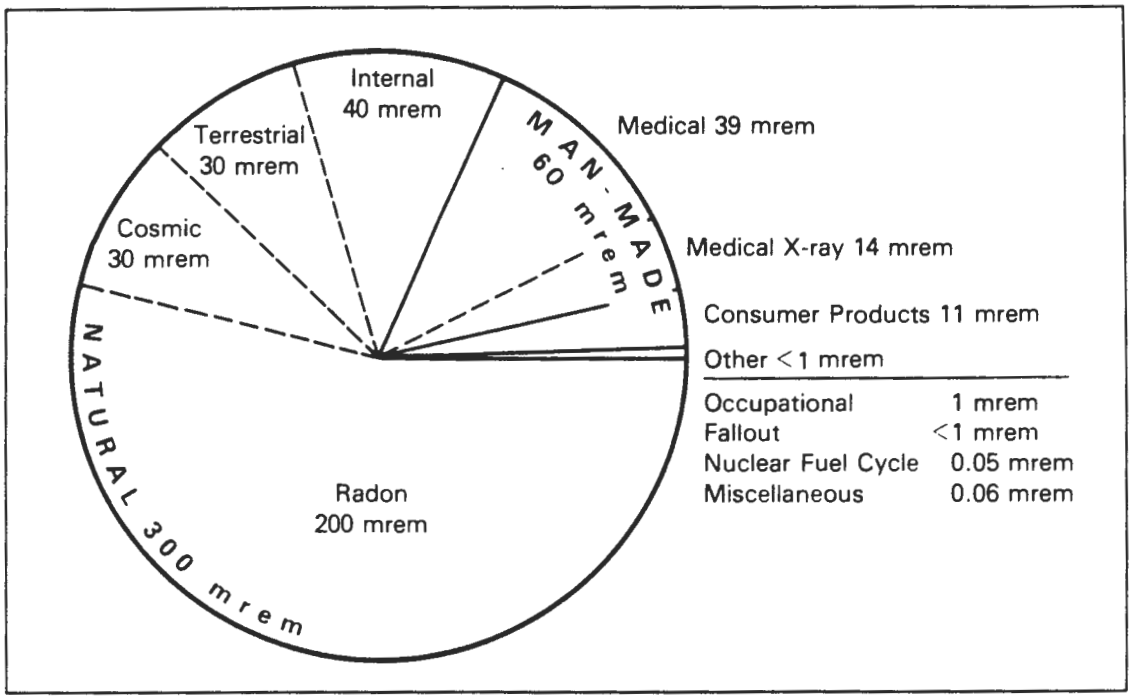

FIGURE 4.3. Annual Radiation Doses from Various Sources (mrem) (NCRP 1987)

RADIOLOGICAL IMPACT FROM PUREX PLANT OPERATIONS

The PUREX Plant operated for 2 months in 1987. In addition to the dose contributions identified earlier from PUREX Plant operations, other minor dose contributions are discussed here. The greatest percentage of the radionuclides emitted to the air from the PUREX Plant in 1987 was 70,000 Ci of ^{85}Kr (see Table G.1, Appendix G). Krypton-85 is an inert gas and is not retained in environmental media or the human body. The dose from inhaling ^{85}Kr is small compared with doses from other radionuclides. Consequently, even though the curie quantity of this radionuclide was large, it was a minor contributor to the radiation dose. The average concentration of ^{85}Kr measured in 1987 at the five perimeter monitoring stations (see Figure 3.5) was 40 pCi/m^3, which was calculated to produce a potential effective dose of 7 x 10^{-4} mrem to an individual who was at that "average" location 100% of the time.

In 1987, there was 0.0004 Ci of $^{239,240}Pu$ in airborne emissions from the PUREX Plant (see Table G.1, Appendix G), compared to 0.003 Ci in 1986. Plutonium-239,240 was a minor contributor to the dose from 1987 Hanford operations, with a maximum potential effective dose of 3 x 10^{-4} mrem (3 x 10^{-6} mSv).

RADIOLOGICAL IMPACT OF DRINKING WATER FROM WELLS

During 1987, ground water was used as the source of drinking water for the 400 Area (FFTF), the Yakima Barricade Guardhouse, and the Hanford Patrol Training Academy. Samples were collected from these systems throughout the year in accordance with applicable drinking water regulations. Radionuclide concentrations observed during 1987 were well below applicable drinking water standards.

With the exception of the FFTF drinking water supply, results for 1987 were similar to those observed in 1986. The concentrations of ^{3}H measured in the FFTF drinking water have been decreasing since a new deeper well was drilled for the water source. The average concentration measured in 1987 was 4,100 pCi/L, compared to 8,500 pCi/L in 1986 and 22,000 pCi/L in 1985. The effective dose to a worker drinking 250 L of water containing the concentration of ^{3}H measured at FFTF in 1987 was calculated to be

0.06 mrem (0.0006 mSV) or 2% of the Washington State Drinking Water Standard of 4 mrem/yr.

One sample of FFTF drinking water was analyzed for ^{129}I in 1987. The result was 0.013 pCi/L. The effective dose from consuming 250 L of such water would be 9×10^{-4} mrem (9×10^{-6} mSv); the corresponding thyroid dose would be 0.03 mrem (0.0003 mSv). These doses are well below DWS. Nonradiological and radiological results from the Hanford Sanitary Water Quality Surveillance Program are discussed in more detail and reported annually by HEHF (Somers 1988).

5.0 QUALITY ASSURANCE

J. A. MacLellan

Comprehensive quality assurance programs were maintained to ensure that data collected were accurate and representative of actual concentrations in the environment. These programs covered surface- and ground-water monitoring for radionuclides and chemicals. Extensive environmental data were obtained to eliminate an unrealistic reliance on only a few results. Newly collected data for each location and each environmental medium were compared with recent results and historical data to ensure that deviations from previous conditions were identified and promptly evaluated. Samples at all locations were collected using well established and well documented procedures to maintain consistency in sample collection. Samples were analyzed by documented standard analytical procedures. The data quality was verified by a continuing program of analytical laboratory quality control, participation in interlaboratory cross-checks, replicate sampling and analysis, and splitting samples with other laboratories. The ground-water monitoring program included procedures for 1) documenting instrument calibrations and procedures used in the field and the laboratory, 2) scheduling maintenance of wells to assure well integrity, 3) inspecting wells using downhole TV cameras and other devices, and 4) using dedicated sampling pumps to avoid cross-contamination. These procedures helped ensure that monitoring data could be used to accurately evaluate environmental impacts from Hanford operations.

SAMPLE COLLECTION QUALITY ASSURANCE

Surface- and ground-water samples were collected by trained Radiation Protection Technologists using documented procedures. The continuity of sampling locations was maintained through documentation in an environmental sampling locations log book. Sample collection for chemical monitoring was performed according to specially developed written procedures. The samples were sealed with evidence tape to prevent tampering and were transported to the laboratory in accordance with the chain-of-custody procedures required by EPA for RCRA monitoring programs.

ANALYTICAL LABORATORY QUALITY ASSURANCE

The routine radiochemical analyses for environmental monitoring were performed by UST and PNL laboratories (water samples only). United States Testing Company maintained an internal quality control program that involved routine calibration of counting instruments, frequent source and background counts, routine yield determinations of radiochemical procedures, replicate analyses to check precision, and analyses of reagents to ensure purity of chemicals. Calibration standards traceable to the National Bureau of Standards were used for radiochemical calibrations when available. Both laboratories continued to participate in the DOE Quality Assessment Program, and UST participated in EPA's Laboratory Intercomparison Studies Program. These programs provided standard samples of various environmental media (water, milk, air filters, soil, foodstuffs, and tissue ash) containing one or more radionuclides in known amounts. After the samples were analyzed, the results were forwarded to DOE and EPA for comparison with known values and results from other laboratories. Both EPA and DOE have established criteria for evaluating the accuracy of results (Jarvis and Siu 1981; Sanderson 1985). These programs provided a regular means for accurate evaluation of results and for indications of where corrective actions were needed. Summaries of the 1987 UST results for both programs are provided in Tables 5.1 and 5.2. About 90% of the results during the year were within 3-sigma control limits. This level of performance was determined to be adequate to assess this concentration of radionuclides in the environment.

Surface Monitoring

In addition to DOE and EPA interlaboratory quality control and the laboratories' internal programs, a quality control program was maintained by PNL to

TABLE 5.1. U. S. Testing Laboratory Performance on DOE Quality Assessment Program Samples in 1987

Sample Media	Radionuclides	Samples Analyzed	Number Within Control Limits[a]
Air filters	^{7}Be, ^{54}Mn, ^{60}Co, ^{89}Sr, ^{90}Sr, ^{95}Zr, ^{106}Ru, ^{125}Sb, ^{137}Cs, ^{44}Ce, ^{234}U, ^{238}U, U(total), ^{239}Pu, ^{241}Am	25	21
Soil	^{40}K, ^{90}Sr, ^{137}Cs, ^{226}Ra, ^{234}U, ^{238}U, U(total), ^{239}Pu	12	11
Vegetation	^{40}K, ^{60}Co, ^{90}Sr, ^{137}Cs, ^{226}Ra, ^{239}Pu, ^{241}Am	10	10
Tissue	^{40}K, ^{90}Sr, ^{137}Cs, ^{226}Ra, ^{234}U, ^{238}U	10	8
Water	^{3}H, ^{54}Mn, ^{57}Co, ^{60}Co, ^{90}Sr, ^{137}Cs, ^{234}U, ^{238}U, U(total), ^{239}Pu, ^{241}Am	18	17

(a) Control limits from Sanderson (1985).

evaluate precision and accuracy and to conduct special intercomparisons as necessary. All data were reviewed by a computerized, anomalous data system that checked each entry against established limits.

To check the precision of sampling and analysis, replicate samples were routinely collected. The replicate data provided an estimate of the variability that can be expected from the sampling and analysis process. The summary of the total precision for surface samples above the minimum detectable concentration, based on replicate sampling, is shown in Table A.55, Appendix A, and Figure 5.1. The estimated precision (or reproducibility) of results in terms of coefficient of variation, was generally less than 20% for samples with activities greater than 2.5 times the minimum detectable amount (MDA).

Each month three pairs of dosimeters were exposed to known levels of radiation and processed with the routine environmental dosimeters. A summary of the 1987 results is shown in Figure 5.2. An average bias of approximately 1.7% was observed between the known and the measured exposures.

During 1987, PNL and WDSHS shared 20 environmental dosimeter locations. The locations were on and around the Hanford Site and around the U.S. Ecology site and the Supply System WNP-2 Plant. Pacific Northwest Laboratory and WDSHS dosimeters were put in place and collected at the same times. The results from the two organizations are shown in Table A.56, Appendix A, and Figure 5.3. The WDSHS results averaged 11% higher than the PNL results. Previous studies showed these results differed because of the different sensitivities of the two types of dosimeters. The environmental dosimeter in routine use at Hanford uses a very sensitive phosphor that is shielded to minimize the over-response to low-energy radiation. The PNL dosimeter did not respond to beta radiation or gamma radiation below 60 keV. The WDSHS dosimeter used an unshielded, less sensitive phosphor that over-responded somewhat to low-energy radiation.

TABLE 5.2. U. S. Testing Laboratory Performance on EPA Intercomparison Program Samples in 1987

Sample Media	Radionuclides	Samples Analyzed	Number Within Control Limits[a]
Water	Gross Alpha, Gross Beta ^{51}Cr, ^{65}Zn, ^{60}Co, ^{106}Ru, ^{131}I, ^{134}Cs, ^{137}Cs	42	35
Water	^{226}Ra, ^{228}Ra, ^{238}U, U(nat), ^{239}Pu	16	14
Water	^{89}Sr, ^{90}Sr	8	8
Water	^{3}H	3	3
Milk	^{89}Sr, ^{90}Sr, ^{131}I, ^{137}Cs	5	3
Food	^{89}Sr, ^{90}Sr, ^{131}I, ^{137}Cs	7	6
Air filters	Gross Alpha, Gross Beta, ^{90}Sr, ^{137}Cs	8	7

(a) Control limits from Jarvis and Siu (1981).

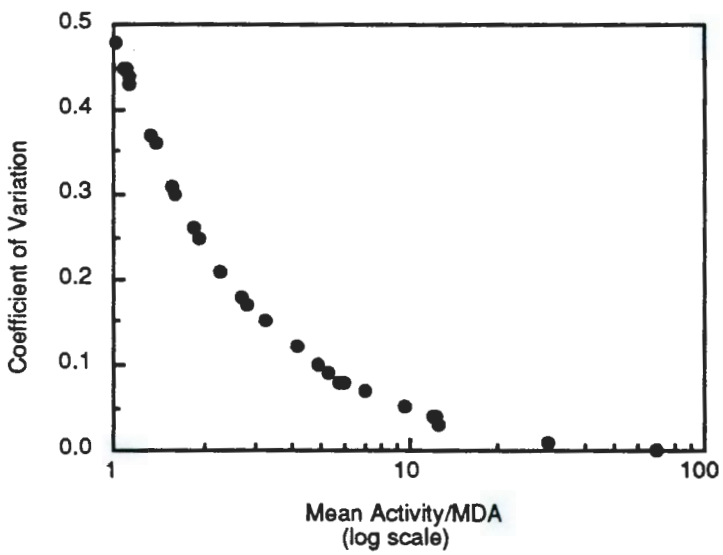

FIGURE 5.1. Relationship of Mean Sample Activity, System Minimum Detectable Amount, and Coefficient of Variation

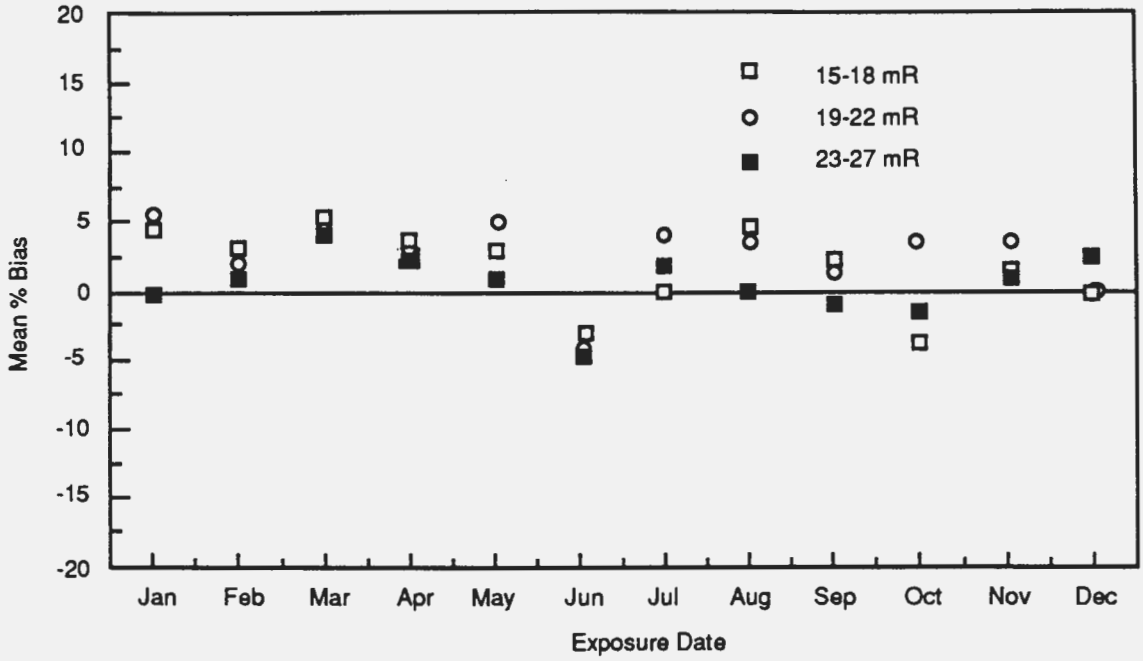

FIGURE 5.2. Comparison of Thermoluminescent Dosimeters Results with Known Exposures

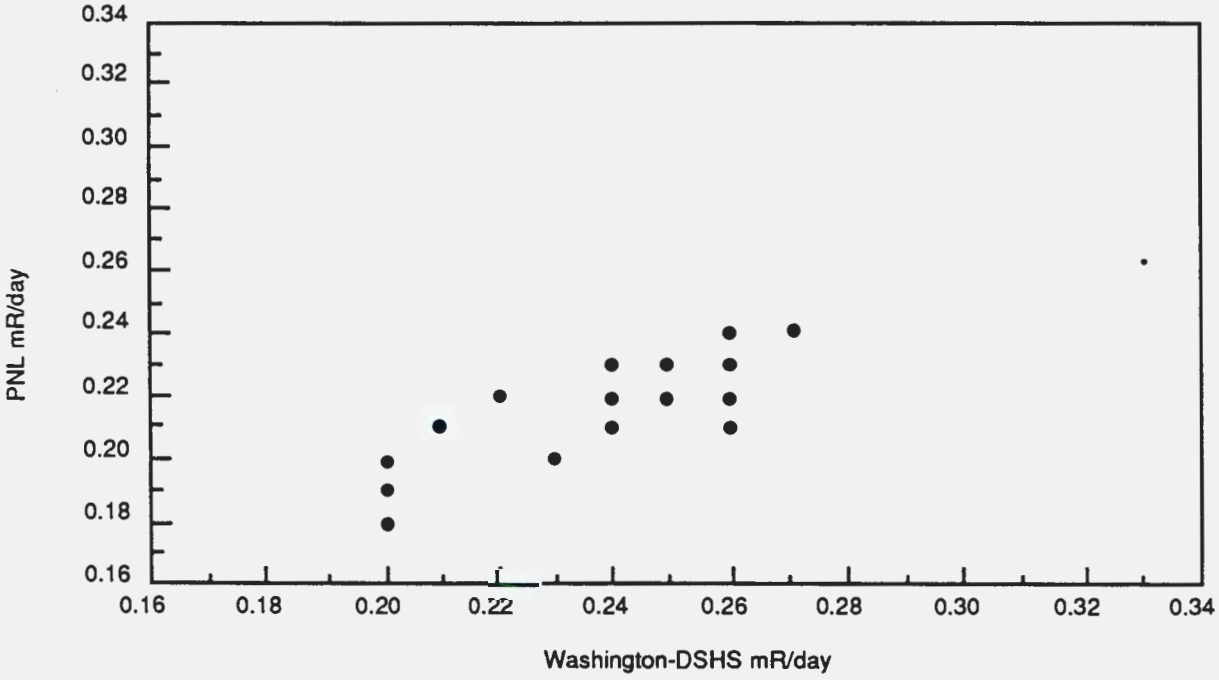

FIGURE 5.3. Comparison of Washington State Department of Social and Health Services and Pacific Northwest Laboratory's Environmental Exposure Rates

Again in 1986, there was a special quality assurance effort involving sampling of the Columbia River and adjacent springs. In July 1986, the states of Washington and Oregon, PNL (for the DOE), and Greenpeace Northwest conducted the joint sampling effort. The samples were shared among the participants. Results from Washington, Oregon, and PNL, which were not available for the 1986 environmental monitoring report, are shown in Table A.57, Appendix A. Results were not available from Greenpeace.

Radiological and Chemical Ground-Water Monitoring

The quality control effort for ground-water radiological and chemical monitoring includes routine internal checks performed by the laboratory contracted to perform the analyses (UST). Also, external checks were conducted by Washington State University (WSU) and PNL to evaluate laboratory performance. Internal checks for radiological, inorganic, and organic analyses included extensive use of analytical standards and check samples, blank samples, and matrix-spiked samples.

Washington State University was contracted to perform an independent review of the ground-water monitoring program. The review focused on three major aspects of the program: sample collection and handling, radiological and chemical analyses, and data handling and reporting. The evaluation was accomplished through onsite inspection of facilities, interviews with project personnel, observation of field sampling, and interlaboratory analysis of sample splits and blind samples.

It was concluded by WSU that the sample collection and analysis procedures used were appropriate for the constituents analyzed in the monitoring program. Their review showed that PNL and UST have adequate checks in place to control data errors during transcription and transmission. Interlaboratory analysis of split and blind samples showed good agreement between results obtained by WSU and UST. Both laboratories demonstrated acceptable accuracy for all ground-water constituents routinely tested in the program.

In PNL's quality control program, duplicate ground-water samples (a record sample and a blank sample) were collected by PNL and submitted to UST to assess the amount of variability that occurred in a single sampling event. A third set of samples (audit samples) was also collected during selected sampling events and submitted to PNL analytical laboratories to verify the results through facilities independent of UST.

Table A.58 presents the results of radiological and NO_3^- analyses of record, blind, and audit samples of PNL's external quality control program. Results are shown in the table when the measured concentration for a sample was greater than the counting error for the analytical method in two of the three measurements. In general, ^3H and NO_3^- showed very good agreement between field duplicates, with the ^3H coefficient of variation typically 10% or less and the NO_3^- coefficient of variation typically 1% or less. The audit samples for ^3H showed generally good agreement with only slightly more variability than the field duplicates. The field duplicates for other radioactive constituents were generally in good agreement as long as the counting errors were one-third or less of the analytical result. The coefficient of variance was typically higher for the audit sample.

Interlaboratory comparisons were also conducted for anions, volatile organics, and metals. Table A.59 summarizes data from well 199-H4-4, a 183-H Area well for which the most complete interlaboratory data set is available. The table shows comparisons between laboratories for selected metals, anions, and volatile constituents. Table A.60 summarizes data from replicate samples and interlaboratory comparisons during 1987. Samples analyzed during 1987 showed that results from UST for these constituents were also comparable to those from PNL laboratories. Blind standards for numerous organic and inorganic constituents were submitted quarterly to UST. In general, UST's performance was very good. Occasionally, results of the analyses caused UST to reevaluate methods or performance.

In addition, UST participated in performance evaluations sponsored by the EPA for both water supply (drinking water) and water pollution (waste water) samples. The EPA-sponsored evaluations covered a wide range of waterborne pollutants, including metals, ions, pesticides and herbicides, and various organic compounds. Performance by UST in these evaluations has been generally good. In 1987 UST qualified for the EPA Contract Laboratory Program for both inorganics and organics. The inorganic analyses included metals

and cyanide; the organic analyses included volatile and semivolatile organic compounds, pesticides, and polychlorinated biphenyls.

DOSE CALCULATIONS QUALITY ASSURANCE

Quality assurance on the radiation dose calculations was provided in several ways. First, comparisons were made against past calculated doses and significant differences were verified. Second, all computed doses were double-checked by the originator and by an independent third party who also checked all input data and assumptions used in the calculation. Dose codes were verified and approved by the Hanford Dose Overview Committee. Third, information necessary to perform all of the calculations was fully documented. (See "Dose Calculations ," Appendix F.)

REFERENCES

Comprehensive Environmental Response, Compensation, and Liability Act of 1980, Public Law 96-150, December 11, 1980, 94 Stat 2767, Title 26.

Corley, J. P., D. H. Denham, R. E. Jaquish, D. E. Michels, A. R. Olsen, and D. A. White. 1981. **A Guide for: Environmental Radiological Surveillance at U.S. Department of Energy Installations.** DOE/EP-0023, U.S. Department of Energy, Washington, D.C.

Dauble, D. D., R. M. Ecker, L. W. Vail, and D. A. Neitzel. 1987. **Downstream Extent of the N Reactor Plume.** PNL-6310, Pacific Northwest Laboratory, Richland, Washington.

DOE - See U.S. Department of Energy.

DSHS - See Washington State Department of Social and Health Services.

Eddy, P. A., D. A. Myers, and J. R. Raymond. 1978. **Vertical Contamination in the Unconfined Groundwater at the Hanford Site, Washington.** PNL-2724, Pacific Northwest Laboratory, Richland, Washington.

ERDA - See U.S. Energy Research and Development Administration.

EPA - See U.S. Environmental Protection Agency.

Evans, J. C., P. J. Mitchell, and D. I. Dennison. 1988. **Hanford Site Ground-Water Monitoring for April through June 1987.** PNL-6315-1, Pacific Northwest Laboratory, Richland, Washington.

Evans J. C., D. I. Dennison, R. W. Bryce, P. J. Mitchell, D. R. Sherwood, K. M. Krupka, N. W. Hinman, E. A. Jacobson, and M. D. Freshley. 1988. **Hanford Site Ground-Water Monitoring for July Through December 1987.** PNL-6315-2, Pacific Northwest Laboratory, Richland, Washington.

Feely, H. W., R. Larsen, and C. Sanderson. 1985. **Annual Report of the Surface Air Sampling Program.** EML-440, Environmental Measurements Laboratory, U.S. Department of Energy, New York.

Feely, H. W., R. Larsen, and C. Sanderson. 1988. **Annual Report of the Surface Air Sampling Program.** EML-497, Environmental Measurements Laboratory, U.S. Department of Energy, New York.

Fix, J. J. 1976. **Association of Long-Lived Radioactivity with Sediment Along the Columbia River Shoreline, Islands, Bottom and Slough Area.** BNWL-SA-5484. Pacific Northwest Laboratory, Richland, Washington.

Fix, J. J., and M. L. Miller. 1978. **The Hanford Environmental CaF_2:MN Thermoluminescent Dosimeter.** PNL-2489, Pacific Northwest Laboratory, Richland, Washington.

Freshley, M. D., and M. J. Graham. 1988. **Estimation of Ground-Water Travel Time at the Hanford Site: Description, Past Work, and Future Needs.** PNL-6328, Pacific Northwest Laboratory, Richland, Washington.

Gephart, R. E., P. A. Eddy, R. C. Arnett, and G. A. Robinson. 1976. **Geohydrologic Study of the West Lake Basin.** ARH-CD-775, Atlantic Richfield Hanford Company, Richland, Washington

Gephart, R. E., R. C. Arnett, R. G. Baca, L. S. Leonhart, and F. A. Spane, Jr. 1979. **Hydrologic Studies Within the Columbia Plateau, Washington: An Integration of Current Knowledge.** RHO-BWI-ST-5, Rockwell Hanford Operations, Richland, Washington.

Graham, M. J., G. V. Last, and K. R. Fecht. 1984. **An Assessment of Aquifer Intercommunication in the B Pond - Gable Mountain Pond Area of the Hanford Site.** RHO-RE-ST-12P, Rockwell Hanford Operations, Richland, Washington.

Graham, M. J., M. D. Hall, S. R. Strait, and W. R. Brown. 1981. **Hydrology of the Separations Area.** RHO-ST-42, Rockwell Hanford Operations, Richland, Washington.

Healy, J. W., B. V. Anderson, H. V. Clukey, and J. K. Soldat. 1958. "Radiation Exposure to People in the Environs of a Major Production Atomic Energy

Plant." In **Proceedings of the Second United Nations International Conference on the Peaceful Uses of Atomic Energy**. Vol. 18, pp. 309-318. United Nations, Geneva.

Heller, P. R., G. W. Gee, and D. A. Myers. 1985. **Moisture and Textural Variations in Unsaturated Soils/Sediments Near the Hanford Wye Barricade.** PNL-5377, Pacific Northwest Laboratory, Richland, Washington.

International Commission on Radiological Protection (ICRP). 1977. **Recommendations of the International Commission on Radiological Protection.** ICRP Publication 26, Annals of the ICRP, Vol. 1, No. 3, Pergamon Press, Elmsford, New York.

International Commission on Radiological Protection (ICRP). 1979-1982. **Limits for Intakes of Radionuclides by Workers.** ICRP Publication 30, Annals of the ICRP, Vol. 2, No. 3/4, through Vol. 8, No. 4, Pergamon Press, Elmsford, New York.

Jarvis, A. B., and L. Siu. 1981. **Environmental Radioactivity Laboratory Intercomparison Studies Program: Fiscal Year 1980-81**. EPA-600/4-81-004, U.S. Environmental Protection Agency, Las Vegas, Nevada.

Krey, P. W., E. P. Hardy, C. Pachuki, F. Rourke, J. Coluzza, and W. K. Benson. 1976. "Mass Isotopic Composition of Global Fall-Out Plutonium in Soils." In **Transuranic Nuclides in the Environment**. STI/PUB/410, International Atomic Energy Agency, Vienna.

McCormack, W. D., and J. M. V. Carlile. 1984. **Investigation of Ground-Water Seepage from the Hanford Shoreline of the Columbia River.** PNL-5289, Pacific Northwest Laboratory, Richland, Washington.

National Council on Radiation Protection and Measurements (NCRP). 1987. **Ionizing Radiation Exposure of the Population of the United States.** Report No. 93, NCRP, Bethesda, Maryland.

Newcomb, R. C., J. R. Strand, and F. J. Frank. 1972. "Geology and Ground-Water Characteristics of the Hanford Reservation of the U.S. Atomic Energy Commission, Washington." **U.S. Geological Survey Professional Paper 717**, U.S. Government Printing Office, Washington, D.C.

Pacific Northwest Laboratory (PNL). 1987. **Environmental Monitoring at Hanford for 1986.** PNL-6120, Pacific Northwest Laboratories, Richland, Washington.

Price, K. R. 1986. **Environmental Monitoring at Hanford for 1985.** PNL-5817, Pacific Northwest Laboratory, Richland, Washington.

Price, K. R., J. M. V. Carlile, R. L. Dirkes, R. E. Jaquish, M. S. Trevathan, and R. K. Woodruff. 1985. **Environmental Monitoring at Hanford for 1984.** PNL-5407, Pacific Northwest Laboratory, Richland, Washington.

Resource Conservation and Recovery Act of 1976. Public Law 94-580, October 21, 1976, 90 Stat. 2795, Title 42.

Rickard, W. H., and D. G. Watson. 1985. "Four Decades of Environmental Change and Their Influence Upon Native Wildlife and Fish on the Mid-Columbia River, Washington, USA." **Environmental Conservation**. 12:24-248.

Sanderson, C. G. March 1985. **Semi-Annual Report of the Department of Energy, Operational Safety, Health and Environment Division, Quality Assessment Program Data Report.** EML-439, Environmental Measurements Laboratory, U.S. Department of Energy, New York.

Schatz, A. L., J. J. Ammerman, and J. A. Serkowski. September 1987. **Hanford Site Water Table Map June 1987.** WHC-EP-0054, Westinghouse Hanford Company, Richland, Washington.

Serkowski, J. A., A. G. Law, J. L. Ammerman, and A. L. Schatz. 1988. **Results of Ground-Water Monitoring for Radionuclides in the Separations Area, 1987.** WHC-EP-0152, Westinghouse Hanford Company, Richland, Washington.

Soldat, J. K. 1962. **A Compilation of Basic Data Relating to the Columbia River Section 8 - Dispersion of Reactor Effluent in the Columbia River.** HW-69369, General Electric, Richland, Washington.

9 2 1 2 5 5 6 0 3 1 7

Soldat, J. K. 1976. "Radiation Doses from Iodine-129 in the Environment." **Health Physics**. Vol. 30, pp. 61-70.

Somers, S. R. 1988. **Hanford Sanitary Water Quality Surveillance, CY-1987.** HEHF-59, Hanford Environmental Health Foundation, Richland, Washington.

Snedecor, G. W., and W. G. Cochran. 1980. **Statistical Methods.** 7th ed., Iowa State University Press, Ames, Iowa.

Speer, D. R., J. J. Fix, and P. J. Blumer. 1976. **Environmental Surveillance at Hanford for CY-1975.** BNWL-1979, Pacific Northwest Laboratory, Richland, Washington.

Sula, M. J. 1980. **Radiological Survey of Exposed Shorelines and Islands of the Columbia River Between Vernita and the Snake River Confluence.** PNL-3127, Pacific Northwest Laboratory, Richland, Washington.

Superfund Amendments and Reauthorization Act of 1986, Public Law 99-499, October 17, 1986, 100 Stat 1613, Title 10.

Tallman, A. M., K. R. Fecht, M. C. Marratt, and G. V. Last. 1979. **Geology of the Separation Areas, Hanford Site, South-Central Washington.** RHO-ST-23, Rockwell Hanford Operations, Richland, Washington.

U.S. Department of Energy (DOE). 1981a. "Environmental Protection, Safety, and Health Protection Program for DOE Operations." **DOE Order 5480.1A,** Washington, D.C.

U.S. Department of Energy (DOE). 1981b. "Environmental Protection, Safety, and Health Protection Information Reporting Requirements." **DOE Order 5484.1**, Washington, D.C.

U.S. Department of Energy (DOE). 1986. **Draft Phase I Installation Assessment of Inactive Waste-Disposal Sites at Hanford. Vol I.** Prepared by the Pacific Northwest Laboratory for the U.S. Department of Energy, Richland, Washington.

U.S. Department of Energy (DOE). 1987a. **Final Environmental Impact Statement Disposal of Hanford Defense High-Level, Transuranic and Tank Wastes**. DOE/EIS-0113, DOE, Richland, Washington.

U.S. Department of Energy (DOE). 1987b. **Ground-Water Monitoring Compliance Projects for Hanford Site Facilities.** Vol. 1. PNL-6467, Prepared by the Pacific Northwest Laboratory for the U.S. Department of Energy, Richland, Washington.

U.S. Energy Research and Development Administration (ERDA). 1977. **Alternatives for Long-Term Management of Defense High-Level Radioactive Waste.** U.S. ERDA-77-44, Energy Research and Development Administration, Richland, Washington.

U.S. Environmental Protection Agency (EPA.) 1977. **TGS-ANSA Method for the Determination of Nitrogen Dioxide in the Atmosphere.** EPA Designated Equivalent Method No. EQN-1277-028, Environmental Monitoring and Support Laboratory, Research Triangle Park, North Carolina.

U.S. Environmental Protection Agency (EPA). 1982. **Test Methods for Evaluating Solid Waste: Physical/Chemical Methods**. 2nd ed., SW-846, Office of Solid Waste and Emergency Response, Washington, D.C.

U.S. Environmental Protection Agency (EPA). 1983. **National Emission Standard for Hazardous Air Pollutants; Standards for Radionuclides.** 40 CFR 61, U.S. Government Printing Office, Washington, D.C.

U.S. Environmental Protection Agency (EPA). 1986a. **Reference Method for the Determination of Suspended Particulate Matter in the Atmosphere (High-Volume Method)**. 40 CFR 50, Appendix B, U.S. Government Printing Office, Washington, D.C.

U.S. Environmental Protection Agency (EPA). 1986b. **Ground-Water Monitoring Technical Enforcement Guidance Document.** OWSER-9950.1, Washington, D.C.

U.S. Environmental Protection Agency (EPA) Quarterly Reports. 1982a-1987c. **Environmental Radiation Data.** Quarterly Reports 29-48, Office of Radiation Programs, Eastern Environmental Radiation Facility (EERF), Montgomery, Alabama.

9 2 1 2 5 5 6 0 3 1 8

U.S. Environmental Protection Agency (EPA). (Petko, C. M., H. M. Mardis, and L. Battist). 1982a. **Environmental Radiation Data.** Report 29, January-March 1982, EPA 520/5-5-83/005, Office of Radiation Programs, Washington, D.C.

U.S. Environmental Protection Agency (EPA). (Petko, C. M., H. M. Mardis, and L. Battist). 1982b. **Environmental Radiation Data.** Report 30, April-June 1982, EPA 520/5/6-83/006, Office of Radiation Programs, Washington, D.C.

U.S. Environmental Protection Agency (EPA). 1982c. **Environmental Radiation Data.** Report 31, July-September 1982, EPA 520/5-83-014, Office of Radiation Programs, Washington, D.C.

U.S. Environmental Protection Agency (EPA). 1983a. **Environmental Radiation Data.** Report 32, October-December 1982, EPA 520/5-83-015, Office of Radiation Programs, Washington, D.C.

U.S. Environmental Protection Agency (EPA). 1983b. **Environmental Radiation Data.** Report 33, January-March 1983, EPA 520/5-83-016, Office of Radiation Programs, Washington, D.C.

U.S. Environmental Protection Agency (EPA). (Petko, C. M., H. M. Mardis and L. Battist). 1983c. **Environmental Radiation Data.** Report 34, April-June 1983, EPA 520/5-83-028, Office of Radiation Programs, Eastern Environmental Radiation Facility (EERF), Montgomery, Alabama.

U.S. Environmental Protection Agency (EPA). 1983d. **Environmental Radiation Data.** Report 35, July-September 1983, EPA 520/1-84-004, Office of Radiation Programs, Eastern Environmental Radiation Facility (EERF), Montgomery, Alabama.

U.S. Environmental Protection Agency (EPA). 1984a. **Environmental Radiation Data.** Report 36, March 1984, EPA 520/5-84-013, Office of Radiation Programs, Eastern Environmental Radiation Facility (EERF), Montgomery, Alabama.

U.S. Environmental Protection Agency (EPA). 1984b. **Environmental Radiation Data.** Report 37, January-March 1984, EPA 520/5-84/019, Office of Radiation Programs, Eastern Environmental Radiation Facility (EERF), Montgomery, Alabama.

U.S. Environmental Protection Agency (EPA). (Petko, C.). 1984c. **Environmental Radiation Data.** Report 38, April-June 1984, EPA 520/5-84/029, Eastern Environmental Radiation Facility (EERF), Montgomery, Alabama.

U.S. Environmental Protection Agency (EPA). (Luster, G. A., J. W. Gunter, and C. M. Petko). 1984d. **Environmental Radiation Data.** Report 39, July-September 1984, EPA 520/5-85/009, Office of Radiation Programs, Eastern Environmental Radiation Facility (EERF), Montgomery, Alabama.

U.S. Environmental Protection Agency (EPA). (Gunter, J. W.). 1985a. **Environmental Radiation Data.** Report 40, October-December 1985, EPA 520/5-85/022, Eastern Environmental Radiation Facility (EERF), Montgomery, Alabama.

U.S. Environmental Protection Agency (EPA). (Petko, C. M., and C. R. Phillips). 1985b. **Environmental Radiation Data.** Report 41, January-March 1985, EPA 520/5-85/030, Eastern Environmental Radiation Facility (EERF), Montgomery, Alabama.

U.S. Environmental Protection Agency (EPA). 1985c. **Environmental Radiation Data.** Report 42, April-June 1985, EPA 520/5-85/031, Washington, D.C.

U.S. Environmental Protection Agency (EPA). 1985d. **Environmental Radiation Data.** Report 43, December 1985, EPA 520/5-86-007, Office of Radiation Programs, Eastern Environmental Radiation Facility (EERF), Montgomery, Alabama.

U.S. Environmental Protection Agency (EPA). 1986c. **Environmental Radiation Data.** Report 44-45, June 1986, EPA 520/5-86-018, Office of Radiation Programs, Eastern Environmental Radiation Facility (EERF), Montgomery, Alabama.

U.S. Environmental Protection Agency (EPA). 1986d. **Environmental Radiation Data.** Report 46 Revised Edition, September 1986, EPA 520/5-87-004, Office of Radiation Programs, Eastern Environmental Radiation Facility (EERF), Montgomery, Alabama.

U.S. Environmental Protection Agency (EPA). 1987a. **Environmental Radiation Data.** Report 47, June 1987, EPA 520/5-87-008, Office of Radiation Programs, Eastern Environmental Radiation Facility (EERF), Montgomery, Alabama.

U.S. Environmental Protection Agency (EPA). 1987b. **Environmental Radiation Data.** Report 48, June 1987, EPA 520/5-87-017, Office of Radiation Programs, Eastern Environmental Radiation Facility (EERF), Montgomery, Alabama.

U.S. Environmental Protection Agency (EPA 1987). **Environmental Radiation Data.** Report 49, January

1987 - March 1987, EPA 520/5-87-018, Office of Radiation Programs, Eastern Environmental Radiation Facility (EERF), Montgomery, Alabama.

U.S. Fish and Wildlife Service. 1986. **Endangered and Threatened Wildlife and Plants**. 50 CFR 17, U.S. Government Printing Office, Washington, D.C.

Washington State Department of Ecology (WDOE). 1982. **Water Quality Standards for Waters of the State of Washington.** Washington Administrative Code, Chapter 173-201, Olympia, Washington.

Washington State Department of Ecology (WDOE). 1986. **Air Pollution Standards: Suspended Particulates.** Washington Administrative Code, Chapter 18-40, Olympia, Washington.

Washington State Department of Social and Health Services (WDSHS). 1987. **Environmental Radiation Program, Twenty-Fourth Annual Report.** Office of Radiation Protection, Olympia, Washington.

Westinghouse Hanford Company (WHC). 1987. **Data Compilation: Iodine-129 in Hanford Groundwater.** WHC-EP-0037, WHC, Richland, Washington.

9 2 1 2 5 6 1 3 2 0

BIBLIOGRAPHY OF PREVIOUSLY ISSUED PNL ENVIRONMENTAL MONITORING REPORTS

Reports for the Offsite Environment

Sula, M. J., and P. J. Blumer. 1981. **Environmental Surveillance at Hanford for CY–1980**. PNL-3728, Pacific Northwest Laboratory, Richland, Washington.

Sula, M. J., W. D. McCormack, R. L. Dirkes, K. R. Price and P. A. Eddy. 1982. **Environmental Surveillance at Hanford for CY-1981**. PNL–4211, Pacific Northwest Laboratory, Richland, Washington.

Sula, M. J., J. M. V. Carlile, K. R. Price, and W. D. McCormack. 1983. **Environmental Surveillance at Hanford for CY-1982**. PNL–4657, Pacific Northwest Laboratory, Richland, Washington.

Price, K. R., J. M. V. Carlile, R. L. Dirkes, and M. S. Trevathan. 1984. **Environmental Surveillance at Hanford for CY-1983**. PNL–5038, Pacific Northwest Laboratory, Richland, Washington.

Price, K. R., and J. M. V. Carlile. 1985. **Environmental Monitoring at Hanford for 1984**. PNL-5407, Pacific Northwest Laboratory, Richland, Washington.

Reports for the Onsite Environment

Sula, M. J., P. J. Blumer, and R. L. Dirkes. 1981. **Environmental Status of the Hanford Site for CY–1980**. PNL-3729, Pacific Northwest Laboratory, Richland, Washington.

Sula, M. J., P. J. Blumer, and R. L. Dirkes. 1982. **Environmental Status of the Hanford Site for CY--1981**. PNL-4212, Pacific Northwest Laboratory, Richland, Washington.

Sula, M. J., P. J. Blumer, R. L. Dirkes, and J. M. V. Carlile. 1983. **Environmental Status of the Hanford Site for CY–1982**. PNL-4658, Pacific Northwest Laboratory, Richland, Washington.

Price, K. R., P. J. Blumer, J. M. V. Carlile, R. L. Dirkes, and M. S. Trevathan. 1984. **Environmental Status of the Hanford Site for CY–1983**. PNL-5039, Pacific Northwest Laboratory, Richland, Washington.

Reports for the Onsite Ground Water

Eddy, P. A., and J. S. Wilbur. 1981. **Radiological Status of the Ground Water Beneath the Hanford Site, January-December, 1980**. PNL-3768, Pacific Northwest Laboratory, Richland, Washington.

Eddy, P. A., C. S. Cline, and L. S. Prater. 1982. **Radiological Status of the Ground Water Beneath the Hanford Site, January-December, 1981**. PNL-4237, Pacific Northwest Laboratory, Richland, Washington.

Eddy, P. A., L. S. Prater, and J. T. Rieger. 1983. **Ground-Water Surveillance at the Hanford Site for CY–1982**. PNL-4659, Pacific Northwest Laboratory, Richland, Washington.

Prater, L. S., J. T. Rieger, C. S. Cline, E. J. Jensen, T. L. Liikala, and K. R. Oster. 1984. **Ground-Water Surveillance at the Hanford Site for CY–1983**. PNL-5041, Pacific Northwest Laboratory, Richland, Washington.

Cline, C. S., J. T. Rieger, and J. R. Raymond. 1985. **Ground-Water Monitoring at the Hanford Site, January-December 1984**. PNL-5408, Pacific Northwest Laboratory, Richland, Washington.

Combined Report

Price, K. R. 1986. **Environmental Monitoring at Hanford for 1985.** PNL-5817, Pacific Northwest Laboratory, Richland, Washington.

APPENDIX A

MONITORING RESULTS FOR 1987

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TABLE A.1. Air Sampling Locations and Sample Composite Groups

Composite Group	Sampling Location	Map Location[a]
ON SITE		
100 Area	100-K	1
	100-N	2
	100-D	3
	Fire Station	4
200-East Area	S of 200-East	5
	E of 200-East	6
	200-East SE	7
North of 200 Areas	Rt. 11A, Mi. 9	8
	N of 200-East	9
200-West Area	SW of BC Cribs	10
	Army Loop Camp	11
	GTE Building	12
300 Area	300 Pond	13
	ACRMS	14
	300-South Gate	15
400 Area	400-East	16
	400-West	17
	400-South	18
	400-North	19
Hanford Townsite	Hanford Townsite	20
Wye Barricade	Wye Barricade	21
PERIMETER		
Northeast Perimeter	Berg Ranch	22
	Sagehill	23
	Ringold	24
East Perimeter	Fir Road	25
	Petlett	26
Southeast Perimeter	Byers Landing	27
	RRC No. 64	28
Prosser Barricade	Horn Rapids Rd. Substation	29
	Prosser Barricade	30
ALE	ALE	31
West Perimeter	Rattlesnake Spring	32
	Yakima Barricade	33
Northwest Perimeter	Vernita Bridge	34
	Wahluke Slope No. 2	35
NEARBY COMMUNITIES		
Northeast Communities	Othello	36
	Connell	37
Tri-Cities	Pasco	38
	Richland	39
	Kennewick	40
Benton City	Benton City	41
	Prosser	42
Ellopia	Ellopia	43
Mattawa	Mattawa	44
DISTANT COMMUNITIES		
Outer Northeast	Moses Lake	45
	Washtucna	46
Outer Southeast	Walla Walla	47
	McNary Dam	48
Sunnyside	Sunnyside	49
Yakima	Yakima	50

(a) Locations are identified in Figure 3.1.

TABLE A.2. Gross Beta Concentrations in Air in the Hanford Environs for 1987

Station No.	Location[b]	No. of Samples	Gross Beta Concentrations,[a] pCi/m³ (10^{-12} µCi/mL) Maximum	Minimum	Mean
ON SITE					
1	100-K	26	0.070 ± 0.0054	0.011 ± 0.0012	0.026 ± 0.0055
2	100-N	24	0.056 ± 0.0051	0.012 ± 0.0012	0.026 ± 0.0049
3	100-D	26	0.060 ± 0.0053	0.011 ± 0.0012	0.025 ± 0.0049
4	100 Fire Station	26	0.061 ± 0.0053	0.009 ± 0.0040	0.025 ± 0.0050
5	S of 200-East	26	0.065 ± 0.0026	0.012 ± 0.0013	0.028 ± 0.0059
6	E of 200-East	26	0.067 ± 0.0026	0.012 ± 0.0013	0.027 ± 0.0056
7	200-East SE	26	0.076 ± 0.0028	0.012 ± 0.0043	0.027 ± 0.0059
8	Rt. 11A, Mi. 9	26	0.066 ± 0.0026	0.010 ± 0.0012	0.027 ± 0.0055
9	N of 200-East	26	0.084 ± 0.0089	0.012 ± 0.0013	0.028 ± 0.0068
10	SW of BC Cribs	26	0.070 ± 0.0026	0.001 ± 0.0012	0.026 ± 0.0059
11	Army Loop Camp	26	0.069 ± 0.0026	0.010 ± 0.0012	0.026 ± 0.0057
12	GTE Building	26	0.064 ± 0.0025	0.008 ± 0.0010	0.025 ± 0.0057
13	300 Pond	26	0.059 ± 0.0024	0.014 ± 0.0042	0.030 ± 0.0054
14	ACRMS	26	0.055 ± 0.0024	0.011 ± 0.0012	0.026 ± 0.0049
15	300-South Gate	26	0.059 ± 0.0053	0.012 ± 0.0012	0.028 ± 0.0056
16	400-East	26	0.059 ± 0.0053	0.012 ± 0.0013	0.027 ± 0.0053
17	400-West	25	0.058 ± 0.0024	0.012 ± 0.0013	0.026 ± 0.0053
18	400-South	26	0.059 ± 0.0024	0.013 ± 0.0013	0.027 ± 0.0053
19	400-North	26	0.062 ± 0.0024	0.011 ± 0.0012	0.027 ± 0.0060
20	Hanford Townsite	23	0.055 ± 0.0024	0.011 ± 0.0012	0.025 ± 0.0050
21	Wye Barricade	26	0.046 ± 0.0022	0.011 ± 0.0012	0.023 ± 0.0034
OVERALL AVERAGE					0.027 ± 0.0012
PERIMETER					
22	Berg Ranch	26	0.059 ± 0.0024	0.012 ± 0.0013	0.027 ± 0.0048
23	Sagehill	27	0.064 ± 0.0025	0.013 ± 0.0012	0.026 ± 0.0049
24	Ringold	27	0.059 ± 0.0024	0.012 ± 0.0012	0.028 ± 0.0049
25	Fir Road	25	0.053 ± 0.0023	0.008 ± 0.0042	0.025 ± 0.0045
26	Pettett	25	0.053 ± 0.0051	0.011 ± 0.0012	0.026 ± 0.0045
27	Byers Landing	24	0.051 ± 0.0051	0.010 ± 0.0041	0.024 ± 0.0041
28	RRC No. 64	26	0.054 ± 0.0023	0.010 ± 0.0011	0.026 ± 0.0050
29	Horn Rapids Substation	26	0.061 ± 0.0025	0.012 ± 0.0013	0.027 ± 0.0054
30	Prosser Barricade	25	0.077 ± 0.0034	0.011 ± 0.0042	0.029 ± 0.0069
31	ALE	26	0.050 ± 0.0023	0.011 ± 0.0012	0.023 ± 0.0042
32	Rattlesnake Springs	25	0.070 ± 0.0027	0.010 ± 0.0012	0.026 ± 0.0063
33	Yakima Barricade	26	0.063 ± 0.0025	0.011 ± 0.0012	0.026 ± 0.0055
34	Vernita Bridge	26	0.056 ± 0.0053	0.010 ± 0.0011	0.025 ± 0.0046
35	Wahluke Slope No. 2	24	0.057 ± 0.0052	0.012 ± 0.0012	0.025 ± 0.0048
OVERALL AVERAGE					0.026 ± 0.0013
NEARBY COMMUNITIES					
36	Othello	27	0.057 ± 0.0024	0.008 ± 0.0011	0.026 ± 0.0048
37	Connell	27	0.059 ± 0.0025	0.013 ± 0.0013	0.027 ± 0.0045
38	Pasco	25	0.054 ± 0.0052	0.013 ± 0.0012	0.026 ± 0.0044
39	Richland	26	0.076 ± 0.0149	0.009 ± 0.0011	0.028 ± 0.0062
40	Kennewick	26	0.048 ± 0.0050	0.007 ± 0.0040	0.023 ± 0.0040
41	Benton City	26	0.059 ± 0.0024	0.007 ± 0.0010	0.024 ± 0.0048
42	Prosser	26	0.053 ± 0.0063	0.007 ± 0.0010	0.023 ± 0.0043
43	Eltopia	27	0.066 ± 0.0025	0.012 ± 0.0012	0.027 ± 0.0054
44	Mattawa	26	0.063 ± 0.0053	0.007 ± 0.0010	0.022 ± 0.0046
OVERALL AVERAGE					0.025 ± 0.0016
DISTANT COMMUNITIES					
45	Moses Lake	26	0.050 ± 0.0023	0.008 ± 0.0014	0.026 ± 0.0042
46	Washtucna	26	0.052 ± 0.0051	0.012 ± 0.0013	0.026 ± 0.0038
47	Walla Walla	25	0.040 ± 0.0020	0.010 ± 0.0011	0.024 ± 0.0034
48	McNary Dam	26	0.052 ± 0.0051	0.010 ± 0.0012	0.026 ± 0.0042
49	Sunnyside	26	0.055 ± 0.0051	0.010 ± 0.0011	0.022 ± 0.0043
50	Yakima	26	0.034 ± 0.0019	0.005 ± 0.0009	0.017 ± 0.0030
OVERALL AVERAGE					0.024 ± 0.0016

(a) Maximum and minimum values ±2 sigma counting error. Averages ±2 standard error of the calculated mean.
(b) Locations are identified in Figure 3.1.

TABLE A.3. Gross Alpha Concentrations in Air in the Hanford Environs for 1987

Station No.	Location[b]	No. of Samples	Gross Beta Concentrations,[a] pCi/m³ (10^{-12} µCi/mL) Maximum	Minimum	Mean
ON SITE					
3	100-D	26	0.0021 ± 0.0007	0.0002 ± 0.0003	0.0009 ± 0.0002
5	S of 200-East	26	0.0017 ± 0.0006	0.0002 ± 0.0003	0.0009 ± 0.0002
6	E of 200-East	26	0.0018 ± 0.0006	0.0003 ± 0.0004	0.0009 ± 0.0002
7	200-East SE	26	0.0015 ± 0.0006	0.0005 ± 0.0004	0.0010 ± 0.0002
8	Rt 11A, Mi. 9	26	0.0017 ± 0.0006	0.0001 ± 0.0003	0.0009 ± 0.0002
9	N of 200-East	26	0.0025 ± 0.0009	0.0003 ± 0.0003	0.0010 ± 0.0002
10	SW of BC Cribs	26	0.0018 ± 0.0006	0.0004 ± 0.0004	0.0009 ± 0.0002
11	Army Loop Camp	26	0.0022 ± 0.0007	0.0003 ± 0.0004	0.0009 ± 0.0002
12	GTE Building	26	0.0017 ± 0.0005	0.0002 ± 0.0003	0.0008 ± 0.0002
13	300 Pond	26	0.0063 ± 0.0012	0.0003 ± 0.0004	0.0023 ± 0.0006
15	300-South Gate	26	0.0017 ± 0.0006	0.0003 ± 0.0004	0.0009 ± 0.0002
16	400-East	26	0.0020 ± 0.0006	0.0002 ± 0.0003	0.0009 ± 0.0002
17	400-West	25	0.0021 ± 0.0007	0.0003 ± 0.0004	0.0008 ± 0.0002
18	400-South	26	0.0022 ± 0.0007	0.0003 ± 0.0003	0.0009 ± 0.0002
19	400-North	26	0.0021 ± 0.0007	0.0003 ± 0.0004	0.0008 ± 0.0002
20	Hanford Townsite	23	0.0023 ± 0.0007	0.0003 ± 0.0003	0.0009 ± 0.0002
21	Wye Barricade	26	0.0019 ± 0.0007	0.0003 ± 0.0003	0.0008 ± 0.0002
OVERALL AVERAGE					0.0010 ± 0.0001
PERIMETER					
22	Berg Ranch	26	0.0022 ± 0.0007	0.0003 ± 0.0004	0.0008 ± 0.0002
23	Sagehill	27	0.0021 ± 0.0007	0.0005 ± 0.0004	0.0010 ± 0.0002
24	Ringold	27	0.0021 ± 0.0007	0.0003 ± 0.0003	0.0010 ± 0.0002
25	Fir Road	25	0.0018 ± 0.0006	0.0002 ± 0.0003	0.0009 ± 0.0002
26	Pettett	24	0.0015 ± 0.0006	0.0002 ± 0.0004	0.0008 ± 0.0002
27	Byers Landing	26	0.0019 ± 0.0007	0.0003 ± 0.0004	0.0008 ± 0.0002
28	RRC No. 64	26	0.0022 ± 0.0009	0.0003 ± 0.0003	0.0009 ± 0.0002
30	Prosser Barricade	26	0.0042 ± 0.0001	0.0003 ± 0.0003	0.0009 ± 0.0003
33	Yakima Barricade	26	0.0022 ± 0.0007	0.0002 ± 0.0004	0.0009 ± 0.0002
35	Wahluke Slope No. 2	24	0.0019 ± 0.0007	0.0006 ± 0.0003	0.0010 ± 0.0002
OVERALL AVERAGE					0.0009 ± 0.0001
NEARBY COMMUNITIES					
39	Richland	26	0.0035 ± 0.0016	0.0002 ± 0.0004	0.0010 ± 0.0003
41	Benton City	26	0.0020 ± 0.0007	0.0002 ± 0.0003	0.0009 ± 0.0002
OVERALL AVERAGE					0.0009 ± 0.0002
DISTANT COMMUNITIES					
49	Sunnyside	26	0.0015 ± 0.0006	0.0001 ± 0.0002	0.0008 ± 0.0002
50	Yakima	26	0.0014 ± 0.0005	0.0001 ± 0.0003	0.0006 ± 0.0002
OVERALL AVERAGE					0.0007 ± 0.0001

(a) Maximum and minimum values ±2 sigma counting error. Averages ±2 standard error of the calculated mean.
(b) Locations are identified in Figure 3.1.

TABLE A.4. Airborne Radionuclide Concentrations in the Hanford Environs for 1987

Radio-nuclide	Composite Group[b]	No. of Samples	Concentration pCi/m³[a] (10^{-12} µCi/mL) Maximum	Minimum	Average	Derived Concentration Guide, pCi/m³[c]
^{3}H	On Site	77	10.3 ± 1.3	-0.4 ± 0.8	2.1 ± 0.5	200,000
	Perimeter	104	10.9 ± 1.8	-1.2 ± 1.2	1.9 ± 0.4	
	Nearby Communities	14	5.0 ± 2.7	-2.1 ± 3.4	1.5 ± 1.1	
	Distant Communities	26	8.1 ± 2.4	-1.0 ± 1.1	2.2 ± 0.8	
^{14}C	On Site	13	1.5 ± 0.1	1.1 ± 0.2	1.3 ± 0.1	500,000
	Distant Communities	12	1.4 ± 0.1	1.2 ± 0.1	1.3 ± 0.1	
^{85}Kr	On Site	20	1600 ± 200	17 ± 9	220 ± 170	60,000
	Perimeter	36	130 ± 18	18 ± 9	34 ± 7	
	Nearby Communities	33	48 ± 9	17 ± 7	28 ± 3	
	Distant Communities	23	48 ± 11	16 ± 7	28 ± 4	
^{90}Sr	On Site	28	0.0005200 ± 0.0001100	0.0000018 ± 0.0000500	0.0000610 ± 0.0000370	9
	Perimeter	24	0.0001100 ± 0.0000530	-0.0000004 ± 0.0000370	0.0000410 ± 0.0000170	
	Nearby Communities	20	0.0004000 ± 0.0000850	-0.0000066 ± 0.0000460	0.0000590 ± 0.0000410	
	Distant Communities	16	0.0000940 ± 0.0000660	0.0000190 ± 0.0000520	0.0000540 ± 0.0000180	
^{106}Ru	On Site	84	0.008 ± 0.006	-0.012 ± 0.011	-0.001 ± 0.001	30
	Perimeter	72	0.016 ± 0.009	-0.024 ± 0.017	0.000 ± 0.002	
	Nearby Communities	60	0.013 ± 0.008	-0.024 ± 0.017	-0.002 ± 0.002	
	Distant Communities	48	0.015 ± 0.008	-0.024 ± 0.020	-0.001 ± 0.003	
^{129}I	On Site	4	0.00071000 ± 0.00005400	0.00016000 ± 0.00000970	0.00036000 ± 0.00027000	70
	Perimeter	8	0.00001500 ± 0.00000120	0.00000410 ± 0.00000031	0.00000880 ± 0.00000270	
	Distant Communities	4	0.00000082 ± 0.00000008	0.00000033 ± 0.00000004	0.00000053 ± 0.00000024	
^{131}I	On Site	180	0.0079 ± 0.0079	-0.0072 ± 0.0066	0.0002 ± 0.0006	400
	Perimeter	126	0.0049 ± 0.0048	-0.0010 ± 0.0082	-0.0002 ± 0.0008	
	Nearby Communities	26	0.0055 ± 0.0055	-0.0070 ± 0.0052	0.0005 ± 0.0017	
	Distant Communities	52	0.0063 ± 0.0063	-0.0075 ± 0.0061	-0.0007 ± 0.0011	
^{137}Cs	On Site	72	0.0009 ± 0.0005	-0.0021 ± 0.0015	0.0000 ± 0.0002	400
	Perimeter	72	0.0017 ± 0.0014	-0.0019 ± 0.0018	0.0002 ± 0.0002	
	Nearby Communities	60	0.0020 ± 0.0010	-0.0018 ± 0.0017	0.0002 ± 0.0002	
	Distant Communities	48	0.0022 ± 0.0011	-0.0019 ± 0.0017	0.0003 ± 0.0003	
U (total)	On Site	19	0.002000 ± 0.000070	0.000003 ± 0.000009	0.000290 ± 0.000260	0.1
	Perimeter	8	0.000490 ± 0.000031	0.000026 ± 0.000013	0.000150 ± 0.000120	
	Distant Communities	4	0.000071 ± 0.000011	0.000025 ± 0.000011	0.000047 ± 0.000023	
^{238}Pu	On Site	28	0.0000012 ± 0.0000010	-0.0000007 ± 0.0000009	0.0000002 ± 0.000000	0.03
	Perimeter	25	0.0000025 ± 0.0000022	-0.0000012 ± 0.0000015	0.0000003 ± 0.0000003	
	Nearby Communities	22	0.0000012 ± 0.0000015	-0.0000006 ± 0.0000009	0.0000001 ± 0.0000002	
	Distant Communities	16	0.0000032 ± 0.0000024	-0.0000018 ± 0.0000028	0.0000003 ± 0.0000007	
^{239}Pu	On Site	28	0.0000041 ± 0.0000029	-0.0000004 ± 0.0000009	0.0000010 ± 0.0000005	0.02
	Perimeter	25	0.0000033 ± 0.0000023	-0.0000004 ± 0.0000016	0.0000005 ± 0.0000004	
	Nearby Communities	22	0.0000015 ± 0.0000023	-0.0000005 ± 0.0000005	0.0000004 ± 0.0000003	
	Distant Communities	16	0.0000027 ± 0.0000043	-0.0000009 ± 0.0000011	0.0000003 ± 0.0000006	

(a) Maximum and minimum values ±2 sigma counting error. Averages ±2 standard errors of calculated mean. Entries have been rounded off.
(b) On Site, perimeter, nearby communities, and distant sampling locations are identified in Table A.1 and Figure 3.1.
(c) From draft DOE Derived Concentration Guide (See Appendix C).

TABLE A.5. Airborne Radionuclide Concentrations Near the 100 Areas in 1987

Radionuclide	Sampling Location[b]	No. of Samples	Concentration pCi/m³[a] (10^{-12} µCi/mL) Maximum	Minimum	Average	Average 1987 Distant[c]
^{3}H	100-N (2)	12	8.2 ± 2.5	0.0 ± 1.2	2.3 ± 1.4	2.2 ± 0.8
	100-D (3)	13	7.0 ± 1.2	-0.3 ± 1.0	1.5 ± 1.1	
^{90}Sr	Composite[d]	4	0.00007 ± 0.00003	0.00003 ± 0.00002	0.00004 ± 0.00002	0.00006 ± 0.00002
^{131}I	100-N (2)	26	0.005 ± 0.005	-0.004 ± 0.005	0.001 ± 0.001	-0.001 ± 0.001
	100-D (3)	26	0.004 ± 0.004	-0.007 ± 0.006	0.001 ± 0.001	
^{137}Cs	Composite	12	0.0009 ± 0.0005	-0.0001 ± 0.0005	0.0004 ± 0.0002	0.0003 ± 0.00031
U(total)	Composite	4	0.00018 ± 0.000017	0.000010 ± 0.000006	0.000069 ± 0.000085	0.000047 ± 0.000023
^{238}Pu	Composite	4	0.0000004 ± 0.0000007	0.0000002 ± 0.0000005	0.0000003 ± 0.0000003	0.0000003 ± 0.0000007
$^{239,240}Pu$	Composite	4	0.0000010 ± 0.0000010	0.0000003 ± 0.0000007	0.0000006 ± 0.0000006	0.0000003 ± 0.0000006
Gross Beta	100-K (1)	26	0.070 ± 0.005	0.011 ± 0.001	0.026 ± 0.005	
	100-N (2)	26	0.060 ± 0.005	0.011 ± 0.001	0.025 ± 0.005	
	100-D (3)	24	0.056 ± 0.005	0.012 ± 0.001	0.026 ± 0.005	
	Fire Station (4)	26	0.061 ± 0.005	0.009 ± 0.004	0.025 ± 0.005	
	Average				0.026 0.003	0.024 ± 0.0016
Gross Alpha	100-D (3)	26	0.0021 ± 0.0007	0.0002 ± 0.0003	0.0009 ± 0.0002	0.0007 0.0001

(a) Maximum and minimum values ±2 sigma counting error. Averages ±2 standard error of calculated mean. Entries have been rounded for clarity.
(b) Sample map location numbers are shown in parentheses. Sampling locations are identified in Table A.1 and Figure 3.1.
(c) Distant locations are identified in Table A.1 and Figure 3.1.
(d) Composites of biweekly samples from the individual sampling locations (1-4) in Table A.1.

TABLE A.6. Airborne Radionuclide Concentrations Near the 200-East Area in 1987

Radionuclide	Sampling Location[b]	No. of Samples	Concentration pCi/m³[a] (10^{-12} µCi/mL) Maximum	Minimum	Average	Average 1987 Distant[c]
^{3}H	200-East SE (7)	13	4.5 ± 1.2	-0.8 ± 0.8	2.4 ± 0.6	2.2 ± 0.8
^{14}C	200-East SE (7)	6	1.5 ± 0.1	1.1 ± 0.2	1.3 ± 0.1	1.3 ± 0.1
^{85}Kr	200-East SE (7)	10	1580 ± 200	17 ± 9	370 ± 300	28 ± 4
^{90}Sr	Composite[d]	4	0.00013 ± 0.00004	0.00002 ± 0.00003	0.00007 ± 0.00006	0.00006 ± 0.00002
^{106}Ru	Composite	12	0.004 ± 0.008	-0.008 ± 0.009	-0.001 ± 0.003	-0.001 ± 0.003
^{129}I	200-East SE (7)	4	0.00071 ± 0.00005	0.00016 ± 0.00001	0.00036 ± 0.00027	0.0000005 ± 0.0000002
^{131}I	S of 200-East (5)	26	0.0039 ± 0.0039	-0.0071 ± 0.0054	0.0005 ± 0.0016	
	E of 200-East (6)	26	0.0064 ± 0.0064	-0.0057 ± 0.0045	0.0005 ± 0.0013	
	200-East SE (7)	26	0.0079 ± 0.0079	-0.0054 ± 0.0055	0.0003 ± 0.0015	
	Average				0.0001 ± 0.0009	-0.0007 ± 0.0011
$^{Cs}137$	Composite	12	0.0008 ± 0.0005	-0.0011 ± 0.0009	-0.0001 ± 0.0004	0.0003 ± 0.0003
U(total)	Composite	4	0.000060 ± 0.000009	0.000015 ± 0.000008	0.000033 ± 0.000022	0.000047 ± 0.000023
^{238}Pu	Composite	4	0.0000014 ± 0.0000021	-0.0000002 ± 0.0000000	0.0000005 ± 0.0000010	0.0000003 ± 0.0000007
^{239}Pu	Composite	4	0.0000018 ± 0.0000014	0.0000003 ± 0.0000017	0.0000013 ± 0.0000012	0.0000003 ± 0.0000006
Gross Beta	S of 200-East (5)	26	0.065 ± 0.003	0.012 ± 0.001	0.028 ± 0.006	
	E of 200-East (6)	26	0.067 ± 0.003	0.012 ± 0.001	0.027 ± 0.006	
	200-East SE (7)	26	0.076 ± 0.003	0.012 ± 0.004	0.027 ± 0.006	
	Average				0.027 ± 0.003	0.024 ± 0.002
Gross Alpha	S of 200-East (5)	26	0.0017 ± 0.0006	0.0002 ± 0.0003	0.0009 ± 0.0002	
	E of 200-East (6)	26	0.0018 ± 0.0006	0.0003 ± 0.0004	0.0009 ± 0.0002	
	200-East SE (7)	26	0.0015 ± 0.0006	0.0005 ± 0.0004	0.0001 ± 0.0002	
	Average				0.0009 ± 0.0001	0.0007 ± 0.0001

(a) Maximum and minimum concentrations ±2 sigma counting error. Averages ±2 standard error of the calculated mean. Entries have been rounded for clarity.
(b) Sample map location numbers are shown in parentheses. Sampling locations are identified in Table A.1 and Figure 3.1.
(c) Distant locations are identified in Table A.1 and Figure 3.1.
(d) Composites of biweekly samples from the individual sampling locations (5-7) in Table A.1.

TABLE A.7. Airborne Radionuclide Concentrations Near the 200-West Area in 1987

Radionuclide	Sampling Location[b]	No. of Samples	Concentration, pCi/m³[a] (10^{-12} µCi/mL) Maximum	Minimum	Average	Average 1987 Distant[c]
^{3}H	GTE Bldg. (12)	13	7.6 ± 1.6	-0.4 ± 0.9	2.3 ± 1.2	2.2 ± 0.8
^{90}Sr	Composite[d]	4	0.00009 ± 0.00004	0.00001 ± 0.00004	0.00003 ± 0.00004	0.00006 ± 0.00002
^{106}Ru	Composite	12	0.0059 ± 0.0042	-0.0120 ± 0.0100	0.0002 ± 0.0032	-0.0009 ± 0.0026
^{137}Cs	Composite	12	0.0008 ± 0.0004	-0.0007 ± 0.0008	0.0001 ± 0.0003	0.0003 ± 0.0003
U(total)	Composite	4	0.000049 ± 0.000008	0.000012 ± 0.000008	0.000031 ± 0.000019	0.000047 ± 0.000023
^{238}Pu	Composite	4	0.0000011 ± 0.0000010	-0.0000007 ± 0.0000009	0.0000001 ± 0.0000010	0.0000003 ± 0.0000007
$^{239,240}Pu$	Composite	4	0.0000027 ± 0.0000016	0.0000006 ± 0.0000013	0.0000018 ± 0.0000013	0.0000003 ± 0.0000006
Gross Beta	SW of BC Crib (10)	26	0.070 ± 0.003	0.010 ± 0.001	0.026 ± 0.006	
	Army Loop Camp (11)	26	0.069 ± 0.003	0.010 ± 0.001	0.027 ± 0.006	
	GTE Bldg. (12)	26	0.064 ± 0.003	0.008 ± 0.001	0.025 ± 0.006	
	Average				0.026 ± 0.003	0.024 ± 0.002
Gross Alpha	SW of BC Cribs (10)	26	0.0018 ± 0.0006	0.0004 ± 0.0004	0.0009 ± 0.0002	
	Army Loop Camp (11)	26	0.0022 ± 0.0007	0.0003 ± 0.0004	0.0009 ± 0.0002	
	GTE Bldg. (12)	26	0.0017 ± 0.0005	0.0002 ± 0.0003	0.0008 ± 0.0002	
	Average				0.0009 ± 0.0001	0.0007 ± 0.0001

(a) Maximum and minimum concentrations ±2 sigma counting error. Averages ±2 standard error of the calculated mean. Entries have been rounded for clarity.
(b) Sample map location numbers are shown in parentheses. Sampling locations are identified in Table A.1 and Figure 3.1.
(c) Distant locations are identified in Table A.1 and Figure 3.1.
(d) Composites of biweekly samples from the individual sampling locations in Table A.1.

TABLE A.8. Airborne Radionuclide Concentrations North of the 200 Areas in 1987

Radionuclide	Sampling Location[b]	No. of Samples	Concentration, pCi/m³[a] (10^{-12} µCi/mL) Maximum	Minimum	Average	Average 1987 Distant[c]
^{90}Sr	Composite[d]	4	0.000091 ± 0.000051	0.000007 ± 0.000047	0.000053 ± 0.000100	0.000054 ± 0.000018
^{106}Ru	Composite	12	0.003 ± 0.009	-0.007 ± 0.013	-0.003 ± 0.004	-0.001 ± 0.003
^{137}Cs	Composite	12	0.0006 ± 0.0009	-0.0019 ± 0.0015	-0.0002 ± 0.0005	0.0003 ± 0.0003
^{238}Pu	Composite	4	0.00000028 ± 0.000000280.0000003 ± 0.0000007	0.00000079 -0.00000016 ±	0.00000000	-0.00000001 ±
$^{239,240}Pu$	Composite	4	0.0000041 ± 0.0000029	0.0000001 ± 0.0000010	0.0000012 ± 0.0000021	0.0000003 ± 0.0000008
Gross Beta	Rt. 11 A, Mi. 9 (8)	26	0.066 ± 0.003	0.010 ± 0.001	0.027 ± 0.005	
	N of 200-East (9)	26	0.084 ± 0.009	0.012 ± 0.001	0.028 ± 0.007	
	Average				0.028 ± 0.004	0.024 ± 0.002
Gross Alpha	Rt. 11 A, Mi. 9 (8)	26	0.0017 ± 0.0006	0.0001 ± 0.0003	0.0009 ± 0.0002	
	N of 200-East (9)	26	0.0025 ± 0.0009	0.0003 ± 0.0003	0.0010 ± 0.0002	
	Average				0.0009 ± 0.0001	0.0007 ± 0.0001

(a) Maximum and minimum concentrations ±2 sigma counting error. Averages ±2 standard error of the calculated mean. Entries have been rounded for clarity.
(b) Sample map location numbers are shown in parentheses. Sampling locations are identified in Table A.1 and Figure 3.1.
(c) Distant locations are identified in Table A.1 and Figure 3.1.
(d) Composites of biweekly samples from the individual sampling locations (8 and 9) in Table A.1.

TABLE A.9. Airborne Radionuclide Concentrations Near the 300 Area in 1987

Radionuclide	Sampling Location[b]	No. of Samples	Concentration pCi/m³[a] (10^{-12} µCi/mL) Maximum	Minimum	Average	Average 1987 Distant[c]
^{14}C	300 Pond (13)	6	1.4 ± 0.1	1.2 ± 0.2	1.3 ± 0.1	1.3 ± 0.1
^{85}Kr	300 Pond (13)	10	230 ± 31	20 ± 8	58 ± 44	28 ± 4
^{90}Sr	Composite(d)	4	0.00004 ± 0.00003	0.00001 ± 0.00002	0.00002 ± 0.00002	0.00005 ± 0.00002
^{131}I	300-South Gate (15)	26	0.0069 ± 0.0069	-0.0067 ± 0.0068	0.0002 ± 0.0016	-0.0007 ± 0.0011
^{137}Cs	Composite	12	0.0004 ± 0.0004	-0.0005 ± 0.0012	0.0001 ± 0.0003	0.0003 ± 0.0003
U(total)	Composite	4	0.00195 ± 0.00007	0.00025 ± 0.00002	0.00118 ± 0.00083	0.00005 ± 0.00002
^{238}Pu	Composite	4	0.0000012 ± 0.0000010	0.0000002 ± 0.0000006	0.0000007 ± 0.0000008	0.0000003 ± 0.0000007
$^{239,240}Pu$	Composite	4	0.0000037 ± 0.0000042	0.0000001 ± 0.0000005	0.0000014 ± 0.0000021	0.0000003 ± 0.0000006
Gross Beta	300 Pond (13)	26	0.059 ± 0.002	0.014 ± 0.004	0.030 ± 0.005	
	ACRMS (14)	26	0.055 ± 0.002	0.011 ± 0.001	0.026 ± 0.005	
	300-South Gate	26	0.059 ± 0.005	0.012 ± 0.001	0.028 ± 0.006	
	Average				0.026 ± 0.003	0.024 ± 0.002
Gross Alpha	300 Pond (13)	26	0.0063 ± 0.0012	0.0003 ± 0.0004	0.0023 ± 0.0006	
	300-South Gate (15)	26	0.0017 ± 0.0006	0.0003 ± 0.0004	0.0009 ± 0.0002	
	Average				0.0016 ± 0.0004	0.0007 ± 0.0001

(a) Maximum and minimum concentrations ±2 sigma counting error. Averages ±2 standard error of the calculated mean. Entries have been rounded for clarity.
(b) Sample map location numbers are shown in parentheses. Sampling locations are identified in Table A.1 and Figure 3.1.
(c) Distant locations are identified in Table A.1 and Figure 3.1.
(d) Composites of biweekly samples from the individual sampling locations (13-14) in Table A.1.

TABLE A.10. Airborne Radionuclide Concentrations Near the 400 Area in 1987

Radionuclide	Sampling Location[b]	No. of Samples	Concentration pCi/m³[a] (10^{-12} µCi/mL) Maximum	Minimum	Average	Average 1987 Distant[c]
^{3}H	400-East(16)	13	4.1 ± 1.5	0.3 ± 0.9	1.7 ± 0.8	2.2 ± 0.8
^{90}Sr	Composite[d]	4	0.001008 ± 0.00003	0.00001 ± 0.00002	0.00003 ± 0.00004	0.00005 ± 0.00002
^{131}I	400-East (16)	26	0.00560 ± 0.00560	-0.00720 ± 0.00860	0.00005 ± 0.00150	-0.00069 ± 0.00114
^{137}Cs	Composite	12	0.0008 ± 0.0005	-0.0006 ± 0.0006	0.00000 ± 0.0003	0.0003 ± 0.0003
^{238}Pu	Composite	4	0.0000000 ± 0.0000000	-0.0000003 ± 0.0000004	-0.0000001 ± 0.0000002	0.0000003 ± 0.0000007
$^{239,240}Pu$	Composite	4	0.0000010 ± 0.0000010	0.0000000 ± 0.0000005	0.0000004 ± 0.0000006	0.0000003 ± 0.0000006
Gross Beta	400-East (16)	26	0.059 ± 0.005	0.012 ± 0.001	0.027 ± 0.005	
	400-West (17)	25	0.058 ± 0.002	0.012 ± 0.001	0.026 ± 0.005	
	400-South (18)	26	0.059 ± 0.002	0.013 ± 0.001	0.027 ± 0.005	
	400-North (19)	26	0.062 ± 0.002	0.011 ± 0.001	0.027 ± 0.006	
	Average				0.027 ± 0.003	0.024 ± 0.002
Gross Alpha	400-East (16)	26	0.0020 ± 0.0006	0.0002 ± 0.0003	0.0009 ± 0.0002	
	400-West (17)	25	0.0021 ± 0.0007	0.0003 ± 0.0004	0.0008 ± 0.0002	
	400-South (18)	26	0.0022 ± 0.0007	0.0003 ± 0.0003	0.0009 ± 0.0002	
	400-North (19)	26	0.0021 ± 0.0007	0.0003 ± 0.0004	0.0008 ± 0.0002	
	Average				0.0009 ± 0.0001	0.0007 ± 0.0001

(a) Maximum and minimum concentrations ±2 sigma counting error. Averages ±2 standard error of the calculated mean.
(b) Sample map location numbers are shown in parentheses. Sampling locations are identified in Table A.1 and Figure 3.1.
(c) Distant locations are identified in Table A.1 and Figure 3.1.
(d) Composites of biweekly samples from the individual sampling locations (16-19) in Table A.1.

TABLE A.11. Airborne Radionuclide Concentrations in the 600 Area in 1987

Radionuclide	Sampling Location[b]	No. of Samples	Concentration pCi/m³[a] (10^{-12} Ci/mL) Maximum	Minimum	Average	Average 1987 Distant[c]
^{90}Sr	Wye Barricade (21)	4	0.000520 ± 0.000110	0.000002 ± 0.000050	0.000170 ± 0.000250	0.000054 ± 0.000018
^{137}Cs	Wye Barricade (21)	12	0.0010 ± 0.0010	-0.0021 ± 0.0015	-0.0001 ± 0.0006	0.0003 ± 0.0003
^{238}Pu	Wye Barricade (21)	4	0.0000003 ± 0.0000009	-0.0000002 ± 0.0000011	-0.0000000 ± 0.0000003	0.0000003 ± 0.0000007
^{239}Pu	Wye Barricade(21)	4	0.0000011 ± 0.0000015	-0.0000004 ± 0.0000009	0.0000003 ± 0.0000010	0.0000003 ± 0.0000006
Gross Beta	Hanford Townsite (20)	23	0.055 ± 0.002	0.011 ± 0.001	0.025 ± 0.005	
	Wye Barricade (21)	26	0.046 ± 0.002	0.011 ± 0.001	0.023 ± 0.003	
	Average				0.024 ± 0.003	0.024 ± 0.002
Gross Alpha	Hanford Townsite (20)	23	0.0023 ± 0.0007	0.0003 ± 0.0003	0.0009 ± 0.0002	
	Wye Barricade (21)	26	0.0019 ± 0.0007	0.0003 ± 0.0003	0.0008 ± 0.0002	
	Average				0.0009 0.0001	0.0007 ± 0.0001

(a) Maximum and minimum concentrations ±2 sigma counting error. Averages ±2 standard error of the calculated mean. Entries have been rounded for clarity.
(b) Sample map location numbers are shown in parentheses. Sampling locations are identified in Table A.1 and Figure 3.1.
(c) Distant locations are identified in Table A.1 and Figure 3.1.

TABLE A.12. Ambient Nitrogen Dioxide (NO_2) Concentrations in the Hanford Environs for 1987

Location	Map Location[a]	Number of 24-h Samples	Annual Average (ppm NO_2)	% Samples Less Than Detection Limit (0.003 ppm NO_2)	Maximum 24-h Sample (ppm NO_2)
ALE	1	192	<0.007 ± 0.006	7.8	0.020
100-B	3	240	<0.006 ± 0.005	9.2	0.018
100-D	4	198	<0.008 ± 0.012	9.1	0.031
Old Hanford Townsite	5	120	<0.004 ± 0.005	25.8	0.015
200-West	2	252	<0.006 ± 0.005	11.1	0.016
Wye Barricade	7	168	<0.008 ± 0.007	4.8	0.020
400 Area	8	234	<0.005 ± 0.006	27.4	0.014
Sullivan Barn	9	114	<0.007 ± 0.007	8.8	0.021
Army Barracks	6	204	<0.006 ± 0.005	7.8	0.013

(a) Locations are identified in Figure 3.2.
(b) Annual averages ± 2 standard error of the mean. Samples less than detectable daily concentrations were assumed equal to the 24-h detection limit (0.003 ppm).

9 2 1 2 5 5 6 0 3 3 0

TABLE A.13. Maximum, Minimum, and Average Tritium (^3H) Concentrations in Ground-Water Samples in 1987

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum		Minimum		Average	
1-B3-1	5	3,630 ±	298	2,560 ±	320	2,930 ±	434
1-B4-1	4	75,500 ±	1,040	8,690 ±	394	35,800 ±	32,500
1-B4-2	4	4,180 ±	311	2,590 ±	228	3,300 ±	786
1-B4-3	4	69,100 ±	1,000	5,060 ±	331	31,600 ±	31,100
1-B4-4	4	2,300 ±	272	1,480 ±	308	1,860 ±	423
1-B5-1	5	1,620 ±	255	1,030 ±	298	1,330 ±	255
1-B9-1	4	1,770 ±	259	1,250 ±	300	1,500 ±	287
1-D2-5	4	32,400 ±	701	6,980 ±	412	22,400 ±	12,400
1-D5-12	4	9,250 ±	453	5,200 ±	290	7,090 ±	1,980
1-D8-3	4	4,700 ±	375	4,130 ±	270	4,410 ±	323
1-F5-1	4	641 ±	177	42 ±	206	353 ±	314
1-F5-3	5	1,310 ±	291	199 ±	211	518 ±	442
1-F5-4	4	23,700 ±	627	16,200 ±	519	18,500 ±	3,660
1-F5-6	4	1,660 ±	298	602 ±	225	1,090 ±	530
1-F7-1	4	964 ±	282	333 ±	216	647 ±	331
1-F8-1	12	30,200 ±	695	10,000 ±	428	16,700 ±	3,680
1-F8-2	11	3,900 ±	347	2,200 ±	319	2,860 ±	363
1-H3-1	4	6,170 ±	300	4,570 ±	270	5,670 ±	797
1-H4-3	4	1,920 ±	212	689 ±	290	1,490 ±	612
1-H4-4	4	1,560 ±	205	915 ±	282	1,110 ±	337
1-H4-5	4	1,690 ±	257	637 ±	289	1,190 ±	529
1-H4-6	4	5,470 ±	346	3,770 ±	356	4,340 ±	843
1-K-11	4	2,380 ±	327	515 ±	222	1,530 ±	916
1-K-19	12	9,850 ±	456	2,500 ±	272	6,360 ±	1,220
1-K-20	4	1,210 ±	300	885 ±	185	1,000 ±	204
1-K-22	11	2,240 ±	322	552 ±	176	915 ±	301
1-K-27	4	1,910 ±	318	1,350 ±	206	1,650 ±	305
1-K-28	4	5,210 ±	379	2,980 ±	288	4,170 ±	1,100
1-K-29	4	16,000 ±	534	6,960 ±	373	11,000 ±	4,400
1-K-30	4	1,300,000 ±	4,300	596,000 ±	2,860	815,000 ±	342,000
1-N-2	3	89,900 ±	1,150	61,800 ±	954	74,200 ±	19,200
1-N-3	3	60,300 ±	949	54,200 ±	772	56,800 ±	4,190
1-N-4	3	130,000 ±	1,370	102,000 ±	1,050	114,000 ±	19,100
1-N-5	3	63,300 ±	831	50,700 ±	867	57,400 ±	8,610
1-N-7	1	164,000 ±	1,310			164,000 ±	---
1-N-14	4	123,000 ±	1,330	93,400 ±	996	113,000 ±	14,400
1-N-15	4	78,100 ±	1,070	39,400 ±	764	55,900 ±	18,800
1-N-16	3	300 ±	272	46 ±	162	202 ±	214
1-N-18	4	33,200 ±	711	4,290 ±	297	24,600 ±	14,100
1-N-19	4	15,300 ±	444	5,780 ±	346	9,320 ±	4,630
1-N-20	4	11,300 ±	399	3,150 ±	291	5,450 ±	3,960
1-N-21	12	5,040 ±	310	1,450 ±	262	2,760 ±	769

9 2 1 2 5 5 6 0 3 3 1

TABLE A.13. (contd)

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum		Minimum		Average	
1-N-22	4	4,060 ±	293	604 ±	216	1,650 ±	1,680
1-N-23	12	8,200 ±	336	1,170 ±	310	4,330 ±	1,670
1-N-24	3	434 ±	212	195 ±	167	296 ±	200
1-N-25	4	284 ±	170	249 ±	271	272 ±	111
1-N-27	3	127,000 ±	1,160	83,300 ±	1,100	108,000 ±	29,800
1-N-28	4	182,000 ±	1,600	92,700 ±	1,000	125,000 ±	43,400
1-N-29	4	115,000 ±	1,110	62,200 ±	956	94,100 ±	25,700
1-N-30	4	189,000 ±	1,630	107,000 ±	1,240	140,000 ±	39,900
1-N-31	3	141,000 ±	1,420	57,100 ±	925	105,000 ±	57,300
1-N-32	4	215,000 ±	1,770	87,700 ±	1,130	148,000 ±	61,900
1-N-33	10	218,000 ±	1,780	84,000 ±	1,100	156,000 ±	35,800
1-N-36	4	158,000 ±	1,510	86,600 ±	1,140	129,000 ±	34,700
1-N-37	3	215,000 ±	1,770	73,400 ±	1,060	156,000 ±	96,600
1-N-39	4	249,000 ±	1,610	122,000 ±	1,300	165,000 ±	61,700
1-N-45	4	148,000 ±	1,250	79,300 ±	1,070	108,000 ±	33,400
1-N-49	3	197,000 ±	1,670	117,000 ±	1,310	166,000 ±	54,600
1-N-50	3	121,000 ±	1,320	81,100 ±	1,090	99,200 ±	27,200
1-N-51	3	79,200 ±	1,070	59,400 ±	942	69,900 ±	13,500
1-N-52	3	120,000 ±	1,310	88,800 ±	983	103,000 ±	21,300
2-E13-5	4	76 ±	267	-158 ±	162	-38 ±	162
2-E13-8	2	203 ±	223	55 ±	169	129 ±	232
2-E13-14	2	291 ±	225	210 ±	173	251 ±	174
2-E13-19	2	183 ±	222	-65 ±	165	59 ±	340
2-E16-2	12	8,450 ±	345	1,810 ±	251	4,460 ±	1,260
2-E17-1	12	9,270,000 ±	22,400	6,840,000 ±	9,410	8,020,000 ±	455,000
2-E17-2	10	170,000 ±	1,540	39,300 ±	1,910	71,900 ±	25,100
2-E17-5	12	5,390,000 ±	19,500	3,890,000 ±	16,500	4,320,000 ±	227,000
2-E17-6	5	126,000 ±	1,360	104 ±	209	34,200 ±	48,400
2-E17-8	11	8,290,000 ±	24,300	4,520,000 ±	15,700	6,660,000 ±	629,000
2-E17-9	12	6,290,000 ±	21,100	3,610,000 ±	14,000	5,100,000 ±	519,000
2-E17-12	12	3,090,000 ±	14,600	254,000 ±	4,410	1,660,000 ±	521,000
2-E17-13	12	3,630,000 ±	14,000	1,140,000 ±	3,990	2,370,000 ±	435,000
2-E19-1	2	65 ±	196	50 ±	222	57 ±	149
2-E23-1	2	11,900 ±	452	10,500 ±	396	11,200 ±	1,780
2-E23-2	2	33,500 ±	1,830	25,900 ±	665	29,700 ±	9,570
2-E24-1	12	11,300,000 ±	28,300	5,890,000 ±	9,150	8,470,000 ±	945,000
2-E24-2	7	4,850,000 ±	18,600	3,830,000 ±	16,100	4,190,000 ±	285,000
2-E24-4	12	37,500 ±	764	9,910 ±	1,280	15,100 ±	4,570
2-E24-7	3	67,600 ±	988	10,300 ±	393	29,500 ±	39,100
2-E24-8	12	8,690 ±	408	4,630 ±	370	6,430 ±	858
2-E24-11	4	13,900,000 ±	31,400	6,270,000 ±	20,800	9,070,000 ±	3,710,000
2-E24-12	12	2,490,000 ±	5,950	330,000 ±	2,170	1,270,000 ±	320,000
2-E24-13	2	22,200 ±	621	8,430 ±	395	15,300 ±	17,300
2-E25-2	3	8,660 ±	1,290	7,190 ±	374	7,840 ±	1,100
2-E25-3	2	6,220 ±	334	3,110 ±	288	4,670 ±	3,900
2-E25-6	12	152,000 ±	1,480	4,380 ±	322	22,700 ±	24,20

9 2 1 2 5 5 6 0 3 3 2

TABLE A.13. (contd)

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum		Minimum		Average	
2-E25-7	1	5,810 ±	340			5,810 ±	---
2-E25-9	11	4,320 ±	367	2,360 ±	273	3,360 ±	350
2-E25-11	12	602,000 ±	2,930	293,000 ±	2,020	421,000 ±	58,700
2-E25-17	12	502,000 ±	5,290	179,000 ±	1,600	364,000 ±	60,500
2-E25-18	12	312,000 ±	4,840	67,000 ±	996	171,000 ±	54,100
2-E25-19	12	6,830,000 ±	19,000	423,000 ±	2,470	3,970,000 ±	1,450,000
2-E25-20	12	858,000 ±	3,500	286,000 ±	2,020	608,000 ±	103,000
2-E25-21	11	9,090 ±	408	2,450 ±	327	4,720 ±	1,050
2-E25-22	10	13,400 ±	479	4,670 ±	251	6,940 ±	1,880
2-E25-23	8	1,590 ±	308	171 ±	204	609 ±	361
2-E25-24	8	3,150 ±	345	490 ±	220	1,060 ±	665
2-E25-25	3	433 ±	276	408 ±	209	418 ±	130
2-E25-26	3	1,940 ±	253	1,640 ±	304	1,800 ±	253
2-E25-27	3	9,670 ±	415	3,350 ±	340	7,510 ±	4,320
2-E25-28	3	2,610 ±	325	1,770 ±	250	2,240 ±	594
2-E26-1	3	17,200 ±	528	10,300 ±	394	14,700 ±	4,720
2-E26-2	4	3,400 ±	329	2,340 ±	221	2,760 ±	534
2-E26-3	3	3,390 ±	288	3,320 ±	284	3,350 ±	173
2-E26-4	4	67,400 ±	2,150	36,800 ±	744	49,000 ±	14,900
2-E26-6	4	3,640 ±	252	135 ±	202	1,380 ±	1,710
2-E26-8[c]	2	180 ±	251	21 ±	199	100 ±	256
2-E27-1	2	2,090 ±	264	1,900 ±	262	2,000 ±	302
2-E27-5	2	3,450 ±	293	3,030 ±	351	3,240 ±	574
2-E28-1	2	7,170 ±	375	4,680 ±	380	5,930 ±	3,130
2-E28-5	2	2,630 ±	275	2,540 ±	274	2,590 ±	224
2-E28-7	3	4,930 ±	279	3,990 ±	299	4,610 ±	663
2-E28-12	12	390,000 ±	4,630	70,200 ±	1,020	145,000 ±	47,200
2-E28-13	5	8,980 ±	411	5,300 ±	340	6,700 ±	1,420
2-E28-17	1	7,800 ±	329			7,800 ±	---
2-E28-18	11	11,900 ±	459	5,130 ±	372	7,980 ±	1,310
2-E28-21	12	9,590 ±	424	4,800 ±	370	6,850 ±	983
2-E28-23	4	7,430 ±	405	5,530 ±	350	6,290 ±	941
2-E32-1	2	7,560 ±	330	6,040 ±	406	6,800 ±	1,920
2-E33-1	2	1,650 ±	213	571 ±	301	1,110 ±	1,360
2-E33-2	1	608 ±	178			608 ±	---
2-E33-3	4	1,690 ±	250	309 ±	286	919 ±	683
2-E33-5	2	2,480 ±	270	827 ±	305	1,650 ±	2,080
2-E33-7	2	8,310 ±	344	4,290 ±	305	6,300 ±	5,040
2-E33-8	2	4,560 ±	278	1,890 ±	329	3,230 ±	3,350
2-E33-9	4	3,820 ±	255	1,620 ±	288	2,490 ±	1,080
2-E33-10	4	4,380 ±	269	3,040 ±	246	3,510 ±	669
2-E33-12[c]	2	492 ±	259	385 ±	212	439 ±	214
2-E33-14	2	525 ±	216	374 ±	226	450 ±	245
2-E33-18	2	1,910 ±	220	467 ±	232	1,190 ±	1,820
2-E33-20	2	2,280 ±	268	280 ±	224	1,280 ±	2,510
2-E33-21	2	4,790 ±	386	3,770 ±	301	4,280 ±	1,300
2-E33-24	2	17,600 ±	535	12,800 ±	511	15,200 ±	6,030
2-E34-1	12	11,300 ±	441	254 ±	271	1,660 ±	1,770

9 2 1 2 5 5 6 0 3 3 3 3

TABLE A.13. (contd)

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum		Minimum		Average	
2-W6-1	3	52,300 ±	866	43,200 ±	698	49,100 ±	6,230
2-W10-1	2	57,700 ±	918	48,900 ±	741	53,300 ±	11,000
2-W10-3	2	122,000 ±	1,340	120,000 ±	1,310	121,000 ±	2,680
2-W10-4	2	111,000 ±	1,090	96,700 ±	1,160	104,000 ±	17,900
2-W10-5	2	10,200 ±	426	8,580 ±	367	9,390 ±	2,050
2-W10-8	2	10,700 ±	393	3,750 ±	261	7,230 ±	8,710
2-W10-9	2	70,900 ±	882	70,800 ±	885	70,900 ±	637
2-W11-3	1	443 ±	209			443 ±	---
2-W11-9	2	1,370 ±	242	911 ±	225	1,140 ±	598
2-W12-1	3	5,520 ±	338	4,010 ±	292	4,750 ±	1,050
2-W14-2	3	116,000 ±	3,150	86,800 ±	1,120	101,000 ±	20,000
2-W14-5	4	16,700 ±	1,740	6,210 ±	360	9,650 ±	5,140
2-W14-6	4	53,700 ±	772	16,500 ±	516	32,700 ±	18,100
2-W14-10	11	2,410 ±	328	248 ±	170	1,480 ±	414
2-W15-2	2	1,570 ±	245	657 ±	188	1,110 ±	1,150
2-W15-4	4	261,000 ±	3,950	164,000 ±	1,310	220,000 ±	47,200
2-W15-6	2	224 ±	202	-69 ±	220	78 ±	396
2-W15-7	1	800 ±	231			800 ±	---
2-W15-10	2	20,300 ±	505	10,700 ±	377	15,500 ±	12,000
2-W15-11	2	7,100 ±	371	761 ±	230	3,930 ±	7,950
2-W18-3	2	668 ±	228	38 ±	195	353 ±	804
2-W18-7	1	299 ±	273			299 ±	---
2-W18-15	12	335 ±	210	-49 ±	277	141 ±	91
2-W18-17	4	763 ±	224	87 ±	214	344 ±	343
2-W18-18	4	233 ±	211	-79 ±	276	78 ±	199
2-W18-20	4	1,690 ±	206	13 ±	158	540 ±	821
2-W19-1	1	222 ±	196			222 ±	---
2-W19-2	4	129,000 ±	2,870	69,900 ±	2,560	108,000 ±	28,700
2-W19-3	12	1,990 ±	315	921 ±	187	1,410 ±	207
2-W19-5	4	643 ±	227	172 ±	193	404 ±	252
2-W19-9	2	1,020 ±	193	724 ±	219	872 ±	399
2-W19-11	12	1,710 ±	255	282 ±	169	1,120 ±	233
2-W19-12	4	288 ±	167	86 ±	198	179 ±	146
2-W19-13	12	728 ±	287	-125 ±	199	217 ±	135
2-W19-14	7	305 ±	168	-36 ±	194	101 ±	123
2-W19-15	2	1,190 ±	199	811 ±	221	1,000 ±	498
2-W19-16	2	856 ±	192	323 ±	204	590 ±	682
2-W19-19	10	3,570 ±	1,130	1,190 ±	307	1,670 ±	454
2-W19-20	12	1,850 ±	259	818 ±	1,360	1,460 ±	207
2-W19-21	6	309 ±	209	-97 ±	200	121 ±	160
2-W19-23	8	1,230 ±	296	847 ±	229	1,040 ±	125
2-W19-24	5	2,300 ±	259	1,780 ±	253	1,980 ±	233
2-W19-25	8	2,500 ±	228	1,470 ±	237	1,710 ±	270
2-W19-26	6	1,510 ±	237	1,300 ±	297	1,380 ±	119
2-W19-27	6	241 ±	204	15 ±	158	123 ±	106
2-W21-1	2	118,000 ±	1,130	115,000 ±	1,300	117,000 ±	3,860

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TABLE A.13. (contd)

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum		Minimum		Average	
2-W22-1	1	240 ±	217			240 ±	---
2-W22-2	1	4,390 ±	300			4,390 ±	---
2-W22-7	2	412,000 ±	2,070	344,000 ±	2,210	378,000 ±	85,200
2-W22-9	2	8,070,000 ±	9,180	7,730,000 ±	12,400	7,900,000 ±	426,000
2-W22-10	2	483,000 ±	2,250	130,000 ±	1,380	307,000 ±	442,000
2-W22-12	3	33,600 ±	705	17,800 ±	1,500	26,100 ±	10,800
2-W22-20	4	268,000 ±	4,520	233,000 ±	1,560	255,000 ±	17,100
2-W22-22	12	2,100 ±	253	1,590 ±	205	1,880 ±	135
2-W22-26	4	31,400 ±	698	19,800 ±	560	25,800 ±	5,660
2-W23-1	3	580 ±	213	225 ±	196	397 ±	272
2-W23-3	1	3,720 ±	294			3,720 ±	---
2-W23-4	3	1,990 ±	264	780 ±	220	1,480 ±	838
2-W23-7	1	1,200 ±	228			1,200 ±	---
2-W23-9	12	1,550,000 ±	10,400	776,000 ±	2,890	1,290,000 ±	165,000
2-W23-10	12	1,020,000 ±	7,440	308,000 ±	4,830	701,000 ±	98,000
2-W23-11	13	1,530,000 ±	9,090	1,000 ±	190	140,000 ±	232,000
2-W26-3	4	271 ±	218	111 ±	163	193 ±	123
2-W26-6	4	370 ±	208	47 ±	160	213 ±	183
2-W27-1	4	14,500 ±	1,690	108 ±	202	5,780 ±	7,020
3-1-1	4	3,560 ±	285	-288 ±	194	993 ±	1,870
3-1-2	4	3,580 ±	285	477 ±	209	1,720 ±	1,510
3-1-3	4	1,900 ±	253	63 ±	209	724 ±	900
3-1-4	4	432 ±	222	62 ±	205	252 ±	211
3-1-5	4	417 ±	208	160 ±	225	272 ±	167
3-1-6	4	1,720 ±	250	-175 ±	198	475 ±	928
3-2-1	4	1,170 ±	305	-86 ±	201	550 ±	621
3-2-2	4	1,090 ±	292	116 ±	210	528 ±	489
3-2-3	4	4,110 ±	349	-66 ±	204	1,470 ±	2,030
3-3-1	4	1,550 ±	314	403 ±	170	788 ±	571
3-3-2	4	473 ±	268	-29 ±	156	176 ±	271
3-3-3	4	522 ±	269	1 ±	206	326 ±	280
3-3-6	4	531 ±	270	255 ±	213	351 ±	179
3-3-7	4	1,710 ±	258	433 ±	282	1,170 ±	633
3-3-9	4	1,420 ±	305	212 ±	164	745 ±	600
3-3-10	4	1,290 ±	307	343 ±	168	819 ±	475
3-3-11	4	2,210 ±	323	1,260 ±	195	1,790 ±	482
3-3-12	4	3,190 ±	287	1,940 ±	213	2,360 ±	624
3-4-1	4	720 ±	180	287 ±	215	488 ±	240
3-4-7	4	1,820 ±	250	1,340 ±	243	1,560 ±	265
3-4-9	4	2,320 ±	326	346 ±	168	1,560 ±	969
3-4-10	4	1,600 ±	246	858 ±	184	1,280 ±	383
3-5-1	4	193 ±	261	-41 ±	276	97 ±	162
3-6-1	11	1,920 ±	324	-385 ±	325	166 ±	380
3-8-1	4	156 ±	261	-72 ±	274	85 ±	159
3-8-2	4	145 ±	198	-19 ±	211	59 ±	134

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TABLE A.13. (contd)

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum		Minimum		Average	
3-8-3	11	900 ±	311	-170 ±	327	233 ±	194
3-8-4	3	450 ±	208	-85 ±	249	143 ±	384
4-S0-7	3	39,000 ±	774	14,100 ±	487	30,200 ±	17,000
4-S0-8	3	50,600 ±	876	38,600 ±	667	43,400 ±	8,200
4-S1-7B	4	59,900 ±	947	54,900 ±	795	58,100 ±	2,470
4-S1-7C	12	93,800 ±	960	76,800 ±	915	81,400 ±	2,540
4-S1-8A	4	92,000 ±	1,160	82,000 ±	1,100	85,900 ±	4,960
4-S1-8B	4	87,000 ±	984	83,800 ±	1,100	86,000 ±	1,640
4-S1-8C	1	2,740 ±	327			2,740 ±	---
6-1-18	4	52,400 ±	895	49,400 ±	850	51,100 ±	1,520
6-2-3	4	108,000 ±	1,250	103,000 ±	1,200	106,000 ±	2,500
6-2-7	4	13,300 ±	408	6,790 ±	335	10,400 ±	3,170
6-2-33A	5	122 ±	262	-192 ±	216	-37 ±	151
6-3-45	2	66 ±	195	39 ±	161	52 ±	131
6-4-E6	4	191 ±	164	-50 ±	165	57 ±	147
6-8-17	4	158,000 ±	1,500	152,000 ±	1,460	156,000 ±	3,000
6-8-25	4	37,100 ±	752	34,600 ±	724	35,900 ±	1,270
6-8-32	3	101 ±	170	-11 ±	158	43 ±	121
6-9-E2	4	710 ±	183	143 ±	225	303 ±	292
6-10-E12	4	16,800 ±	532	13,500 ±	432	15,100 ±	1,620
6-10-54A	4	453 ±	296	38 ±	159	243 ±	228
6-13-64	4	221 ±	291	-82 ±	191	99 ±	180
6-14-E6T	2	47,600 ±	732	41,800 ±	798	44,700 ±	7,290
6-14-38	3	101 ±	162	-83 ±	198	1 ±	169
6-14-47	5	236 ±	264	-71 ±	155	34 ±	153
6-15-15B	4	114 ±	268	-23 ±	159	44 ±	130
6-15-26	11	64,800 ±	974	60,400 ±	933	63,600 ±	822
6-17-5	4	241 ±	218	78 ±	197	155 ±	123
6-17-47	3	333 ±	206	-111 ±	154	126 ±	320
6-17-70	4	122 ±	198	-120 ±	283	-8 ±	156
6-19-43	4	58 ±	272	-204 ±	194	-30 ±	164
6-19-58	4	76 ±	281	-109 ±	190	-13 ±	139
6-19-88	4	126 ±	198	-177 ±	152	-40 ±	181
6-20-E5A	4	67,400 ±	864	56,200 ±	793	63,100 ±	5,460
6-20-E5AP[c]	2	75 ±	201	22 ±	272	48 ±	182
6-20-E5AQ[c]	2	76 ±	196	70 ±	273	73 ±	168
6-20-E5AR[c]	2	259 ±	203	208 ±	276	234 ±	183
6-20-E12	4	657 ±	216	142 ±	199	498 ±	270
6-20-E12P[c]	2	253 ±	277	59 ±	199	156 ±	297
6-20-20	4	203,000 ±	1,470	166,000 ±	1,540	186,000 ±	18,000
6-20-39[c]	4	170 ±	203	-135 ±	154	33 ±	178
6-20-82	4	146 ±	199	-186 ±	281	-34 ±	193
6-21-6	4	53,600 ±	772	50,300 ±	868	52,500 ±	1,650
6-22-70	4	51 ±	198	-94 ±	190	-34 ±	127

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TABLE A.13. (contd)

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum		Minimum		Average	
6-24-1T	2	13,700 ±	416	10,800 ±	374	12,300 ±	3,640
6-24-1P[c]	2	269 ±	276	44 ±	195	157 ±	329
6-24-1Q[c]	2	281 ±	278	87 ±	197	184 ±	297
6-24-1R[c]	2	100 ±	198	81 ±	273	90 ±	170
6-24-1S[c]	2	251 ±	278	238 ±	202	245 ±	173
6-24-33	4	106,000 ±	1,240	66,400 ±	1,000	81,600 ±	19,300
6-24-46	4	105 ±	161	-135 ±	196	3 ±	152
6-25-55	4	222 ±	166	53 ±	272	140 ±	135
6-25-70	4	1,170 ±	235	889 ±	186	1,070 ±	182
6-26-15A	4	388,000 ±	2,340	307,000 ±	2,110	352,000 ±	39,400
6-27-8	4	329,000 ±	1,880	297,000 ±	2,080	314,000 ±	15,600
6-28-40	3	12,300 ±	457	10,000 ±	459	11,200 ±	1,590
6-28-40P[c]	2	80 ±	196	-52 ±	269	14 ±	234
6-28-52A	4	22,900 ±	600	-57 ±	156	5,930 ±	11,200
6-29-4	4	135,000 ±	1,210	121,000 ±	1,310	129,000 ±	6,830
6-29-78	4	507 ±	211	155 ±	202	345 ±	204
6-31-31	4	55,900 ±	925	44,900 ±	829	48,900 ±	5,360
6-31-31P[c]	2	239 ±	277	165 ±	199	202 ±	194
6-32-22	4	306,000 ±	2,090	256,000 ±	1,670	274,000 ±	24,300
6-32-43	3	464,000 ±	2,600	259,000 ±	1,920	391,000 ±	140,000
6-32-62	4	2,020 ±	214	1,540 ±	246	1,830 ±	267
6-32-70B	5	287,000 ±	2,000	266,000 ±	1,910	275,000 ±	8,120
6-32-72	4	155,000 ±	1,480	139,000 ±	1,400	147,000 ±	7,810
6-32-77	4	375 ±	207	229 ±	270	286 ±	134
6-33-42	4	368,000 ±	2,300	267,000 ±	1,950	315,000 ±	49,100
6-33-56	4	172 ±	166	-139 ±	162	12 ±	188
6-34-39A	4	15,900 ±	539	6,990 ±	361	10,200 ±	4,340
6-34-41B	4	58,400 ±	812	51,800 ±	760	54,900 ±	3,230
6-34-42	4	109,000 ±	1,090	84,200 ±	946	97,400 ±	12,100
6-34-51	4	549 ±	241	-5 ±	199	168 ±	293
6-34-88	4	209 ±	201	-6 ±	158	94 ±	148
6-35-9	4	195,000 ±	1,690	173,000 ±	1,350	184,000 ±	10,700
6-35-66	4	1,210,000 ±	4,100	1,150,000 ±	3,450	1,190,000 ±	29,200
6-35-70	4	1,440,000 ±	3,890	1,240,000 ±	4,150	1,340,000 ±	97,200
6-35-78A	11	319 ±	277	-168 ±	195	82 ±	115
6-36-46P[c]	2	149 ±	199	131 ±	274	140 ±	171
6-36-46Q[c]	2	189 ±	276	183 ±	200	186 ±	171
6-36-61B	4	476 ±	222	52 ±	198	243 ±	239
6-36-93	2	243 ±	203	-6 ±	157	118 ±	338
6-37-E4	5	49,400 ±	870	39,000 ±	785	43,700 ±	4,020
6-37-43	4	67,800 ±	1,000	11,000 ±	438	47,900 ±	27,600
6-37-82A	4	490 ±	175	76 ±	273	234 ±	234
6-38-15	4	526,000 ±	2,400	457,000 ±	2,510	498,000 ±	33,600
6-38-65	4	380,000 ±	2,320	335,000 ±	1,870	355,000 ±	21,900
6-38-70	4	1,270 ±	242	1,060 ±	231	1,190 ±	154
6-39-0	5	251,000 ±	1,900	226,000 ±	1,770	237,000 ±	9,650

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TABLE A.13. (contd)

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum		Minimum		Average	
6-39-39	2	244 ±	205	65 ±	161	154 ±	260
6-39-79	5	204 ±	263	6 ±	197	89 ±	129
6-40-1	5	242,000 ±	1,640	233,000 ±	1,830	237,000 ±	3,550
6-40-33A	4	168 ±	176	-148 ±	194	58 ±	176
6-40-62	4	78,700 ±	917	62,800 ±	836	68,300 ±	7,740
6-41-1	11	270,000 ±	—	231,000 ±	1,800	244,000 ±	6,100
6-41-23	4	178,000 ±	1,600	147,000 ±	1,460	159,000 ±	15,100
6-42-2	5	226,000 ±	1,810	213,000 ±	1,730	218,000 ±	5,060
6-42-12A	4	322,000 ±	1,860	306,000 ±	1,470	314,000 ±	7,830
6-42-40A	12	700 ±	225	3 ±	3	319 ±	143
6-42-40B	12	15,000 ±	538	-95 ±	272	1,730 ±	2,460
6-42-40C[c]	2	1,170 ±	232	908 ±	218	1,040 ±	365
6-43-3	5	236,000 ±	1,620	213,000 ±	1,750	228,000 ±	8,880
6-43-88	5	333 ±	208	19 ±	192	150 ±	157
6-44-4	4	145,000 ±	1,440	114,000 ±	1,290	130,000 ±	15,100
6-44-64	4	521 ±	278	431 ±	221	475 ±	121
6-45-2	5	223,000 ±	1,570	162,000 ±	1,530	203,000 ±	23,500
6-45-42	7	54,100 ±	781	51,100 ±	869	52,400 ±	896
6-45-69A	4	467 ±	210	186 ±	277	306 ±	176
6-46-4	5	198,000 ±	1,680	152,000 ±	1,480	168,000 ±	17,700
6-46-21B	4	48,400 ±	730	42,800 ±	574	46,400 ±	2,740
6-47-5	13	211,000 ±	1,750	97,800 ±	1,190	164,000 ±	18,700
6-47-35A	4	102 ±	160	-90 ±	164	40 ±	128
6-47-46A	4	179 ±	199	-60 ±	155	70 ±	156
6-47-50[c]	2	325 ±	199	265 ±	204	295 ±	161
6-47-60	4	141 ±	269	-52 ±	166	78 ±	140
6-48-7	4	277 ±	168	-48 ±	198	74 ±	184
6-48-18	4	402 ±	181	-249 ±	191	139 ±	328
6-48-71	4	204 ±	216	-96 ±	188	36 ±	175
6-49-13E	5	296 ±	278	39 ±	169	149 ±	134
6-49-28	4	1,260 ±	196	340 ±	206	948 ±	458
6-49-55A	4	17,800 ±	391	16,100 ±	515	16,900 ±	863
6-49-57	4	3,340 ±	293	1,550 ±	309	2,180 ±	881
6-49-79	4	467 ±	176	-221 ±	192	159 ±	352
6-49-100C	3	62 ±	161	-20 ±	158	9 ±	115
6-50-28B	4	630 ±	288	-223 ±	194	298 ±	428
6-50-30	4	162 ±	275	23 ±	212	76 ±	128
6-50-42	4	4,040 ±	313	3,210 ±	243	3,720 ±	427
6-50-45[c]	2	56 ±	268	-33 ±	193	11 ±	200
6-50-48B[c]	1	130 ±	269			130 ±	---
6-50-53	4	3,470 ±	297	1,400 ±	306	2,210 ±	1,020
6-50-85	4	228 ±	278	-5 ±	194	107 ±	165
6-51-46	2	7,790 ±	377	-113 ±	191	3,840 ±	9,900
6-51-63	4	350 ±	220	-57 ±	155	146 ±	226
6-51-75	4	170 ±	163	-27 ±	157	89 ±	134
6-52-19	4	165,000 ±	1,320	-35 ±	198	41,200 ±	80,200

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TABLE A.13. (contd)

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum		Minimum		Average	
6-52-46A[c]	1	-96 ±	154			-96 ±	---
6-52-48[c]	2	190 ±	195	130 ±	199	160 ±	158
6-53-35	4	6 ±	158	-197 ±	190	-101 ±	143
6-53-50[c]	2	60 ±	197	-74 ±	155	-7 ±	210
6-53-103[c]	2	346 ±	206	55 ±	160	200 ±	387
6-54-34	4	206 ±	270	-60 ±	157	37 ±	164
6-54-37A	4	174 ±	164	-158 ±	259	0 ±	190
6-54-42	4	184 ±	269	-232 ±	193	35 ±	226
6-54-45A	3	174 ±	225	-316 ±	189	-3 ±	355
6-54-57[c]	2	60 ±	197	-94 ±	272	-17 ±	256
6-55-40	4	115 ±	162	-103 ±	197	10 ±	146
6-55-44	4	23 ±	264	-132 ±	197	-34 ±	125
6-55-50A	4	234 ±	271	-145 ±	196	120 ±	211
6-55-50C	4	261 ±	169	128 ±	206	193 ±	122
6-55-50D	3	365 ±	173	-95 ±	198	129 ±	338
6-55-70	5	16,400 ±	513	26 ±	212	3,390 ±	6,300
6-55-89	4	218 ±	165	-177 ±	275	52 ±	220
6-56-43	4	131 ±	164	-182 ±	195	-24 ±	184
6-56-53[c]	2	82 ±	162	75 ±	198	79 ±	128
6-57-25A	4	428 ±	171	-102 ±	284	123 ±	283
6-57-29A	4	746 ±	223	590 ±	279	664 ±	144
6-58-24	3	254 ±	205	13 ±	159	122 ±	198
6-59-32	4	883 ±	292	594 ±	217	723 ±	192
6-59-58	4	951 ±	294	652 ±	209	770 ±	191
6-60-32	4	975 ±	229	621 ±	220	814 ±	217
6-60-57	4	616 ±	216	412 ±	284	539 ±	160
6-60-60	4	8,150 ±	430	7,620 ±	382	7,830 ±	328
6-61-37	4	962 ±	294	524 ±	217	740 ±	246
6-61-41	4	338 ±	208	-103 ±	195	95 ±	243
6-61-62	4	9,470 ±	453	8,420 ±	432	9,060 ±	553
6-61-66	4	457 ±	282	-39 ±	196	129 ±	269
6-62-43F	4	801 ±	290	490 ±	277	647 ±	197
6-63-25A	4	182 ±	274	-126 ±	278	-13 ±	192
6-63-51	4	823 ±	290	537 ±	300	672 ±	190
6-63-55	4	958 ±	228	321 ±	295	626 ±	335
6-63-58	4	1,490 ±	244	697 ±	290	1,170 ±	407
6-63-90	5	170 ±	200	-157 ±	268	30 ±	166
6-64-27	4	170 ±	282	-86 ±	198	29 ±	170
6-64-62	4	9,880 ±	459	9,040 ±	445	9,380 ±	462
6-65-50	4	687 ±	220	492 ±	216	586 ±	147
6-65-59	4	619 ±	177	498 ±	291	558 ±	129
6-65-72	4	3,820 ±	357	3,040 ±	276	3,510 ±	412
6-65-83	4	1,320 ±	237	845 ±	232	1,050 ±	263
6-66-58	4	613 ±	285	417 ±	287	494 ±	158
6-66-64	4	9,300 ±	416	6,420 ±	405	7,180 ±	1,410
6-66-103	4	418 ±	223	145 ±	197	261 ±	175

9 2 1 2 5 5 6 0 3 3 9

TABLE A.13. (contd)

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum		Minimum		Average	
6-67-51	4	752 ±	297	511 ±	217	640 ±	174
6-67-86	4	1,070 ±	298	713 ±	229	924 ±	212
6-67-98	4	1,980 ±	318	-143 ±	191	480 ±	1,040
6-68-105	4	338 ±	206	-58 ±	190	169 ±	223
6-69-38	4	383 ±	211	-53 ±	274	102 ±	244
6-70-68	4	2,090 ±	216	1,530 ±	246	1,780 ±	297
6-71-30	4	156 ±	274	-199 ±	276	-48 ±	210
6-71-52	4	1,130 ±	302	911 ±	292	1,060 ±	170
6-71-77	4	3,180 ±	288	3,000 ±	275	3,100 ±	162
6-72-73	2	3,250 ±	243	2,350 ±	267	2,800 ±	1,140
6-72-88	4	3,350 ±	292	2,640 ±	330	2,960 ±	375
6-72-92	2	2,180 ±	261	1,770 ±	313	1,980 ±	553
6-73-61	4	280 ±	203	15 ±	202	165 ±	171
6-74-44	4	-1 ±	201	-176 ±	270	-81 ±	134
6-77-36	4	156 ±	285	-102 ±	197	38 ±	174
6-77-54	2	38 ±	193	-178 ±	192	-70 ±	303
6-81-58	4	303 ±	202	-55 ±	273	97 ±	212
6-83-47	2	758 ±	182	700 ±	222	729 ±	161
6-84-35AO	2	269 ±	203	35 ±	271	152 ±	339
6-87-55	4	60,300 ±	821	50,500 ±	743	55,700 ±	4,780
6-89-35	4	743 ±	182	534 ±	217	657 ±	155
6-90-45	4	3,580 ±	358	3,290 ±	287	3,480 ±	206
6-96-49	4	14,300 ±	428	13,500 ±	519	13,900 ±	450
6-97-43	4	9,740 ±	356	9,350 ±	458	9,500 ±	272
6-97-51A	4	15,400 ±	463	14,900 ±	539	15,000 ±	337
6-101-48B	4	379 ±	172	8 ±	201	226 ±	210
6-S3-E12	4	5,940 ±	299	4,910 ±	366	5,240 ±	527
6-S3-25	2	59 ±	159	-38 ±	198	11 ±	176
6-S6-E4B	4	27,400 ±	656	20,800 ±	564	25,500 ±	3,220
6-S6-E4D	11	42,100 ±	689	33,000 ±	709	36,200 ±	1,450
6-S6E14A[c]	2	76 ±	159	-202 ±	194	-63 ±	371
6-S7-34	4	286 ±	204	-154 ±	281	27 ±	239
6-S8-19	4	323 ±	266	-259 ±	192	34 ±	300
6-S11E12A	2	3,380 ±	292	3,190 ±	337	3,290 ±	326
6-S11E12AP[c]	2	268 ±	206	120 ±	268	194 ±	251
6-S12-3	4	220 ±	266	-201 ±	194	37 ±	228
6-S12-29	4	73 ±	196	-141 ±	153	-56 ±	143
6-S14-20A	4	89 ±	261	-112 ±	154	10 ±	146
6-S18-51	4	306 ±	170	-87 ±	154	79 ±	216
6-S19-11	2	147 ±	199	-1 ±	264	73 ±	248

9 2 1 2 5 5 6 0 3 4 0

TABLE A.13. (contd)

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum		Minimum		Average	
6-S19-E13	4	6,450 ±	307	4,990 ±	316	5,820 ±	728
6-S27-E14	12	853 ±	312	-213 ±	191	78 ±	169
6-S28-E0	4	89 ±	191	-99 ±	163	3 ±	129
6-S29-E12	4	208 ±	167	-288 ±	188	25 ±	258
6-S30E15A	3	389 ±	274	239 ±	167	299 ±	158
6-S31-1P[c]	3	-54 ±	155	-192 ±	188	-104 ±	135

(a) Maximum and minimum concentrations ±2-sigma counting error. Average concentrations ±2 standard error of the calculated mean (no estimate of standard error for one sample).
(b) See Figures 3.10, 3.11, and 3.12 for well locations.
(c) Wells that sample a confined aquifer or a composite of confined and unconfined aquifer.

9 2 1 2 5 5 6 0 3 4 1

TABLE A.14. Maximum, Minimum, and Average Gross Alpha Concentrations in Ground-Water Samples in 1987

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum			Minimum			Average		
100-B River	1	0.348	±	0.592				0.348	±	---
1-B3-1	2	2.24	±	1.34	1.59	±	1.10	1.92	±	1.19
1-B4-1	3	2.16	±	1.22	0.435	±	0.835	1.06	±	1.31
1-B4-4	2	0.532	±	0.827	0.463	±	0.729	0.498	±	0.558
1-B5-1	1	3.70	±	1.55				3.70	±	---
1-B9-1	3	1.68	±	1.40	0.927	±	0.950	1.42	±	0.921
1-D2-5	2	1.36	±	1.54	0.905	±	1.60	1.13	±	1.25
1-D5-12	3	17.0	±	4.25	1.48	±	1.31	6.87	±	10.7
1-D8-3	2	1.44	±	1.11	0.756	±	0.782	1.10	±	1.09
1-F5-1	4	2.08	±	1.17	-2.46	±	1.52	0.160	±	2.27
1-F5-3	1	1.27	±	0.983				1.27	±	---
1-F5-4	1	7.36	±	2.87				7.36	±	---
1-F5-6	2	1.46	±	1.06	-0.057	±	0.575	0.701	±	1.99
1-F7-1	3	7.06	±	3.22	3.92	±	2.26	5.95	±	2.68
1-F8-1	4	219	±	17.9	138	±	14.1	187	±	40.2
1-F8-2	1	66.6	±	8.10				66.6	±	---
1-H3-1	10	8.86	±	2.97	3.46	±	1.73	5.37	±	1.26
1-H3-2A	11	2.91	±	1.61	0.891	±	0.958	1.60	±	0.501
1-H3-2B	11	2.76	±	1.37	0.974	±	0.913	1.79	±	0.503
1-H3-2C	10	3.05	±	1.56	0.290	±	0.781	1.40	±	0.675
1-H4-3	12	269	±	25.1	71.2	±	9.16	162	±	40.1
1-H4-4	14	103	±	15.5	3.04	±	1.32	55.8	±	13.4
1-H4-5	10	3.93	±	1.83	1.17	±	0.884	2.37	±	0.736
1-H4-6	10	6.78	±	2.55	1.23	±	1.21	3.13	±	1.21
1-H4-7	11	4.20	±	1.75	1.36	±	1.09	2.38	±	0.623
1-H4-8	10	3.85	±	1.93	1.63	±	1.21	2.63	±	0.662
1-H4-9	12	13.2	±	3.59	3.45	±	1.75	7.56	±	1.85
1-H4-10	10	3.07	±	1.52	0.724	±	0.731	1.74	±	0.608
1-H4-11	11	3.34	±	1.57	1.51	±	1.04	2.46	±	0.568
1-H4-12A	11	39.5	±	5.49	2.38	±	1.25	19.0	±	7.14
1-H4-12B	11	21.5	±	3.87	5.19	±	1.90	10.2	±	3.25
1-H4-12C	11	4.28	±	1.71	0.852	±	0.916	1.83	±	0.701
1-H4-13	11	2.70	±	1.25	0.529	±	0.755	1.13	±	0.469
1-H4-14	11	1.97	±	1.20	0.662	±	0.840	1.36	±	0.415
1-H4-15A	11	2.28	±	1.33	0.487	±	0.733	1.47	±	0.483
1-H4-15B	11	2.32	±	1.63	1.14	±	0.997	1.68	±	0.443
1-H4-16	7	2.12	±	1.19	0.820	±	0.894	1.25	±	0.517
1-H4-17	5	4.31	±	1.90	1.77	±	1.38	2.88	±	1.25
1-H4-18	6	5.03	±	2.02	1.58	±	1.10	2.92	±	1.27
1-K-11	2	3.20	±	1.62	2.90	±	1.46	3.05	±	1.15
1-K-19	3	2.16	±	1.32	0.672	±	0.844	1.21	±	1.19
1-K-20	3	1.75	±	1.10	0.740	±	0.852	1.08	±	0.880
1-K-22	3	1.47	±	1.08	0.595	±	0.801	0.990	±	0.808
1-K-27	3	4.20	±	1.72	3.11	±	1.52	3.83	±	1.21
1-K-28	2	3.35	±	1.51	3.33	±	1.75	3.34	±	1.16

9 2 1 2 5 5 6 0 3 4 2

TABLE A.14. (contd)

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum			Minimum			Average		
1-K-29	3	2.26	±	1.19	1.67	±	1.06	2.05	±	0.777
1-K-30	3	3.79	±	1.65	1.57	±	1.18	2.56	±	1.72
1-N-2	1	0.348	±	0.673				0.348	±	---
1-N-3	1	1.97	±	1.43				1.97	±	---
1-N-4	1	1.60	±	1.02				1.60	±	---
1-N-6	2	0.185	±	0.553	0.019	±	0.452	0.102	±	0.413
1-N-14	4	1.16	±	0.810	-0.150	±	0.456	0.413	±	0.709
1-N-27	1	0.529	±	0.658				0.529	±	---
1-N-28	3	1.99	±	1.14	1.76	±	1.07	1.86	±	0.642
1-N-29	4	0.818	±	0.718	0.088	±	0.460	0.431	±	0.468
1-N-31	1	0.033	±	0.461				0.033	±	---
1-N-32	1	0.749	±	0.870				0.749	±	---
1-N-36	1	0.348	±	0.592				0.348	±	---
1-N-39	1	0.083	±	0.581				0.083	±	---
1-N-41	1	0.041	±	0.527				0.041	±	---
1-N-42	1	0.181	±	0.590				0.181	±	---
1-N-49	1	0.949	±	0.932				0.949	±	---
1-N-52	1	0.308	±	0.691				0.308	±	---
1-N-58	1	-0.643	±	2.56				-0.643	±	---
1-N-59	1	36.6	±	54.4				36.6	±	---
1-N-60	1	1.19	±	2.34				1.19	±	---
1-N-61	1	-2.38	±	2.17				-2.38	±	---
2-E13-5	4	1.69	±	1.23	0.998	±	1.12	1.24	±	0.663
2-E13-14	3	3.01	±	1.54	2.61	±	1.38	2.76	±	0.874
2-E16-2	12	2.27	±	0.657	0.885	±	0.465	1.48	±	0.276
2-E17-1	16	3.35	±	0.800	0.530	±	0.945	2.28	±	0.527
2-E17-2	10	8.89	±	1.26	4.60	±	0.927	7.04	±	0.856
2-E17-5	16	8.87	±	1.28	4.87	±	2.00	6.46	±	0.603
2-E17-6	4	0.929	±	0.919	-0.056	±	0.590	0.480	±	0.617
2-E17-9	16	4.16	±	0.864	1.66	±	1.28	2.93	±	0.497
2-E17-12	12	4.86	±	0.943	1.77	±	0.588	3.67	±	0.582
2-E17-13	12	7.68	±	1.17	3.15	±	0.748	5.39	±	0.972
2-E24-2	8	6.52	±	1.11	1.38	±	1.32	4.56	±	1.33
2-E24-7	1	4.71	±	1.74				4.71	±	---
2-E24-8	3	2.50	±	1.38	0.718	±	0.846	1.49	±	1.37
2-E24-12	3	18.1	±	3.41	11.7	±	2.81	15.4	±	4.73
2-E25-6	12	1.56	±	0.546	0.184	±	0.308	1.07	±	0.261
2-E25-7	1	1.42	±	1.01				1.42	±	---
2-E25-9	11	1.55	±	0.547	0.058	±	0.241	0.725	±	0.253
2-E25-10	3	1.49	±	0.546	1.19	±	0.501	1.30	±	0.363
2-E25-11	12	1.81	±	0.595	0.514	±	0.384	1.09	±	0.252
2-E25-17	12	1.50	±	0.553	0.140	±	0.265	1.05	±	0.288
2-E25-18	16	19.5	±	3.28	0.982	±	0.449	2.43	±	2.29
2-E25-19	13	1.73	±	0.566	0.381	±	0.353	1.15	±	0.242
2-E25-20	16	2.40	±	0.671	0.399	±	1.03	1.68	±	0.326
2-E25-21	14	2.34	±	0.663	0.479	±	0.916	1.37	±	0.319
2-E25-22	13	1.69	±	1.15	0.564	±	0.351	1.08	±	0.253
2-E25-23	9	1.63	±	1.21	0.748	±	0.418	1.09	±	0.283
2-E25-24	9	1.31	±	0.546	0.662	±	0.402	0.954	±	0.233
2-E25-25	3	1.04	±	0.878	0.392	±	0.731	0.688	±	0.632

9 2 1 2 5 5 6 0 3 4 3

TABLE A.14. (contd)

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum			Minimum			Average		
2-E25-26	3	0.617	±	0.741	0.254	±	0.709	0.437	±	0.473
2-E25-27	3	0.936	±	0.975	0.599	±	0.734	0.769	±	0.546
2-E25-28	3	2.06	±	1.18	1.00	±	0.924	1.40	±	0.940
2-E26-1	1	1.09	±	0.985				1.09	±	---
2-E26-3	1	0.765	±	0.772				0.765	±	---
2-E26-6	4	0.932	±	0.449	0.263	±	0.327	0.633	±	0.384
2-E27-5	3	2.26	±	1.24	1.41	±	1.12	1.84	±	0.888
2-E27-7	3	1.69	±	0.580	1.46	±	0.559	1.57	±	0.358
2-E28-7	5	2.05	±	1.21	0.847	±	0.401	1.32	±	0.558
2-E28-9	4	10.2	±	1.35	6.24	±	1.03	8.37	±	2.02
2-E28-16	4	8.24	±	1.22	6.37	±	1.06	7.06	±	1.07
2-E28-17	5	6.81	±	1.10	4.00	±	0.859	5.75	±	1.21
2-E28-18	12	94.1	±	4.06	34.3	±	5.49	53.4	±	9.81
2-E28-21	16	55.7	±	3.12	0.003	±	0.480	42.6	±	6.90
2-E28-23	4	57.2	±	7.37	23.3	±	2.03	39.3	±	16.7
2-E28-24	4	0.562	±	0.340	0.178	±	0.271	0.308	±	0.243
2-E28-25	4	9.02	±	1.27	3.43	±	0.810	6.85	±	2.77
2-E32-1	2	2.85	±	1.42	2.83	±	1.47	2.84	±	1.02
2-E33-1	3	1.65	±	1.43	1.59	±	1.18	1.63	±	0.735
2-E33-2	1	0.546	±	0.761				0.546	±	---
2-E33-3	3	1.98	±	1.32	1.24	±	1.07	1.55	±	0.852
2-E33-5	3	0.857	±	0.918	0.592	±	0.828	0.761	±	0.550
2-E33-8	2	2.38	±	1.25	2.10	±	1.15	2.24	±	0.919
2-E33-10	2	1.33	±	1.08	1.05	±	0.882	1.19	±	0.780
2-E33-18	3	2.62	±	1.36	1.19	±	1.00	1.77	±	1.18
2-E33-21	2	1.60	±	1.04	0.761	±	0.868	1.18	±	1.25
2-E33-24	2	1.51	±	1.11	0.894	±	0.995	1.20	±	1.07
2-E34-1	13	2.94	±	0.736	-0.182	±	0.846	2.07	±	0.476
2-W6-1	1	0.615	±	1.11				0.615	±	---
2-W10-3	4	29.2	±	2.93	11.2	±	1.43	17.2	±	8.80
2-W10-4	4	2.38	±	1.93	0.479	±	1.59	1.52	±	1.33
2-W10-8	7	3.10	±	1.52	0.317	±	0.771	1.59	±	0.848
2-W10-9	7	5.21	±	3.40	1.58	±	0.588	2.93	±	1.30
2-W11-11	4	2.47	±	0.671	1.47	±	0.536	1.94	±	0.574
2-W11-23	4	3.56	±	0.799	0.880	±	0.455	2.51	±	1.35
2-W11-24	4	1.06	±	0.455	0.348	±	0.351	0.686	±	0.398
2-W12-1	1	0.697	±	1.02				0.697	±	---
2-W14-2	9	5.07	±	2.26	0.390	±	1.07	2.14	±	1.15
2-W14-5	4	7.69	±	3.88	3.90	±	3.04	6.19	±	2.45
2-W14-6	3	3.79	±	2.07	0.725	±	1.20	2.42	±	2.31
2-W14-10	11	7.27	±	1.49	1.32	±	0.540	4.12	±	1.07
2-W15-4	3	7.58	±	5.20	1.01	±	3.39	5.20	±	5.15
2-W15-6	4	0.858	±	0.411	0.775	±	0.440	0.812	±	0.215
2-W15-7	1	0.811	±	0.411				0.811	±	---
2-W15-10	7	1.38	±	0.509	0.106	±	0.779	0.876	±	0.446
2-W15-11	7	2.64	±	0.693	1.07	±	1.23	1.96	±	0.584
2-W18-5	4	0.844	±	0.411	0.085	±	0.249	0.633	±	0.416
2-W18-9	4	1.35	±	0.662	0.140	±	0.265	0.609	±	0.628
2-W18-15	14	88.3	±	5.01	32.0	±	4.03	52.7	±	8.01
2-W18-17	4	1.38	±	0.515	-0.167	±	0.150	0.306	±	0.768
2-W18-18	4	1.41	±	0.517	0.018	±	0.161	0.567	±	0.703

9 2 1 2 5 5 6 0 3 4 4

TABLE A.14. (contd)

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum			Minimum			Average		
2-W18-20	4	2.34	±	0.854	0.366	±	0.329	0.989	±	0.997
2-W19-1	1	6.10	±	2.00				6.10	±	---
2-W19-2	6	91.4	±	4.05	16.9	±	1.67	53.4	±	24.1
2-W19-3	15	10,500	±	435	3,930	±	267	7,390	±	1,210
2-W19-5	3	8.72	±	1.22	6.81	±	2.05	7.82	±	1.70
2-W19-9	15	4,260	±	281	1,360	±	30.9	2,620	±	506
2-W19-11	16	5,240	±	308	-6.96	±	16.5	3,530	±	638
2-W19-12	4	4.76	±	0.913	4.27	±	0.890	4.44	±	0.511
2-W19-13	16	18.7	±	2.32	5.41	±	1.97	9.39	±	1.66
2-W19-14	7	5.16	±	1.26	3.02	±	0.734	4.00	±	0.689
2-W19-15	16	652	±	29.3	94.5	±	8.20	203	±	72.2
2-W19-16	16	1,790	±	181	883	±	24.7	1,310	±	126
2-W19-17	11	53.7	±	6.77	12.8	±	3.76	24.5	±	7.41
2-W19-18	10	5,090	±	304	3,620	±	260	4,480	±	342
2-W19-19	10	486	±	9.32	272	±	6.97	383	±	46.9
2-W19-20	14	344	±	12.7	154	±	5.09	236	±	32.4
2-W19-21	7	19.9	±	1.90	11.8	±	1.45	17.0	±	2.36
2-W19-23	8	171	±	5.53	126	±	4.69	142	±	11.7
2-W19-24	7	548	±	9.90	370	±	32.1	470	±	50.2
2-W19-25	8	293	±	7.24	182	±	12.5	245	±	27.9
2-W19-26	6	166	±	12.7	107	±	4.32	130	±	19.4
2-W19-27	6	10.4	±	1.34	8.51	±	1.23	9.12	±	0.800
2-W22-1	2	4.80	±	0.927	4.64	±	0.910	4.72	±	0.680
2-W22-2	2	5.96	±	1.03	5.08	±	0.956	5.52	±	1.31
2-W22-10	5	0.417	±	0.427	-0.014	±	0.224	0.200	±	0.214
2-W22-12	3	1.76	±	1.06	1.68	±	1.15	1.72	±	0.644
2-W22-18	4	3.36	±	0.788	1.45	±	0.543	2.26	±	0.984
2-W22-20	3	16.3	±	4.77	11.1	±	4.44	14.5	±	4.54
2-W22-21	4	18.7	±	1.79	14.5	±	1.57	16.1	±	2.20
2-W22-22	15	1.13	±	0.486	0.053	±	0.258	0.544	±	0.213
2-W22-26	3	7.28	±	1.15	4.17	±	1.75	5.44	±	2.31
2-W23-1	2	14.0	±	1.52	8.64	±	2.29	11.3	±	6.86
2-W23-3	1	2.68	±	1.35				2.68	±	---
2-W23-4	4	24.2	±	2.06	14.6	±	1.56	18.7	±	4.75
2-W23-7	1	10.5	±	2.67				10.5	±	---
2-W23-9	12	48.4	±	3.71	14.3	±	1.59	27.3	±	5.61
2-W23-10	15	44.7	±	2.83	16.1	±	3.34	31.5	±	5.17
2-W23-11	14	38.9	±	2.56	12.5	±	2.59	20.7	±	3.10
2-W26-3	4	1.70	±	0.593	1.21	±	0.501	1.40	±	0.358
2-W26-6	4	1.23	±	0.491	0.619	±	0.403	0.806	±	0.367
2-W27-1	16	10.3	±	1.69	3.50	±	1.76	6.69	±	0.999
3-1-1	7	19.8	±	3.71	9.53	±	2.19	14.5	±	3.06
3-1-2	7	14.2	±	2.88	5.66	±	1.77	10.1	±	2.55
3-1-3	5	34.7	±	4.18	24.3	±	3.52	29.5	±	4.36
3-1-4	7	39.6	±	4.19	24.9	±	3.56	28.6	±	4.35
3-1-5	7	119	±	7.85	24.8	±	3.70	52.9	±	26.4
3-1-6	7	15.7	±	2.74	5.70	±	1.68	10.9	±	2.93
3-1-7	6	40.5	±	4.70	22.4	±	3.46	30.4	±	6.06
3-1-8	7	21.4	±	3.37	5.68	±	1.96	17.8	±	4.56
3-1-9	4	0.915	±	1.10	-0.231	±	0.625	0.549	±	0.731
3-1-10	6	11.3	±	2.35	6.70	±	1.82	8.93	±	1.71

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TABLE A.14. (contd)

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum			Minimum			Average		
3-1-11	6	156	±	9.24	27.3	±	3.56	74.5	±	41.6
3-1-12	6	53.3	±	5.19	26.0	±	3.50	43.3	±	9.01
3-1-13	8	14.0	±	2.64	4.81	±	1.59	10.5	±	2.43
3-1-14	6	28.1	±	3.80	10.0	±	2.28	16.5	±	5.95
3-1-15	6	16.6	±	3.25	3.99	±	1.70	9.33	±	4.18
3-1-16A	6	13.0	±	2.56	8.33	±	2.10	10.9	±	1.80
3-1-16B	5	3.17	±	1.66	2.10	±	1.55	2.47	±	0.796
3-1-16C	5	4.20	±	1.71	0.273	±	0.986	1.91	±	1.62
3-1-16D	1	-0.195	±	0.755				-0.195	±	---
3-1-17A	6	79.1	±	6.56	1.75	±	1.05	49.3	±	25.0
3-1-17B	5	0.936	±	1.02	-0.348	±	0.352	0.278	±	0.599
3-1-17C	5	1.13	±	1.17	-0.480	±	0.651	0.276	±	0.729
3-1-18A	6	4.15	±	1.81	2.13	±	1.39	3.16	±	0.934
3-1-18B	5	0.792	±	1.07	-1.04	±	0.292	0.115	±	0.814
3-1-18C	5	0.582	±	0.876	-0.089	±	0.936	0.221	±	0.472
3-1-19	5	208	±	10.6	52.4	±	5.58	111	±	59.9
3-2-1	7	11.7	±	2.57	7.38	±	1.94	8.82	±	1.46
3-3-7	7	10.3	±	2.60	6.80	±	2.11	8.29	±	1.31
3-3-10	7	51.6	±	5.40	7.30	±	2.02	18.5	±	12.5
3-4-1	7	12.7	±	2.72	10.7	±	2.64	11.4	±	1.15
3-4-7	7	36.6	±	4.63	23.1	±	3.80	30.6	±	4.11
3-4-11	6	16.1	±	3.96	8.23	±	2.30	11.3	±	2.79
3-8-1	1	5.74	±	2.04				5.74	±	---
3-8-2	7	2.80	±	1.55	0.830	±	0.978	1.83	±	0.724
3-8-3	1	4.37	±	1.78				4.37	±	---
4-S1-7C	1	3.76	±	2.01				3.76	±	---
4-S1-8A	1	3.47	±	1.69				3.47	±	---
4-S1-8B	1	4.69	±	2.27				4.69	±	---
6-2-3	2	2.25	±	1.39	0.976	±	0.975	1.61	±	1.81
6-2-33A	2	3.59	±	1.48	2.69	±	1.33	3.14	±	1.50
6-8-25	2	4.07	±	2.02	3.35	±	1.74	3.71	±	1.61
6-9-E2	3	1.71	±	1.19	1.08	±	0.963	1.44	±	0.770
6-10-E12	1	1.59	±	1.33				1.59	±	---
6-15-26	2	3.88	±	1.77	3.58	±	1.75	3.73	±	1.30
6-19-43	1	3.51	±	1.62				3.51	±	---
6-20-E5A	2	2.93	±	1.32	1.93	±	1.11	2.43	±	1.52
6-20-20	3	2.75	±	1.53	2.44	±	1.35	2.59	±	0.870
6-20-39[c]	3	2.77	±	1.41	1.34	±	1.12	1.91	±	1.21
6-23-34	2	4.04	±	1.90	3.95	±	1.86	4.00	±	1.33
6-24-33	4	3.88	±	1.82	2.96	±	1.75	3.48	±	0.999
6-24-34A	2	2.76	±	1.62	2.32	±	1.56	2.54	±	1.25
6-24-34B	3	3.29	±	1.79	2.38	±	1.93	2.87	±	1.23
6-24-34C	2	3.72	±	1.76	2.15	±	1.52	2.94	±	2.29
6-24-35	2	4.13	±	1.85	4.10	±	1.72	4.12	±	1.26
6-24-46	1	1.92	±	1.32				1.92	±	---
6-25-33A	4	3.44	±	1.87	1.64	±	1.20	2.76	±	1.17
6-25-34A	4	3.93	±	1.71	1.31	±	1.22	2.59	±	1.47
6-25-34B	4	3.72	±	1.69	1.94	±	1.35	2.55	±	1.13
6-25-34C	1	3.08	±	1.58				3.08	±	---
6-26-33	4	2.85	±	1.49	1.13	±	1.03	2.22	±	1.07

TABLE A.14. (contd)

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum			Minimum			Average		
6-26-34	4	3.40	±	1.60	2.40	±	1.43	2.83	±	0.889
6-26-35A	4	4.49	±	1.87	2.64	±	1.53	3.24	±	1.21
6-26-35C	4	2.54	±	1.50	1.21	±	1.14	1.72	±	0.910
6-28-40	1	1.95	±	1.05				1.95	±	---
6-29-4	2	4.45	±	1.80	4.24	±	1.61	4.35	±	1.24
6-29-78	1	1.55	±	1.13				1.55	±	---
6-32-22	2	1.81	±	1.10	1.20	±	1.12	1.51	±	1.10
6-32-43	1	4.96	±	1.82				4.96	±	---
6-32-62	4	2.87	±	0.733	2.06	±	0.642	2.39	±	0.520
6-32-70B	1	1.53	±	1.23				1.53	±	---
6-32-72	12	1.52	±	0.699	-0.076	±	0.185	0.566	±	0.307
6-32-77	1	0.636	±	0.892				0.636	±	---
6-33-42	1	2.99	±	1.53				2.99	±	---
6-33-56	3	3.94	±	0.846	2.11	±	1.36	3.17	±	1.38
6-34-42	1	2.41	±	1.50				2.41	±	---
6-34-51	1	2.05	±	1.26				2.05	±	---
6-35-9	2	3.33	±	1.62	1.14	±	1.14	2.24	±	2.92
6-35-66	1	2.00	±	1.40				2.00	±	---
6-35-70	1	1.70	±	1.22				1.70	±	---
6-35-78A	12	13.7	±	1.57	4.67	±	0.938	9.04	±	1.65
6-36-61A	1	1.36	±	1.07				1.36	±	---
6-37-E4	2	3.24	±	0.761	2.82	±	1.56	3.03	±	1.01
6-37-43	1	3.28	±	2.26				3.28	±	---
6-37-82A	1	0.142	±	0.580				0.142	±	---
6-38-65	2	5.03	±	1.93	0.621	±	0.962	2.83	±	5.63
6-38-70	4	47.0	±	2.90	11.7	±	2.84	26.8	±	17.3
6-39-0	1	3.62	±	0.838				3.62	±	---
6-39-79	4	7.05	±	3.87	4.05	±	1.53	5.56	±	1.90
6-40-1	4	4.65	±	1.79	1.79	±	1.25	3.37	±	1.55
6-40-33A	2	0.784	±	0.881	0.442	±	0.858	0.613	±	0.749
6-40-62	1	1.39	±	1.24				1.39	±	---
6-41-1	2	4.02	±	1.69	3.53	±	0.801	3.78	±	1.12
6-42-2	2	3.17	±	1.53	2.88	±	0.721	3.03	±	0.920
6-42-40A	12	1.67	±	0.741	0.027	±	0.236	0.723	±	0.290
6-43-3	2	3.53	±	0.808	2.77	±	1.47	3.15	±	1.27
6-43-88	3	0.226	±	0.819	-0.070	±	0.588	0.082	±	0.447
6-44-64	1	1.24	±	1.14				1.24	±	---
6-45-2	2	3.87	±	0.835	2.72	±	1.53	3.30	±	1.68
6-45-42	5	2.09	±	0.664	1.67	±	0.573	1.83	±	0.382
6-45-69A	1	1.25	±	1.11				1.25	±	---
6-46-4	2	3.26	±	1.63	3.14	±	0.771	3.20	±	0.914
6-47-5	2	4.75	±	1.81	1.95	±	0.634	3.35	±	3.64
6-47-46A	1	1.32	±	1.26				1.32	±	---
6-47-50	1	1.86	±	1.68				1.86	±	---
6-47-60	1	0.806	±	0.924				0.806	±	---
6-48-7	2	1.35	±	0.947	0.438	±	0.735	0.894	±	1.29
6-48-18	2	2.49	±	1.39	2.25	±	1.34	2.37	±	1.01
6-48-71	2	1.30	±	1.26	0.460	±	0.769	0.880	±	1.29
6-49-13E	1	2.46	±	0.704				2.46	±	---
6-49-55A	4	5.62	±	3.14	1.23	±	1.52	3.36	±	2.44
6-49-57	6	1.50	±	1.15	0.505	±	0.723	0.983	±	0.530
6-49-79	3	0.608	±	0.758	-0.212	±	0.430	0.154	±	0.670

TABLE A.14. (contd)

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum			Minimum			Average		
6-49-100C	3	2.65	±	0.698	-0.170	±	0.164	0.789	±	1.94
6-50-42	2	2.33	±	0.693	0.641	±	0.392	1.49	±	2.15
6-50-53	6	6.09	±	4.89	2.16	±	1.94	3.69	±	1.90
6-50-85	1	1.64	±	1.20				1.64	±	---
6-51-75	3	3.05	±	1.38	0.560	±	0.844	1.71	±	1.83
6-53-47A	11	6.21	±	1.32	0.102	±	0.273	2.55	±	1.24
6-53-47B	12	5.43	±	1.30	2.90	±	0.751	3.68	±	0.494
6-53-48A	12	18.8	±	1.82	0.877	±	0.440	4.59	±	2.87
6-53-48B	12	2.22	±	0.669	-0.164	±	0.155	0.353	±	0.371
6-53-55A	11	1.81	±	0.755	0.348	±	0.307	1.07	±	0.274
6-54-48	11	2.24	±	0.655	0.909	±	0.466	1.51	±	0.296
6-54-49	11	1.81	±	0.757	0.795	±	0.423	1.07	±	0.234
6-55-50C	5	0.830	±	0.426	0.425	±	0.320	0.647	±	0.261
6-55-50D	4	1.94	±	0.615	-0.117	±	0.208	0.928	±	1.02
6-55-76	1	0.772	±	0.889				0.772	±	---
6-56-51	1	0.384	±	0.341				0.384	±	---
6-59-58	2	1.24	±	0.508	1.16	±	0.463	1.20	±	0.358
6-63-58	2	0.887	±	0.433	0.723	±	0.393	0.805	±	0.357
6-65-72	1	1.40	±	1.10				1.40	±	---
6-65-83	1	0.266	±	1.60				0.266	±	---
6-67-86	1	0.855	±	0.957				0.855	±	---
6-70-68	1	0.540	±	0.801				0.540	±	---
6-71-30	1	7.03	±	2.81				7.03	±	---
6-71-52	1	1.90	±	1.23				1.90	±	---
6-71-77	1	1.03	±	1.05				1.03	±	---
6-73-61	1	0.828	±	0.909				0.828	±	---
6-74-44	1	0.654	±	0.848				0.654	±	---
6-77-36	1	10.2	±	3.53				10.2	±	---
6-77-54	2	1.28	±	1.02	1.09	±	1.01	1.19	±	0.756
6-81-58	1	1.31	±	0.947				1.31	±	---
6-83-47	2	3.94	±	1.87	2.19	±	1.37	3.07	±	2.48
6-89-35	2	2.68	±	1.49	2.10	±	1.39	2.39	±	1.25
6-90-45	3	2.25	±	1.34	0.804	±	0.782	1.43	±	1.17
6-96-49	1	0.513	±	0.748				0.513	±	---
6-97-43	1	1.20	±	1.12				1.20	±	---
6-97-51A	1	0.061	±	0.884				0.061	±	---
6-101-48B	1	0.080	±	0.494				0.080	±	---
6-S3-E12	1	1.16	±	1.03				1.16	±	---
6-S3-25	2	4.34	±	1.93	4.20	±	1.91	4.27	±	1.37
6-S6E14A[c]	2	3.00	±	1.35	2.73	±	1.38	2.87	±	1.02
6-S8-19	2	1.99	±	1.31	1.81	±	1.30	1.90	±	0.950
6-S11E12AP[c]	1	0.201	±	0.715				0.201	±	---
6-S12-3	3	63.0	±	6.59	3.14	±	1.61	23.1	±	40.9
6-S19-E13	7	2.82	±	1.58	2.29	±	1.47	2.46	±	0.597

TABLE A.14. (contd)

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum			Minimum			Average		
6-S28-E0	4	2.01	±	0.619	1.66	±	0.567	1.85	±	0.345
6-S29-E12	3	2.64	±	1.36	0.977	±	1.04	1.65	±	1.32
6-S30E15A	7	2.63	±	1.48	0.639	±	1.02	1.21	±	0.701
6-S31-1	2	0.726	±	0.871	0.247	±	0.725	0.487	±	0.825

(a) Maximum and minimum concentrations ±2-sigma counting error. Average concentrations ±2 standard errors of the calculated mean (no estimate of standard error for one sample).
(b) See Figure 3.10, 3.12, and 3.13 for well locations.
(c) Wells that sample a confined aquifer or a composite of a confined and unconfined aquifer.

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TABLE A.15. Maximum, Minimum, and Average Gross Beta Concentrations in Ground-Water Samples in 1987

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum			Minimum			Average		
100-B River	1	0.43	±	3.04				0.43	±	---
1-B3-1	2	164	±	11.3	147	±	11.2	156	±	22.7
1-B4-1	3	68.6	±	7.88	66.8	±	7.23	67.6	±	4.52
1-B4-4	2	92.8	±	9.15	91.0	±	8.47	91.9	±	6.63
1-B5-1	1	16.5	±	4.22				16.5	±	---
1-B9-1	3	24.7	±	4.97	17.9	±	4.34	20.9	±	5.42
1-D2-5	2	10.9	±	4.57	8.95	±	3.89	9.93	±	3.87
1-D5-12	3	116	±	9.98	73.1	±	7.91	93.6	±	29.7
1-D8-3	2	11.7	±	3.87	9.51	±	4.23	10.6	±	3.97
1-F5-1	4	73.9	±	8.07	59.5	±	6.90	67.8	±	7.96
1-F5-3	1	447	±	17.9				447	±	---
1-F5-4	1	8.51	±	4.30				8.51	±	---
1-F5-6	2	13.0	±	3.91	11.5	±	4.25	12.3	±	3.45
1-F7-1	3	17.5	±	4.84	11.7	±	4.76	14.1	±	4.84
1-F8-1	4	117	±	11.1	63.6	±	8.29	88.3	±	26.4
1-F8-2	1	68.3	±	7.95				68.3	±	---
1-H3-1	10	12.2	±	4.03	7.81	±	3.94	10.7	±	1.63
1-H3-2A	11	10.9	±	3.69	3.27	±	3.48	7.04	±	1.82
1-H3-2B	11	11.7	±	3.72	1.73	±	3.11	6.89	±	2.04
1-H3-2C	10	13.0	±	3.99	3.66	±	3.26	7.95	±	2.44
1-H4-3	12	908	±	30.7	166	±	12.3	522	±	158
1-H4-4	14	481	±	21.2	6.88	±	3.11	277	±	75.7
1-H4-5	10	16.4	±	4.68	3.17	±	3.47	9.78	±	2.76
1-H4-6	10	28.3	±	5.76	5.90	±	3.28	11.5	±	4.29
1-H4-7	11	12.3	±	4.12	3.39	±	3.47	7.43	±	2.04
1-H4-8	10	11.6	±	4.00	5.49	±	3.15	8.60	±	1.74
1-H4-9	12	305	±	17.4	37.2	±	6.00	142	±	45.9
1-H4-10	10	9.62	±	3.79	5.26	±	2.98	7.37	±	1.47
1-H4-11	11	84.2	±	9.04	58.8	±	6.94	68.5	±	5.31
1-H4-12A	11	320	±	16.4	7.91	±	3.37	82.1	±	51.8
1-H4-12B	11	85.1	±	8.55	18.5	±	5.10	48.8	±	12.7
1-H4-12C	11	9.72	±	3.68	4.08	±	3.39	7.34	±	1.64
1-H4-13	11	98.2	±	8.72	56.2	±	6.62	71.6	±	7.47
1-H4-14	11	12.5	±	3.74	4.55	±	3.39	7.88	±	1.70
1-H4-15A	11	13.1	±	4.03	5.54	±	3.53	9.30	±	1.78
1-H4-15B	11	13.2	±	4.44	4.27	±	3.35	9.24	±	1.84
1-H4-16	7	25.1	±	5.32	8.99	±	3.77	18.0	±	4.84
1-H4-17	5	16.1	±	4.85	5.95	±	3.79	12.5	±	4.40
1-H4-18	6	71.7	±	8.43	14.9	±	4.72	27.6	±	18.5
1-K-11	2	10.5	±	3.89	8.82	±	4.02	9.66	±	3.50
1-K-19	3	43.2	±	6.65	29.4	±	5.26	36.9	±	10.0
1-K-20	3	39.3	±	6.23	37.8	±	5.75	38.6	±	3.55
1-K-22	3	16.3	±	4.18	14.1	±	4.39	14.9	±	2.92
1-K-27	3	35.7	±	6.10	21.6	±	5.19	30.9	±	10.2
1-K-28	2	18.5	±	4.55	13.5	±	4.76	16.0	±	7.08
1-K-29	3	6.35	±	3.32	4.18	±	3.32	5.31	±	2.47

9 2 1 2 5 5 6 0 3 5 0

TABLE A.15. (contd)

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum			Minimum			Average		
1-K-30	3	12.2	±	3.96	5.75	±	3.61	9.42	±	4.92
1-N-2	1	1,130	±	29.4				1,130	±	---
1-N-3	1	4,380	±	120				4,380	±	---
1-N-4	1	181	±	12.0				181	±	---
1-N-6	2	416	±	16.8	396	±	17.2	406	±	27.8
1-N-14	4	2,790	±	46.5	1,630	±	33.3	2,250	±	564
1-N-27	1	486	±	19.0				486	±	---
1-N-28	3	424	±	17.1	332	±	16.2	392	±	63.6
1-N-29	4	1,790	±	36.3	1,070	±	26.8	1,390	±	350
1-N-31	1	248	±	13.8				248	±	---
1-N-32	1	286	±	14.8				286	±	---
1-N-36	1	434	±	17.9				434	±	---
1-N-39	1	1,770	±	36.4				1,770	±	---
1-N-41	1	126	±	10.2				126	±	---
1-N-42	1	127	±	10.2				127	±	---
1-N-49	1	134	±	10.5				134	±	---
1-N-52	1	113	±	9.67				113	±	---
1-N-58	1	7.94	±	4.56				7.94	±	---
1-N-59	1	4.05	±	4.05				4.05	±	---
1-N-60	1	4.10	±	4.14				4.10	±	---
1-N-61	1	8.62	±	5.11				8.62	±	---
2-E13-5	8	9.66	±	4.10	5.97	±	2.06	7.68	±	1.42
2-E13-8	4	7.45	±	2.17	6.14	±	1.97	6.86	±	1.23
2-E13-14	7	10.5	±	4.22	4.38	±	1.75	7.09	±	2.04
2-E13-19	4	90.4	±	6.80	3.85	±	1.70	26.6	±	42.1
2-E16-2	12	18.1	±	2.97	9.76	±	2.24	12.9	±	1.64
2-E17-1	16	39.4	±	6.86	23.7	±	3.79	30.3	±	2.69
2-E17-2	10	570	±	24.3	89.3	±	9.58	267	±	109
2-E17-5	16	613	±	17.5	46.5	±	4.73	201	±	107
2-E17-6	17	194	±	9.67	6.34	±	3.56	33.5	±	26.0
2-E17-8	11	31.9	±	4.13	12.2	±	2.65	19.9	±	3.90
2-E17-9	16	41.8	±	6.44	14.2	±	2.87	24.9	±	3.86
2-E17-12	12	45.6	±	4.58	14.8	±	2.84	25.7	±	6.20
2-E17-13	12	38.9	±	4.39	10.7	±	2.47	24.3	±	6.84
2-E23-2	2	7.77	±	2.15	5.11	±	1.80	6.44	±	3.62
2-E24-1	12	62.3	±	5.99	31.5	±	4.05	42.9	±	5.36
2-E24-2	8	21.2	±	5.46	14.1	±	2.72	18.3	±	2.16
2-E24-4	12	6.74	±	1.97	2.59	±	1.51	4.74	±	0.84
2-E24-7	1	47.1	±	6.67				47.1	±	---
2-E24-8	15	48.0	±	4.57	12.9	±	2.56	24.8	±	6.57
2-E24-11	12	39.5	±	4.54	10.2	±	2.53	18.3	±	4.66
2-E24-12	15	476	±	29.4	21.7	±	3.23	92.9	±	67.1
2-E24-13	4	9.44	±	2.21	6.89	±	2.01	8.18	±	1.63
2-E25-2	2	4.44	±	1.66	3.82	±	1.63	4.13	±	1.40
2-E25-3	4	5.24	±	1.73	3.98	±	1.65	4.58	±	1.03
2-E25-6	12	8.72	±	2.09	1.13	±	0.76	4.67	±	1.11
2-E25-7	1	8.94	±	3.72				8.94	±	---
2-E25-9	11	6.43	±	1.94	4.07	±	1.66	5.00	±	0.73
2-E25-10	3	6.87	±	1.91	5.09	±	1.73	6.07	±	1.62
2-E25-11	12	15.0	±	2.72	8.77	±	2.21	11.1	±	1.28

9 2 1 2 5 5 6 0 3 5 1

TABLE A.15. (contd)

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum			Minimum			Average		
2-E25-13	4	11.1	±	2.98	7.78	±	2.45	9.69	±	2.13
2-E25-17	12	17.8	±	2.86	6.34	±	1.92	10.3	±	1.90
2-E25-18	16	11.7	±	2.46	4.42	±	1.71	7.67	±	1.12
2-E25-19	13	119	±	7.63	9.28	±	2.25	51.6	±	20.8
2-E25-20	16	20.9	±	5.52	9.16	±	2.40	15.1	±	1.86
2-E25-21	14	20.7	±	4.69	9.04	±	2.21	12.4	±	1.88
2-E25-22	13	11.2	±	3.68	3.50	±	1.49	7.03	±	1.60
2-E25-23	9	21.2	±	5.12	13.2	±	2.58	15.6	±	2.07
2-E25-24	9	22.2	±	3.29	8.05	±	2.01	15.6	±	3.34
2-E25-25	3	10.1	±	3.45	5.54	±	3.41	7.74	±	3.71
2-E25-26	3	9.02	±	3.46	1.57	±	3.00	5.48	±	5.43
2-E25-27	3	9.27	±	4.05	2.91	±	3.20	5.93	±	4.78
2-E25-28	3	8.28	±	3.78	5.45	±	2.90	7.15	±	2.79
2-E26-1	1	9.14	±	3.86				9.14	±	---
2-E26-2	4	6.49	±	1.88	4.60	±	1.64	5.46	±	1.28
2-E26-3	1	7.17	±	3.68				7.17	±	---
2-E26-4	4	6.44	±	1.93	4.66	±	1.68	5.38	±	1.25
2-E26-6	4	5.26	±	1.71	2.03	±	1.30	3.61	±	1.75
2-E27-5	7	86.7	±	6.12	53.3	±	4.91	69.9	±	9.66
2-E27-7	3	7.53	±	2.09	3.88	±	1.58	5.97	±	2.72
2-E28-7	5	1,160	±	30.6	112	±	7.07	385	±	403
2-E28-9	4	11.5	±	2.65	8.68	±	2.30	9.97	±	1.84
2-E28-12	12	20.4	±	3.33	9.35	±	2.50	15.4	±	1.95
2-E28-13	5	9.51	±	2.39	6.95	±	2.06	8.21	±	1.40
2-E28-16	4	11.0	±	2.57	6.96	±	2.13	8.22	±	2.26
2-E28-17	2	11.0	±	4.44	8.88	±	2.36	9.94	±	3.66
2-E28-18	12	26.8	±	3.73	14.6	±	2.84	19.1	±	2.40
2-E28-21	16	20.6	±	5.32	4.00	±	3.14	15.4	±	2.33
2-E28-23	4	15,700	±	501	9,140	±	382	12,100	±	3,190
2-E28-24	4	381	±	14.4	201	±	10.1	299	±	87.7
2-E28-25	4	8,510	±	169	4,370	±	42.9	6,020	±	2,010
2-E32-1	4	37.5	±	4.21	28.8	±	5.53	33.9	±	4.91
2-E33-1	7	140	±	7.81	63.5	±	5.30	106	±	21.6
2-E33-2	1	61.1	±	7.70				61.1	±	---
2-E33-3	8	438	±	28.0	27.7	±	5.56	137	±	102
2-E33-5	7	309	±	15.2	169	±	11.9	245	±	39.4
2-E33-7	4	1,010	±	31.7	553	±	23.0	738	±	223
2-E33-8	6	109	±	6.86	36.6	±	4.42	68.9	±	23.5
2-E33-9	4	226	±	9.74	130	±	7.52	200	±	46.9
2-E33-10	6	27.7	±	3.57	11.6	±	2.42	19.6	±	5.41
2-E33-18	7	14.9	±	3.94	8.63	±	2.15	11.4	±	2.12
2-E33-20	4	13.6	±	2.66	8.39	±	2.12	10.8	±	2.79
2-E33-21	6	12.7	±	2.55	5.97	±	1.84	9.93	±	2.47
2-E33-24	6	391	±	17.1	216	±	9.59	307	±	56.7
2-E33-26	3	271	±	10.8	197	±	9.38	224	±	50.8
2-E34-1	13	18.1	±	5.09	7.61	±	2.23	10.2	±	1.66
2-W6-1	1	20.1	±	5.39				20.1	±	---
2-W10-1	4	40.4	±	4.86	29.8	±	4.23	34.4	±	5.63
2-W10-3	4	47.1	±	5.94	33.8	±	4.69	40.3	±	6.96
2-W10-4	8	89.3	±	9.05	50.8	±	5.22	64.0	±	9.88
2-W10-8	7	11.3	±	4.47	2.61	±	1.53	5.43	±	2.69

9 2 1 2 5 5 6 0 3 5 2

TABLE A.15. (contd)

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum			Minimum			Average		
2-W10-9	7	89.2	±	9.64	34.1	±	4.49	52.9	±	15.6
2-W11-11	4	55.7	±	5.33	43.4	±	4.90	49.3	±	6.49
2-W11-15	3	21.4	±	3.24	18.7	±	3.12	19.6	±	2.60
2-W11-18	4	55.2	±	5.54	47.6	±	5.12	51.1	±	4.55
2-W11-23	4	46.2	±	5.21	20.5	±	3.65	33.9	±	12.7
2-W11-24	4	56.2	±	5.61	8.48	±	2.48	20.7	±	23.3
2-W12-1	1	35.4	±	6.23				35.4	±	---
2-W14-2	9	106	±	9.63	45.2	±	4.91	76.9	±	13.9
2-W14-5	8	37.7	±	6.39	23.4	±	3.58	29.2	±	3.99
2-W14-6	7	26.0	±	3.82	6.85	±	4.05	15.2	±	5.55
2-W14-10	11	9.71	±	2.53	4.65	±	1.89	6.41	±	1.10
2-W15-3	4	88.3	±	6.63	73.2	±	6.18	81.0	±	8.01
2-W15-4	7	24.1	±	5.96	10.5	±	2.87	15.3	±	4.16
2-W15-6	4	5.12	±	1.84	4.04	±	1.71	4.39	±	1.02
2-W15-7	1	23.8	±	3.41				23.8	±	---
2-W15-10	7	24.9	±	5.66	14.9	±	4.65	19.8	±	3.21
2-W15-11	7	26.0	±	5.71	11.8	±	2.69	17.0	±	4.26
2-W18-5	4	9.27	±	2.48	3.94	±	1.67	7.17	±	2.81
2-W18-9	4	8.59	±	3.83	1.84	±	1.27	4.60	±	3.48
2-W18-15	14	29.3	±	3.59	8.44	±	3.74	16.4	±	2.99
2-W18-17	4	6.08	±	1.74	2.33	±	1.32	4.14	±	1.98
2-W18-18	4	4.39	±	1.64	2.46	±	1.30	3.09	±	1.18
2-W18-20	4	6.11	±	1.79	3.71	±	1.51	4.70	±	1.43
2-W19-1	1	17.7	±	4.90				17.7	±	---
2-W19-2	6	128	±	8.60	69.8	±	6.47	97.2	±	19.0
2-W19-3	15	10,100	±	637	1,090	±	30.8	6,260	±	1,330
2-W19-5	6	30.3	±	3.69	16.8	±	2.82	25.1	±	4.67
2-W19-9	15	5,060	±	456	516	±	21.0	2,700	±	779
2-W19-11	16	6,970	±	533	-0.27	±	96.3	3,920	±	1,060
2-W19-12	4	28.4	±	3.67	9.65	±	2.31	18.6	±	9.24
2-W19-13	16	26.7	±	5.84	11.6	±	2.56	18.6	±	2.18
2-W19-14	7	13.2	±	2.61	8.17	±	2.18	10.1	±	1.66
2-W19-15	16	817	±	202	81.9	±	11.8	355	±	124
2-W19-16	16	2,680	±	337	350	±	17.1	1,540	±	355
2-W19-17	11	82.1	±	12.7	42.7	±	4.58	60.1	±	7.16
2-W19-18	10	9,290	±	613	6,290	±	507	7,940	±	672
2-W19-19	10	518	±	18.4	180	±	10.7	284	±	77.7
2-W19-20	14	1,150	±	38.4	133	±	9.13	664	±	179
2-W19-21	7	16.9	±	2.77	7.74	±	1.93	11.5	±	2.71
2-W19-23	8	345	±	36.2	85.7	±	7.19	230	±	65.1
2-W19-24	7	1,440	±	43.9	626	±	20.5	1,040	±	228
2-W19-25	8	3,090	±	107	637	±	19.3	1,950	±	609
2-W19-26	6	383	±	38.8	86.7	±	7.22	210	±	96.2
2-W19-27	6	19.2	±	3.01	11.6	±	2.34	15.6	±	2.69
2-W22-1	1	35.2	±	3.94				35.2	±	---
2-W22-2	1	16.4	±	2.77				16.4	±	---
2-W22-10	4	120	±	6.86	65.5	±	5.21	88.3	±	26.7
2-W22-12	6	8.43	±	3.48	6.10	±	1.93	6.96	±	1.39
2-W22-18	4	48.8	±	4.69	4.15	±	1.64	22.0	±	21.8
2-W22-20	7	43.8	±	6.56	33.0	±	4.31	39.5	±	3.72
2-W22-21	4	224	±	9.78	180	±	8.76	197	±	21.9
2-W22-22	15	6.13	±	3.26	-0.29	±	0.64	3.70	±	0.96

TABLE A.15. (contd)

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum			Minimum			Average		
2-W22-26	6	28.5	±	5.06	12.7	±	2.50	21.1	±	5.33
2-W23-1	5	1,450	±	50.4	37.0	±	9.04	437	±	544
2-W23-2	5	1,440	±	50.0	533	±	15.2	1,030	±	349
2-W23-3	5	143	±	7.85	44.5	±	4.40	82.4	±	38.0
2-W23-4	1	7.96	±	1.97				7.96	±	---
2-W23-7	2	808	±	18.7	736	±	24.7	772	±	91.5
2-W23-9	12	22.4	±	3.67	8.72	±	2.21	12.6	±	2.32
2-W23-10	16	34.4	±	5.90	13.2	±	2.66	22.4	±	3.86
2-W23-11	13	19.9	±	3.08	7.02	±	1.97	11.0	±	2.51
2-W26-3	4	5.85	±	1.81	2.13	±	1.39	4.31	±	1.99
2-W26-6	4	6.63	±	1.97	2.47	±	1.44	4.43	±	2.19
2-W27-1	16	34.7	±	6.25	5.72	±	1.98	9.74	±	3.52
3-1-1	7	11.6	±	3.65	7.31	±	3.22	8.59	±	1.80
3-1-2	7	24.3	±	4.69	6.37	±	3.45	12.7	±	5.23
3-1-3	5	46.9	±	6.56	22.1	±	4.95	33.4	±	9.85
3-1-4	7	12.2	±	3.97	6.00	±	3.52	9.77	±	2.21
3-1-5	7	50.0	±	6.47	12.9	±	4.05	30.8	±	10.6
3-1-6	7	13.5	±	3.83	4.39	±	3.37	7.79	±	2.86
3-1-7	6	49.9	±	6.66	14.3	±	4.34	32.4	±	11.7
3-1-8	7	29.9	±	5.18	13.5	±	3.94	24.2	±	4.96
3-1-9	4	10.1	±	4.29	7.37	±	3.45	8.59	±	2.36
3-1-10	6	9.73	±	3.47	4.46	±	3.30	6.68	±	2.19
3-1-11	6	50.6	±	6.49	5.02	±	2.02	24.1	±	14.8
3-1-12	6	47.1	±	6.28	10.1	±	3.71	19.4	±	12.1
3-1-13	8	13.4	±	4.13	4.38	±	3.37	9.57	±	2.61
3-1-14	6	16.0	±	4.22	3.94	±	3.25	9.08	±	4.16
3-1-15	6	17.3	±	4.46	5.81	±	3.46	11.2	±	4.05
3-1-16A	6	20.2	±	4.39	5.61	±	3.57	10.9	±	4.96
3-1-16B	5	8.58	±	4.06	4.43	±	3.78	7.36	±	2.29
3-1-16C	5	14.5	±	4.08	6.08	±	3.60	10.1	±	3.67
3-1-16D	1	14.8	±	4.68				14.8	±	---
3-1-17A	6	113	±	9.24	17.9	±	3.20	50.1	±	30.8
3-1-17B	5	9.62	±	3.69	4.07	±	2.14	7.41	±	2.63
3-1-17C	5	54.7	±	7.38	9.48	±	2.70	20.9	±	17.5
3-1-18A	6	14.9	±	4.55	5.75	±	3.72	12.4	±	3.42
3-1-18B	5	13.9	±	4.15	5.65	±	3.68	9.80	±	3.64
3-1-18C	5	9.69	±	3.84	6.68	±	3.74	8.12	±	2.05
3-1-19	5	121	±	9.58	31.4	±	4.00	79.8	±	34.6
3-2-1	7	22.8	±	4.56	9.62	±	3.91	14.2	±	4.00
3-3-7	7	14.2	±	4.40	7.41	±	3.97	10.5	±	2.40
3-3-10	7	17.0	±	4.61	6.03	±	3.68	12.8	±	3.42
3-4-1	7	18.9	±	4.56	5.53	±	3.13	10.5	±	4.02
3-4-7	7	40.0	±	6.11	4.98	±	2.22	16.8	±	9.93
3-4-11	6	12.9	±	3.92	7.76	±	3.48	10.2	±	2.30
3-8-1	1	5.21	±	3.51				5.21	±	---
3-8-2	7	10.7	±	4.10	7.40	±	3.91	9.47	±	1.72
3-8-3	1	7.37	±	3.85				7.37	±	---
4-S1-7C	7	50.0	±	16.0	23.0	±	3.60	30.9	±	8.29
4-S1-8A	3	30.8	±	3.91	23.5	±	5.43	26.3	±	5.59
4-S1-8B	5	28.7	±	5.94	24.8	±	3.73	27.1	±	2.46

9 2 1 2 5 5 6 0 3 5 4

TABLE A.15. (contd)

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum			Minimum			Average		
6-2-3	2	36.6	±	5.88	27.9	±	5.79	32.3	±	11.7
6-2-33A	2	2.97	±	2.90	1.72	±	3.31	2.34	±	2.70
6-8-25	2	25.5	±	5.11	19.1	±	5.20	22.3	±	8.81
6-9-E2	3	9.78	±	3.55	4.26	±	3.59	6.63	±	4.30
6-10-E12	1	9.60	±	4.26				9.60	±	---
6-15-26	4	27.1	±	3.75	20.4	±	3.29	24.6	±	3.97
6-19-43	1	6.55	±	3.61				6.55	±	---
6-20-E5A	2	20.2	±	4.59	17.2	±	4.83	18.7	±	5.02
6-20-20	5	45.5	±	6.31	29.7	±	5.81	40.3	±	6.56
6-20-39[c]	3	9.30	±	4.08	3.31	±	3.36	6.14	±	4.63
6-23-34	2	23.8	±	5.64	19.1	±	5.14	21.5	±	7.02
6-24-33	6	27.8	±	5.20	14.8	±	4.83	22.0	±	4.60
6-24-34A	2	24.2	±	5.63	21.9	±	5.35	23.0	±	4.84
6-24-34B	3	27.9	±	5.87	22.3	±	5.49	24.8	±	5.02
6-24-34C	2	27.9	±	5.96	18.9	±	5.00	23.4	±	11.9
6-24-35	2	17.8	±	4.87	16.2	±	4.82	17.0	±	3.97
6-24-46	1	10.0	±	4.00				10.0	±	---
6-25-33A	4	10.9	±	3.82	6.80	±	3.40	8.96	±	2.76
6-25-34A	4	32.5	±	5.47	21.6	±	5.16	26.4	±	5.92
6-25-34B	4	34.3	±	5.65	22.2	±	5.20	28.5	±	6.48
6-25-34C	1	16.7	±	4.76				16.7	±	---
6-26-33	4	33.9	±	5.55	22.9	±	5.12	28.2	±	5.98
6-26-34	4	38.0	±	5.82	21.3	±	5.08	31.7	±	8.59
6-26-35A	4	35.7	±	5.81	24.2	±	5.55	29.2	±	6.24
6-26-35C	4	32.5	±	5.48	15.5	±	4.75	25.2	±	8.66
6-28-40	1	25.4	±	5.32				25.4	±	---
6-29-4	2	37.6	±	5.81	26.2	±	5.52	31.9	±	14.8
6-29-78	1	2.46	±	3.20				2.46	±	---
6-32-22	2	46.8	±	6.81	39.5	±	6.44	43.2	±	10.3
6-32-43	1	54.3	±	7.38				54.3	±	---
6-32-70B	1	25.1	±	5.33				25.1	±	---
6-32-72	12	15.7	±	2.80	3.13	±	1.45	8.51	±	2.90
6-32-77	1	3.37	±	3.28				3.37	±	---
6-33-42	1	63.1	±	7.76				63.1	±	---
6-33-56	1	7.22	±	4.43				7.22	±	---
6-34-42	1	14.5	±	4.79				14.5	±	---
6-34-51	1	7.58	±	3.86				7.58	±	---
6-35-9	2	48.2	±	7.20	39.2	±	6.53	43.7	±	12.3
6-35-66	1	14.6	±	4.63				14.6	±	---
6-35-70	1	28.7	±	5.83				28.7	±	---
6-35-78A	12	10.1	±	2.29	4.42	±	1.67	6.73	±	1.22
6-36-61A	1	9.01	±	3.98				9.01	±	---
6-37-E4	2	26.4	±	3.60	19.1	±	4.92	22.8	±	9.64
6-37-43	1	9.10	±	4.09				9.10	±	---
6-37-82A	1	14.1	±	4.37				14.1	±	---
6-38-65	2	16.9	±	4.39	15.5	±	5.01	16.2	±	3.76
6-38-70	4	381	±	16.1	278	±	16.3	327	±	50.7
6-39-0	1	66.6	±	5.61				66.6	±	---
6-39-79	4	11.0	±	3.65	4.05	±	3.02	6.87	±	3.83
6-40-1	4	64.9	±	7.35	38.7	±	6.39	53.2	±	13.1
6-40-33A	2	8.18	±	3.88	5.78	±	3.65	6.98	±	4.02
6-40-62	1	7.96	±	4.11				7.96	±	---

TABLE A.15. (contd)

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum			Minimum			Average		
6-41-1	2	64.4	±	5.51	40.1	±	6.44	52.3	±	30.7
6-42-2	2	61.5	±	5.41	41.2	±	6.49	51.4	±	25.8
6-42-40A	12	5.10	±	1.68	3.32	±	1.50	4.09	±	0.58
6-42-40B	12	6.90	±	1.85	2.15	±	1.31	4.04	±	0.88
6-43-3	2	50.1	±	7.09	46.5	±	4.75	48.3	±	6.21
6-43-88	3	8.13	±	4.11	6.66	±	3.37	7.24	±	2.41
6-44-64	1	16.2	±	4.66				16.2	±	---
6-45-2	2	52.2	±	5.01	41.3	±	6.51	46.8	±	14.3
6-45-42	5	8.07	±	3.85	2.95	±	1.54	4.77	±	2.22
6-45-69A	1	10.2	±	4.19				10.2	±	---
6-46-4	2	43.0	±	4.54	30.5	±	5.84	36.8	±	16.1
6-47-5	2	27.0	±	3.68	22.7	±	5.24	24.9	±	6.27
6-47-46A	1	10.9	±	4.20				10.9	±	---
6-47-50	1	11.0	±	4.40				11.0	±	---
6-47-60	1	6.23	±	3.87				6.23	±	---
6-48-7	2	3.80	±	3.35	2.67	±	3.21	3.24	±	2.72
6-48-18	2	11.1	±	4.35	6.83	±	3.80	8.96	±	6.08
6-48-71	2	20.7	±	5.16	5.21	±	3.61	13.0	±	19.7
6-49-13E	1	4.03	±	1.68				4.03	±	---
6-49-55A	4	1,390	±	36.7	1,180	±	33.3	1,240	±	103
6-49-57	6	299	±	15.9	174	±	11.3	255	±	40.7
6-49-79	3	7.64	±	3.55	3.79	±	3.49	6.34	±	3.38
6-49-100C	3	10.2	±	2.39	6.80	±	2.06	8.35	±	2.66
6-50-42	2	7.35	±	2.10	5.84	±	1.91	6.60	±	2.37
6-50-53	6	2,770	±	55.2	1,240	±	32.3	2,100	±	494
6-50-85	1	3.67	±	3.23				3.67	±	---
6-51-75	3	9.62	±	3.64	5.70	±	3.59	7.47	±	3.44
6-53-47A	11	143	±	7.99	86.8	±	6.28	111	±	10.2
6-53-47B	12	190	±	9.39	135	±	7.79	157	±	8.91
6-53-48A	12	16.2	±	4.49	5.94	±	3.23	9.69	±	1.99
6-53-48B	12	691	±	36.6	365	±	25.7	545	±	63.4
6-53-55A	11	9.57	±	2.31	6.31	±	1.99	7.96	±	0.91
6-54-48	11	117	±	7.49	89.5	±	6.49	105	±	5.51
6-54-49	11	123	±	7.45	22.4	±	3.24	69.1	±	22.2
6-55-50C	5	6.95	±	3.61	3.68	±	1.61	5.24	±	1.61
6-55-50D	4	45.6	±	4.64	4.76	±	1.69	24.8	±	19.9
6-55-76	1	6.37	±	3.59				6.37	±	---
6-56-51	1	5.07	±	1.76				5.07	±	---
6-59-58	2	5.03	±	1.77	4.54	±	1.71	4.79	±	1.38
6-63-58	2	17.8	±	2.95	14.3	±	2.67	16.0	±	4.82
6-65-72	1	26.6	±	5.44				26.6	±	---
6-65-83	1	9.32	±	4.47				9.32	±	---
6-67-86	1	4.76	±	3.52				4.76	±	---
6-70-68	1	13.3	±	4.18				13.3	±	---
6-71-30	1	7.13	±	3.86				7.13	±	---
6-71-52	1	5.01	±	3.52				5.01	±	---
6-71-77	1	27.1	±	5.51				27.1	±	---
6-73-61	1	3.41	±	3.36				3.41	±	---
6-74-44	1	1.58	±	3.07				1.58	±	---
6-77-36	1	8.58	±	4.13				8.58	±	---
6-77-54	2	8.51	±	3.86	7.06	±	3.66	7.79	±	3.22
6-81-58	1	0.85	±	3.04				0.85	±	---

TABLE A.15. (contd)

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum			Minimum			Average		
6-83-47	2	11.1	±	4.34	8.08	±	3.86	9.59	±	4.77
6-89-35	2	12.2	±	4.38	3.31	±	3.51	7.76	±	11.5
6-90-45	3	5.67	±	3.66	4.07	±	3.29	4.70	±	2.29
6-96-49	5	7.88	±	3.85	4.89	±	1.83	6.04	±	1.58
6-97-43	5	6.76	±	2.04	3.72	±	3.43	5.14	±	1.56
6-97-51A	1	3.89	±	3.70				3.89	±	---
6-101-48B	1	4.83	±	3.37				4.83	±	---
6-S3-E12	1	4.84	±	3.52				4.84	±	---
6-S3-25	2	11.7	±	4.43	11.5	±	3.93	11.6	±	2.97
6-S6E14A[c]	2	9.26	±	3.54	7.18	±	3.96	8.22	±	3.72
6-S8-19	2	11.1	±	3.83	9.74	±	4.24	10.4	±	3.33
6-S11E12AP[c]	1	7.38	±	4.26				7.38	±	---
6-S12-3	3	11.0	±	4.26	3.55	±	3.12	7.03	±	5.53
6-S19-E13	7	43.1	±	6.90	6.15	±	3.78	14.8	±	10.5
6-S28-E0	4	8.17	±	2.22	5.76	±	1.89	6.48	±	1.53
6-S29-E12	3	15.0	±	4.03	3.89	±	3.48	11.3	±	7.91
6-S30E15A	10	10.6	±	3.82	4.33	±	1.83	7.18	±	1.74
6-S31-1	2	5.74	±	3.61	5.50	±	3.59	5.62	±	2.56

(a) Maximum and minimum concentrations± 2-sigma counting error. Average concentrations ±2 standard error of the calculated mean (no estimate of standard error for one sample).
(b) See Figures 3.10, 3.11 and 3.12 for well locations.
(c) Wells that sample a confined aquifer or a composite of confined and unconfined aquifer.

TABLE A.16. Maximum, Minimum, and Average Uranium Concentrations in Ground-Water Samples in 1987

Well Name[a]	No. of Samples	Concentration (pCi/L) Maximum	Minimum	Average[b]
1-D5-12	2	3.54	1.86	2.70 ± 2.11
1-F5-1	4	0.883	0.532	0.711 ± 0.171
1-F5-3	4	1.18	0.113	0.404 ± 0.519
1-F5-4	4	7.12	4.02	5.84 ± 1.51
1-F5-6	4	1.02	-0.065	0.373 ± 0.527
1-F7-1	4	5.65	4.60	5.13 ± 0.510
1-F8-1	12	362	71.7	256 ± 57.9
1-F8-2	8	144	26.6	87.0 ± 29.1
1-H3-1	4	6.80	4.18	5.89 ± 1.27
1-H4-3	4	186	91.0	148 ± 46.2
1-H4-4	4	67.0	0.544	36.5 ± 32.3
1-H4-5	4	2.31	1.82	2.04 ± 0.238
1-H4-6	4	3.59	2.44	2.97 ± 0.559
1-K-11	4	4.05	3.15	3.59 ± 0.437
1-K-19	12	1.12	0.624	0.805 ± 0.089
1-K-20	4	1.29	0.967	1.08 ± 0.157
1-K-22	8	1.17	0.629	0.915 ± 0.134
1-K-27	4	4.31	2.69	3.29 ± 0.787
1-K-28	4	4.08	3.41	3.76 ± 0.326
1-K-29	4	1.70	1.34	1.54 ± 0.175
1-K-30	4	1.86	1.55	1.71 ± 0.151
2-E13-5	2	1.65	1.59	1.62 ± 0.075
2-E13-8	2	1.96	1.47	1.72 ± 0.614
2-E13-14	2	2.28	1.80	2.04 ± 0.601
2-E13-19	2	2.31	1.50	1.91 ± 1.01
2-E17-2	3	6.80	4.86	5.65 ± 1.32
2-E17-5	12	7.43	4.09	5.75 ± 0.546
2-E17-9	12	3.03	1.94	2.52 ± 0.213
2-E17-12	12	4.07	1.75	3.04 ± 0.390
2-E17-13	12	5.73	3.13	4.16 ± 0.574
2-E24-8	2	2.02	1.23	1.63 ± 0.990
2-E25-10	3	1.13	1.06	1.10 ± 0.048
2-E27-1	2	0.832	0.719	0.776 ± 0.142
2-E27-5	2	1.39	1.19	1.29 ± 0.251
2-E28-7	4	1.35	1.06	1.18 ± 0.141
2-E28-9	4	8.82	4.55	6.82 ± 2.08
2-E28-16	4	8.06	4.72	6.18 ± 1.62
2-E28-17	4	8.40	4.11	6.28 ± 2.08
2-E28-18	11	84.0	35.6	50.9 ± 9.86
2-E28-21	12	55.1	30.7	44.4 ± 4.61
2-E28-23	4	35.8	23.7	27.1 ± 5.88
2-E28-24	4	0.517	0.148	0.280 ± 0.179

TABLE A.16. (contd)

Well Name[a]	No. of Samples	Concentration (pCi/L) Maximum	Minimum	Average[b]
2-E28-25	4	5.07	2.47	3.74 ± 1.26
2-E33-1	2	1.20	0.868	1.03 ± 0.416
2-E33-3	5	4.60	1.04	1.92 ± 1.37
2-E33-5	2	1.17	0.576	0.873 ± 0.744
2-E33-7	2	1.16	0.975	1.07 ± 0.232
2-E33-8	2	1.40	1.23	1.32 ± 0.213
2-E33-9	1	1.45		1.45 ± ---
2-E33-10	2	1.42	1.20	1.31 ± 0.276
2-E33-12[c]	2	0.102	0.006	0.054 ± 0.120
2-E33-14	2	1.30	1.22	1.26 ± 0.100
2-E33-18	2	1.34	1.18	1.26 ± 0.200
2-E33-20	2	1.19	1.08	1.14 ± 0.138
2-E33-21	2	1.37	1.22	1.30 ± 0.188
2-E33-24	2	1.54	1.43	1.49 ± 0.138
2-W10-1	2	2.52	1.52	2.02 ± 1.25
2-W10-3	2	17.7	8.20	13.0 ± 11.9
2-W10-4	2	0.921	0.646	0.784 ± 0.345
2-W10-8	2	1.28	0.889	1.08 ± 0.490
2-W10-9	2	2.10	1.89	2.00 ± 0.263
2-W11-3	2	1.07	1.03	1.05 ± 0.050
2-W11-9	2	0.458	0.277	0.368 ± 0.227
2-W14-2	2	1.21	0.832	1.02 ± 0.474
2-W14-5	2	0.967	0.448	0.708 ± 0.650
2-W14-6	2	2.00	0.878	1.44 ± 1.41
2-W15-4	2	5.45	4.07	4.76 ± 1.73
2-W18-15	12	53.1	40.8	47.1 ± 2.07
2-W19-2	6	65.6	16.1	42.5 ± 16.0
2-W19-3	12	11,500	4,080	7,560 ±1,340
2-W19-5	3	8.44	5.79	7.47 ± 1.81
2-W19-9	11	6,650	1,580	3,460 ± 913
2-W19-11	12	6,580	2.01	4,280 ±1,020
2-W19-12	4	4.76	3.34	3.77 ± 0.690
2-W19-13	12	11.2	5.44	8.46 ± 0.980
2-W19-14	7	3.29	2.60	2.93 ± 0.193
2-W19-15	12	554	133	267 ± 85.8
2-W19-16	12	1,790	1,060	1,400 ± 142
2-W19-17	11	42.1	21.7	33.7 ± 3.75
2-W19-18	10	6,700	4,270	5,150 ± 461
2-W19-19	10	526	288	376 ± 45.1
2-W19-20	12	480	138	295 ± 57.6
2-W19-21	7	18.7	8.40	15.4 ± 2.88
2-W19-23	8	160	129	143 ± 7.69
2-W19-24	6	512	438	464 ± 23.9
2-W19-25	8	285	155	248 ± 32.3
2-W19-26	6	170	86.1	126 ± 27.1
2-W19-27	6	9.03	7.57	8.36 ± 0.471

9 2 1 2 5 5 6 0 3 5 9

TABLE A.16. (contd)

Well Name[a]	No. of Samples	Concentration (pCi/L) Maximum	Minimum	Average[b]
2-W22-1	2	3.15	3.15	3.15 ± 0.00
2-W22-2	2	6.45	5.96	6.21 ± 0.614
2-W22-7	2	0.922	0.860	0.891 ± 0.078
2-W22-9	2	4.42	4.25	4.34 ± 0.213
2-W22-10	2	0.512	0.491	0.502 ± 0.026
2-W22-12	1	0.997		0.997 ± ---
2-W22-20	2	4.85	3.80	4.32 ± 1.32
2-W22-21	4	16.1	10.4	13.5 ± 2.77
2-W22-22	12	0.826	0.090	0.436 ± 0.137
2-W22-26	3	9.93	5.28	6.91 ± 3.17
2-W23-1	3	12.8	7.14	10.4 ± 3.86
2-W23-2	4	4.15	2.40	3.42 ± 0.851
2-W23-4	5	20.1	12.5	17.0 ± 2.92
2-W23-9	11	50.8	18.7	27.7 ± 5.96
2-W23-10	11	47.7	27.6	35.5 ± 4.02
2-W23-11	13	21.9	12.9	16.2 ± 1.43
2-W26-3	4	1.03	0.689	0.874 ± 0.166
2-W27-1	4	6.46	4.17	5.25 ± 1.11
3-1-1	5	24.4	11.9	15.0 ± 4.81
3-1-2	5	18.6	8.58	12.1 ± 3.85
3-1-3	7	33.1	9.00	22.7 ± 6.74
3-1-4	5	36.0	19.1	24.8 ± 6.50
3-1-5	4	58.2	18.7	32.3 ± 19.2
3-1-6	5	15.0	8.97	11.5 ± 2.32
3-1-7	1	26.2		26.2 ± ---
3-1-8	1	17.2		17.2 ± ---
3-1-10	1	7.92		7.92 ± ---
3-1-11	12	53.2	23.5	34.9 ± 4.91
3-1-12	1	33.4		33.4 ± ---
3-1-13	2	9.79	9.10	9.45 ± 0.865
3-1-14	1	12.6		12.6 ± ---
3-1-15	1	5.47		5.47 ± ---
3-1-16A	2	9.17	8.96	9.07 ± 0.263
3-1-16B	1	2.86		2.86 ± ---
3-1-16C	1	1.74		1.74 ± ---
3-1-17A	12	71.5	29.2	42.4 ± 7.37
3-1-18A	1	2.97		2.97 ± ---
3-1-18B	1	0.030		0.030 ± ---
3-1-18C	1	0.049		0.049 ± ---
3-1-19	12	310	57.8	136 ± 39.5
3-2-1	5	12.0	5.53	8.60 ± 2.49
3-2-2	4	22.1	13.1	16.7 ± 4.37
3-2-3	4	15.0	6.48	9.98 ± 4.14
3-3-1	4	8.41	6.80	7.28 ± 0.782
3-3-2	4	8.94	0.963	6.05 ± 3.88
3-3-3	4	9.94	7.72	8.71 ± 1.08

9 2 1 2 5 5 6 0 3 6 0

TABLE A.16. (contd)

Well Name[a]	No. of Samples	Concentration (pCi/L) Maximum	Minimum	Average[b]
3-3-6	4	13.8	9.98	11.8 ± 1.86
3-3-7	5	10.7	7.36	9.43 ± 1.28
3-3-9	4	18.7	10.2	14.9 ± 4.13
3-3-10	5	53.3	13.9	31.2 ± 15.2
3-3-11	4	28.9	20.5	24.5 ± 4.08
3-3-12	4	41.0	26.5	31.1 ± 7.05
3-4-1	5	16.1	11.1	13.2 ± 1.92
3-4-7	4	38.2	3.25	25.9 ± 17.0
3-4-9	4	29.8	24.3	26.5 ± 2.67
3-4-10	4	38.3	17.6	28.6 ± 10.1
3-4-11	1	11.7		11.7 ± ---
3-5-1	4	4.61	3.46	3.96 ± 0.559
3-6-1	11	13.0	4.38	7.09 ± 1.62
3-8-1	5	4.59	3.33	3.68 ± 0.485
3-8-2	5	4.49	1.76	2.60 ± 1.05
3-8-3	12	7.07	2.70	4.35 ± 0.770
3-8-4	3	2.29	1.69	1.98 ± 0.409
6-3-45	2	0.323	0.297	0.310 ± 0.033
6-20-20	4	3.62	2.81	3.13 ± 0.394
6-32-70B	2	1.20	1.18	1.19 ± 0.025
6-32-72	2	0.487	0.225	0.356 ± 0.328
6-35-66	4	2.04	1.56	1.81 ± 0.233
6-35-70	2	2.34	2.16	2.25 ± 0.226
6-35-78A	11	13.5	5.45	7.97 ± 1.42
6-37-E4	1	2.24		2.24 ± ---
6-38-65	2	1.57	1.54	1.56 ± 0.038
6-38-70	3	39.2	36.4	38.3 ± 1.91
6-39-0	1	3.12		3.12 ± ---
6-40-1	1	2.81		2.81 ± ---
6-41-1	2	2.53	2.34	2.44 ± 0.238
6-42-2	1	3.04		3.04 ± ---
6-42-12A	4	2.15	1.71	1.93 ± 0.214
6-42-40A	4	0.692	0.269	0.487 ± 0.206
6-43-3	1	2.51		2.51 ± ---
6-45-2	1	2.78		2.78 ± ---
6-45-42	4	1.76	1.28	1.53 ± 0.233
6-46-4	1	2.33		2.33 ± ---
6-47-5	5	4.92	1.71	2.65 ± 1.23
6-47-46A	2	2.15	1.43	1.79 ± 0.902
6-47-60	2	1.58	1.55	1.57 ± 0.038
6-49-13E	1	1.60		1.60 ± ---
6-49-55A	2	3.23	2.75	2.99 ± 0.601
6-55-89	2	1.06	0.758	0.909 ± 0.378
6-61-62	2	1.18	1.09	1.14 ± 0.113
6-63-58	2	0.705	0.568	0.637 ± 0.172
6-66-64	2	1.67	1.42	1.55 ± 0.313

TABLE A.16. (contd)

Well Name[a]	No. of Samples	Concentration (pCi/L) Maximum	Minimum	Average[b]
6-S6-E4B	4	3.49	2.70	3.01 ± 0.384
6-S6-E4D	11	7.50	2.56	3.60 ± 0.996
6-S12-3	2	2.94	2.90	2.92 ± 0.050
6-S14-20A	2	0.673	0.077	0.375 ± 0.747
6-S19-E13	8	4.16	1.33	2.92 ± 0.702
6-S27-E14	12	4.95	2.63	3.95 ± 0.366
6-S29-E12	4	2.78	2.26	2.46 ± 0.253
6-S30E15A	4	1.48	1.40	1.45 ± 0.039

(a) See Figures 3.10, 3.11, and 3.12 for well locations.
(b) Average concentrations ± 2 standard error of the calculated mean.
(c) Wells that sample a confined aquifer or a composite of confined and unconfined aquifer.

TABLE A.17. Maximum, Minimum, and Average Strontium-90 (^{90}Sr) Concentrations in Ground-Water Samples in 1987

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum			Minimum			Average		
1-B3-1	1	55.2	±	3.61				55.2	±	---
1-B4-1	1	27.3	±	2.65				27.3	±	---
1-B4-4	2	35.4	±	2.54	31.0	±	2.86	33.2	±	5.84
1-D2-5	1	-0.156	±	0.50				-0.156	±	---
1-D5-12	1	45.9	±	3.37				45.9	±	---
1-F8-1	2	0.414	±	0.869	0.409	±	0.718	0.412	±	0.564
1-H3-1	4	0.471	±	0.343	-0.0323	±	0.461	0.232	±	0.307
1-H4-3	4	1.03	±	0.367	0.647	±	0.389	0.835	±	0.285
1-H4-4	4	8.05	±	1.93	2.82	±	1.07	5.03	±	2.64
1-H4-5	4	0.927	±	0.852	0.197	±	0.516	0.550	±	0.542
1-H4-6	4	0.518	±	0.738	-0.313	±	0.617	0.168	±	0.530
1-N-2	3	4390	±	39.9	1270	±	18.0	3110	±	2130
1-N-3	3	1460	±	60.0	1220	±	17.8	1340	±	165
1-N-4	3	14.3	±	1.91	11.1	±	1.81	12.6	±	2.43
1-N-5	3	871	±	36.7	250	±	8.99	511	±	424
1-N-7	1	2.79	±	1.26				2.79	±	---
1-N-14	2	1170	±	54.0	962	±	17.1	1070	±	262
1-N-15	4	2.07	±	0.947	0.778	±	0.836	1.36	±	0.773
1-N-16	2	2.49	±	1.09	-0.17	±	0.7	1.16	±	3.40
1-N-18	4	541	±	25.6	255	±	10.5	366	±	139
1-N-19	4	129	±	5.99	86.5	±	4.88	103	±	20.8
1-N-20	4	45.5	±	3.66	12.2	±	1.71	28.3	±	16.2
1-N-21	10	11.9	±	2.38	2.82	±	1.18	6.32	±	1.92
1-N-22	4	1.47	±	0.889	0.116	±	0.716	0.807	±	0.771
1-N-23	11	8.87	±	2.21	0.451	±	0.474	2.66	±	1.82
1-N-24	3	6.61	±	1.41	6.38	±	1.46	6.52	±	0.856
1-N-25	4	1.21	±	1.05	0.265	±	0.767	0.591	±	0.624
1-N-27	3	148	±	6.46	93.5	±	4.98	129	±	37.3
1-N-28	3	54.6	±	3.67	1.62	±	0.946	23.7	±	36.2
1-N-29	2	669	±	41	444	±	11.6	557	±	283
1-N-30	4	6.16	±	1.63	4.55	±	1.13	5.09	±	1.03
1-N-31	3	22.3	±	2.56	14.9	±	2.13	19.6	±	5.25
1-N-32	4	7.1	±	1.71	2.87	±	1.11	4.94	±	2.17
1-N-33	8	663	±	19.9	0.52	±	15.4	518	±	165
1-N-36	4	135	±	7.78	73.3	±	5.03	110	±	30.1
1-N-37	3	36.3	±	4.38	31.6	±	3.22	33.2	±	3.81
1-N-39	3	10400	±	240	856	±	15.4	4050	±	6510
1-N-45	4	3160	±	91.8	258	±	25.8	1760	±	1410
1-N-49	3	1.37	±	0.845	0.0792	±	0.494	0.830	±	0.984
1-N-50	3	0.0274	±	0.702	-0.172	±	0.433	-0.0676	±	0.369
1-N-51	3	0.291	±	0.866	-0.142	±	0.484	0.0334	±	0.489
1-N-52	3	0.0382	±	0.685	-0.428	±	0.684	-0.156	±	0.482

TABLE A.17. (contd)

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum			Minimum			Average		
2-E13-5	2	0.950	±	0.915	0.483	±	0.985	0.717	±	0.891
2-E13-8	2	0.705	±	0.803	0.677	±	0.947	0.691	±	0.622
2-E13-14	2	0.766	±	0.948	0.523	±	0.836	0.645	±	0.702
2-E13-19	2	0.770	±	0.873	0.657	±	0.934	0.714	±	0.655
2-E16-2	4	0.620	±	0.715	-0.232	±	0.660	0.193	±	0.544
2-E17-1	4	6.94	±	1.58	5.91	±	1.42	6.43	±	0.899
2-E17-2	3	4.12	±	1.21	2.93	±	1.00	3.55	±	1.05
2-E17-5	4	6.78	±	1.92	2.52	±	1.14	3.78	±	2.18
2-E17-6	2	0.153	±	0.924	0.00837	±	0.636	0.0807	±	0.589
2-E17-8	4	3.56	±	1.19	2.50	±	1.08	2.95	±	0.758
2-E17-9	4	3.43	±	1.15	2.75	±	0.984	3.19	±	0.645
2-E17-12	12	0.609	±	0.789	-0.214	±	0.568	0.0634	±	0.254
2-E17-13	12	0.743	±	0.770	0.0960	±	0.676	0.393	±	0.248
2-E24-1	2	16.3	±	2.27	14.3	±	2.13	15.3	±	2.95
2-E24-2	7	3.34	±	1.19	1.42	±	0.761	2.40	±	0.675
2-E24-4	2	0.464	±	0.768	0.226	±	0.737	0.345	±	0.610
2-E24-8	2	0.214	±	0.608	0.141	±	0.766	0.178	±	0.497
2-E24-11	4	1.38	±	0.878	0.922	±	0.866	1.09	±	0.486
2-E24-12	4	4.31	±	1.16	2.96	±	1.09	3.60	±	0.875
2-E24-13	2	0.465	±	0.703	0.201	±	0.915	0.333	±	0.665
2-E25-2	2	4.99	±	1.51	0.0965	±	0.706	2.54	±	6.19
2-E25-3	2	0.738	±	0.982	0.289	±	0.694	0.514	±	0.823
2-E25-6	4	0.332	±	0.831	-0.178	±	0.628	0.109	±	0.438
2-E25-9	4	0.701	±	0.795	0.0321	±	0.649	0.356	±	0.490
2-E25-11	4	2.61	±	1.35	0.0161	±	0.623	0.760	±	1.35
2-E25-17	4	1.22	±	0.906	-0.232	±	0.547	0.584	±	0.801
2-E25-18	4	2.34	±	1.01	0.0526	±	0.721	0.667	±	1.18
2-E25-19	4	0.407	±	0.674	-0.628	±	0.508	-0.037	±	0.597
2-E25-20	4	0.156	±	0.767	-0.128	±	0.634	0.069	±	0.385
2-E25-21	4	0.958	±	0.951	-0.156	±	0.669	0.291	±	0.658
2-E25-22	4	0.840	±	0.747	0.0272	±	0.639	0.404	±	0.525
2-E25-23	2	0.151	±	0.739	-0.138	±	0.606	0.0065	±	0.600
2-E25-24	3	0.289	±	0.778	0.0284	±	0.665	0.145	±	0.448
2-E25-25	1	0.00453	±	0.251				0.00453	±	---
2-E25-26	1	0.0975	±	0.286				0.0975	±	---
2-E25-27	1	-0.0721	±	0.223				-0.721	±	---
2-E25-28	1	-0.111	±	0.282				-0.111	±	---
2-E26-2	2	0.402	±	0.932	-0.172	±	0.611	0.115	±	0.910
2-E26-3	2	0.0749	±	0.586	0.0636	±	0.830	0.0693	±	0.508
2-E26-4	2	0.0768	±	0.605	-0.134	±	0.832	-0.0286	±	0.578
2-E26-6	4	0.643	±	0.781	0.260	±	0.711	0.457	±	0.400
2-E27-1	2	0.425	±	0.746	0.259	±	0.732	0.342	±	0.562
2-E27-5	2	0.657	±	0.935	0.285	±	0.755	0.471	±	0.760
2-E28-1	2	-0.0654	±	0.537	-0.177	±	0.630	-0.121	±	0.437
2-E28-7	5	145	±	6.18	69.3	±	4.55	95.6	±	29.2
2-E28-18	3	0.940	±	0.838	0.0548	±	0.645	0.380	±	0.738
2-E28-21	4	1.19	±	0.835	0.114	±	0.666	0.514	±	0.643
2-E28-23	4	7800	±	201	4040	±	176	6110	±	1830

TABLE A.17. (contd)

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum			Minimum			Average		
2-E28-24	4	192	±	6.92	186	±	7.65	189	±	4.69
2-E28-25	4	3490	±	66.7	227	±	7.40	2420	±	1590
2-E33-1	4	0.576	±	0.859	0.0543	±	0.686	0.228	±	0.454
2-E33-3	2	0.508	±	0.819	0.452	±	0.745	0.480	±	0.558
2-E33-5	4	0.826	±	0.758	0.0677	±	0.653	0.450	±	0.520
2-E33-7	4	40.3	±	3.36	-0.458	±	0.604	10.2	±	19.8
2-E33-8	4	0.657	±	0.827	0.0562	±	0.674	0.353	±	0.473
2-E33-9	4	2.01	±	1.06	1.09	±	0.738	1.40	±	0.635
2-E33-10	2	-0.0264	±	0.705	-0.114	±	0.676	-0.0702	±	0.501
2-E33-12[c]	2	0.825	±	1.02	0.279	±	0.687	0.552	±	0.920
2-E33-14	2	1.67	±	1.14	0.172	±	0.667	0.921	±	1.99
2-E33-18	2	2.41	±	0.980	0.665	±	0.808	1.54	±	2.28
2-E33-20	2	2.00	±	0.981	0.735	±	0.780	1.37	±	1.70
2-E33-21	2	0.612	±	0.844	0.0954	±	0.711	0.354	±	0.851
2-E33-24	4	0.935	±	0.863	-0.0199	±	0.636	0.441	±	0.603
2-E33-26	3	0.612	±	0.939	0.185	±	0.717	0.429	±	0.551
2-W10-1	4	0.225	±	0.689	-0.499	±	0.725	-0.116	±	0.500
2-W10-3	4	0.527	±	0.774	-0.0415	±	0.654	0.222	±	0.459
2-W10-4	2	1.83	±	1.05	-0.0941	±	0.672	0.868	±	2.49
2-W10-8	4	1.35	±	1.26	0.0653	±	0.686	0.481	±	0.756
2-W10-9	5	0.461	±	1.10	-0.0588	±	0.785	0.226	±	0.413
2-W11-3	2	0.544	±	0.872	0.0817	±	0.701	0.313	±	0.805
2-W11-9	2	0.945	±	0.917	0.0775	±	0.703	0.511	±	1.23
2-W11-11	4	0.437	±	0.754	-0.0881	±	0.649	0.0723	±	0.441
2-W11-18	2	0.814	±	0.795	0.183	±	0.653	0.499	±	0.943
2-W11-23	4	0.256	±	0.737	-0.151	±	0.620	0.0416	±	0.397
2-W11-24	4	0.940	±	1.20	0.0299	±	0.781	0.266	±	0.618
2-W14-2	2	1.65	±	1.32	0.745	±	0.794	1.20	±	1.37
2-W14-5	2	0.422	±	0.710	0.393	±	0.701	0.408	±	0.500
2-W14-6	2	0.267	±	0.767	0.164	±	0.639	0.216	±	0.516
2-W14-10	4	0.388	±	0.682	0.0111	±	0.669	0.122	±	0.387
2-W15-3	2	0.101	±	0.738	-0.0703	±	0.582	0.0153	±	0.517
2-W15-4	2	0.404	±	0.803	0.212	±	0.658	0.308	±	0.572
2-W15-7	1	0.804	±	0.999				0.804	±	---
2-W15-11	4	0.233	±	0.790	-0.222	±	0.641	0.0444	±	0.444
2-W19-2	4	15.8	±	2.04	10.6	±	2.26	13.4	±	2.74
2-W19-3	4	6.34	±	1.38	0.390	±	0.730	2.80	±	2.94
2-W19-9	1							0.423	±	0.706
2-W19-11	4	2.79	±	1.04	0.0816	±	0.672	1.67	±	1.39
2-W19-12	4	1.36	±	1.06	-0.212	±	0.559	0.449	±	0.857
2-W19-13	4	0.0976	±	0.740	-0.0392	±	0.617	0.0364	±	0.349
2-W19-14	2	0.977	±	0.843	0.0295	±	0.659	0.503	±	1.30
2-W19-15	2	0.230	±	0.661	-0.264	±	0.497	-0.017	±	0.744
2-W19-16	2	3.73	±	1.23	0.245	±	0.675	1.99	±	4.42
2-W19-19	10	0.925	±	0.914	-0.103	±	0.673	0.402	±	0.345
2-W19-20	10	0.668	±	0.859	-0.129	±	0.931	0.326	±	0.287

TABLE A.17. (contd)

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum			Minimum			Average		
2-W19-21	7	0.470	±	0.697	0.0154	±	0.774	0.310	±	0.299
2-W19-23	7	0.768	±	0.873	-0.740	±	0.768	0.132	±	0.509
2-W19-24	6	1.95	±	0.868	0.402	±	0.787	1.25	±	0.622
2-W19-25	7	0.504	±	0.823	-0.0703	±	0.643	0.207	±	0.340
2-W19-26	5	0.643	±	0.791	-0.389	±	0.612	0.172	±	0.529
2-W19-27	6	0.470	±	0.823	-0.294	±	0.759	0.00433	±	0.364
2-W22-1	1	17.0	±	3.43				17.0	±	---
2-W22-2	1	3.71	±	1.22				3.71	±	---
2-W22-7	2	0.196	±	0.827	-1.43	±	5.92	-0.617	±	3.62
2-W22-9	2	0.300	±	0.700	0.0358	±	0.648	0.168	±	0.581
2-W22-10	5	94.0	±	6.08	27.6	±	2.74	51.5	±	25.6
2-W22-12	1	0.275	±	0.614				0.275	±	---
2-W22-18	4	12.0	±	2.18	-0.177	±	0.598	3.40	±	5.95
2-W22-20	2	0.949	±	0.841	-0.0435	±	0.497	0.453	±	1.34
2-W22-21	2	1.47	±	0.979	0.627	±	0.817	1.05	±	1.23
2-W22-22	4	0.783	±	0.885	-0.169	±	0.562	0.285	±	0.592
2-W22-26	2	0.160	±	0.626	0.0954	±	0.678	0.128	±	0.468
2-W23-1	2	0.0885	±	0.645	0.00461	±	0.624	0.0466	±	0.461
2-W23-2	4	0.399	±	0.725	0.0834	±	0.729	0.288	±	0.390
2-W23-3	4	0.133	±	0.782	-0.302	±	0.604	-0.0203	±	0.404
2-W23-4	3	0.671	±	1.14	0.165	±	0.690	0.477	±	0.620
2-W23-9	4	0.479	±	0.723	-0.225	±	0.548	0.242	±	0.478
2-W23-10	4	0.795	±	0.731	-0.236	±	0.556	0.175	±	0.600
2-W26-6	4	1.03	±	0.897	-0.154	±	0.753	0.342	±	0.728
2-W27-1	4	0.726	±	0.832	-0.367	±	0.497	0.265	±	0.638
3-1-3	3	0.716	±	0.562	0.260	±	0.280	0.490	±	0.393
3-3-9	4	0.553	±	0.702	0.0565	±	0.599	0.378	±	0.459
3-3-10	4	0.774	±	0.858	0.128	±	0.632	0.383	±	0.474
3-3-11	4	6.97	±	1.50	6.24	±	1.47	6.71	±	0.895
3-3-12	4	0.670	±	0.805	-0.058	±	0.637	0.196	±	0.496
3-4-9	4	0.783	±	1.03	0.121	±	0.646	0.358	±	0.506
3-4-10	4	0.267	±	0.639	-0.303	±	0.541	-0.0652	±	0.408
6-3-45	2	2.84	±	1.06	-0.195	±	0.534	1.32	±	3.85
6-35-70	2	0.202	±	0.718	-0.181	±	0.597	0.0105	±	0.670
6-37-E4	1	0.288	±	0.626				0.288	±	---
6-38-70	2	0.302	±	0.722	-0.161	±	0.597	0.0705	±	0.746
6-39-0	1	0.308	±	0.641				0.308	±	---
6-40-1	2	0.173	±	0.621	0.160	±	0.626	0.167	±	0.441
6-41-1	2	0.0964	±	0.690	-0.0587	±	0.641	0.0189	±	0.509
6-42-2	1	0.242	±	0.633				0.242	±	---
6-42-12A	4	0.648	±	0.747	-0.111	±	0.606	0.338	±	0.510
6-42-40A	4	0.826	±	0.874	-0.256	±	0.541	0.210	±	0.635
6-42-40B	4	0.442	±	0.884	-0.0264	±	0.636	0.158	±	0.416
6-43-3	1	0.295	±	0.657				0.295	±	---
6-45-2	1	0.349	±	0.730				0.349	±	---

TABLE A.17. (contd)

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum			Minimum			Average		
6-45-42	4	0.221	±	0.695	-0.274	±	0.540	0.0597	±	0.409
6-46-4	1	0.248	±	0.590				0.248	±	---
6-47-5	9	0.372	±	0.770	-0.338	±	0.629	0.00665	±	0.277
6-49-13E	1	0.521	±	0.667				0.521	±	---
6-49-57	1	0.257	±	0.716				0.257	±	---
6-49-100C	3	0.326	±	0.818	-0.361	±	0.598	0.0693	±	0.617
6-50-42	4	0.307	±	0.609	-0.146	±	0.656	0.0935	±	0.389
6-50-53	1	0.165	±	0.916				0.165	±	---
6-53-47A	11	79.9	±	5.25	42.7	±	3.64	61.5	±	6.47
6-53-47B	12	115	±	5.68	70.3	±	4.34	85.2	±	6.55
6-53-48A	12	1.62	±	1.17	-0.0134	±	0.694	0.795	±	0.359
6-53-48B	12	439	±	52.8	201	±	38.3	314	±	42.9
6-53-55A	3	0.268	±	0.678	-0.200	±	0.668	0.0843	±	0.508
6-54-48	11	59.0	±	4.36	37.9	±	3.33	50.5	±	4.06
6-54-49	11	58.1	±	3.86	12.0	±	1.97	33.0	±	10.1
6-55-50C	4	0.761	±	0.730	-0.0827	±	0.767	0.501	±	0.582
6-55-50D	4	0.914	±	0.739	-0.176	±	0.624	0.329	±	0.634
6-55-89	2	0.195	±	0.754	0.0163	±	0.608	0.106	±	0.534
6-59-58	2	-0.299	±	0.590	-0.440	±	0.536	-0.370	±	0.436
6-63-58	2	0.0808	±	0.667	-0.148	±	0.565	-0.0336	±	0.523
6-S19-E13	3	0.432	±	0.707	0.148	±	0.290	0.260	±	0.340
6-S28-E0	4	0.273	±	0.543	0.0325	±	0.642	0.126	±	0.336

(a) Maximum and minimum concentrations ±2-sigma counting error. Average concentrations ±2 standard error of the calculated mean. Single sample shown as maximum.
(b) See Figures 3.10, 3.11, and 3.12 for well locations.
(c) Wells that sample a confined aquifer or a composite of a confined and unconfined aquifer.

TABLE A.18. Maximum, Minimum, and Average Technetium-99 (^{99}Tc) Concentrations in Ground-Water Samples in 1987

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum			Minimum			Average		
1-B4-4	1	66.6	±	1.72				66.6	±	---
1-D5-12	1	2.66	±	1.08				2.66	±	---
1-F8-1	1	4.95	±	1.08				4.95	±	---
1-H4-3	3	3,860	±	14.7	1,610	±	6.76	3,090	±	1,540
1-H4-4	1							1,170	±	5.73
1-N-2	1	12.2	±	1.11				12.2	±	---
1-N-14	1	3.90	±	2.04				3.90	±	---
1-N-29	1	4.02	±	2.04				4.02	±	---
1-N-33	1	4.14	±	1.05				4.14	±	---
2-E17-1	1	32.5	±	1.67				32.5	±	---
2-E17-2	1	114	±	2.05				114	±	---
2-E17-5	2	411	±	3.73	226	±	3.10	319	±	232
2-E25-25	2	1.47	±	0.170	0.291	±	0.006	0.881	±	1.48
2-E25-27	2	1.16	±	0.180	0.820	±	0.007	0.990	±	0.435
2-E25-28	2	4.38	±	0.200	1.91	±	0.011	3.15	±	3.10
2-E33-1	1	964	±	5.95				964	±	---
2-E33-3	1	1,400	±	6.35				1,400	±	---
2-E33-5	1	1,980	±	12.1				1,980	±	---
2-E33-7	1	4,700	±	18.5				4,700	±	---
2-E33-8	1	192	±	2.91				192	±	---
2-E33-9	1	592	±	4.43				592	±	---
2-E33-24	1	1,580	±	6.69				1,580	±	---
2-E33-26	1	1,420	±	6.62				1,420	±	---
2-W10-3	1	610	±	5.11				610	±	---
2-W10-4	1	277	±	2.98				277	±	---
2-W10-8	1	1.39	±	1.04				1.39	±	---
2-W11-11	1	385	±	3.46				385	±	---
2-W11-18	1	510	±	3.94				510	±	---
2-W11-23	1	270	±	2.97				270	±	---
2-W11-24	1	25.0	±	1.36				25.0	±	---
2-W19-2	2	581	±	4.22	289	±	3.06	435	±	366
2-W19-3	5	2,740	±	8.78	1,860	±	26.2	2,360	±	339
2-W19-9	2	2,220	±	7.93	1,120	±	21.5	1,670	±	1,380
2-W19-11	4	3,200	±	31.8	2,320	±	27.9	2,810	±	428
2-W19-15	2	784	±	7.33	586	±	4.16	685	±	248
2-W19-16	2	1,630	±	24.9	1,190	±	5.90	1,410	±	551
2-W19-17	1	194	±	4.08				194	±	---
2-W19-18	1	8,160	±	51.9				8,160	±	---
2-W19-20	1	11,600	±	27.2				11,600	±	---
2-W19-23	1	1,330	±	9.58				1,330	±	---

TABLE A.18. (contd)

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum			Minimum			Average		
2-W19-24	2	13,,700	±	28.6	13,000	±	27.3	13,400	±	877
2-W19-25	3	16300	±	30.7	10,700	±	25.1	13600	±	3,820
2-W19-26	1	1,800	±	10.8				1,800	±	---
2-W22-20	1	85.6	±	2.15				85.6	±	---
2-W22-21	1	906	±	5.37				906	±	---
2-W22-26	1	102	±	2.27				102	±	---
2-W23-1	1	380	±	4.23				380	±	---
2-W23-2	1	5,420	±	13.0				5,480	±	—
2-W23-7	2	5,380	±	13.2	2,480	±	12.7	3,930	±	3,630
6-27-8	1	319	±	3.16				319	±	---
6-32-22	1	206	±	2.60				206	±	---
6-32-43	1	65.9	±	1.67				65.9	±	---
6-35-70	1	112	±	2.09				112	±	---
6-37-43	1	-0.616	±	0.984				-0.616	±	---
6-38-70	3	2,860	±	9.25	1,380	±	6.24	2,270	±	1,010
6-40-1	1	278	±	2.94				278	±	---
6-41-1	1	308	±	3.13				308	±	---
6-41-23	1	69.1	±	1.78				69.1	±	---
6-46-4	1	192	±	2.59				192	±	---
6-47-50	1	-0.622	±	0.980				-0.622	±	---
6-50-53	2	29,100	±	30.5	13,600	±	27.4	21,400	±	19,400

(a) Maximum and minimum concentrations ±2-sigma counting error. Average concentrations ±2 standard error of the calculated mean. Single sample shown as maximums.
(b) See Figures 3.10, 3.11, and 3.12 for well locations.

TABLE A.19. Maximum, Minimum, and Average Iodine-129 (^{129}I) Concentrations in Ground-Water Samples in 1987

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum	Minimum	Average
1-N-14	1	0.00774 ± 0.000650		0.00774 ± ---
1-N-29	1	0.00620 ± 0.000533		0.00620 ± ---
1-N-33	1	0.0211 ± 0.00181		0.0211 ± ---
2-E17-1	1	47.3 ± 5.52		47.3 ± ---
2-E17-2	1	1.33 ± 1.61		1.33 ± ---
2-E17-5	1	25.0 ± 3.20		25.0 ± ---
2-E17-6	2	4.73 ± 1.81	1.87 ± 1.14	3.30 ± 3.74
2-E17-8	1	29.2 ± 3.54		29.2 ± ---
2-E17-9	1	27.0 ± 3.42		27.0 ± ---
2-E17-12	1	7.29 ± 2.02		7.29 ± ---
2-E17-13	1	10.1 ± 1.95		10.1 ± ---
2-E24-1	1	44.6 ± 5.10		44.6 ± ---
2-E25-25	2	1.07 ± 0.420	0.248 ± 0.005	0.659 ± 1.05
2-E25-27	2	1.82 ± 0.290	0.338 ± 0.007	1.08 ± 1.86
2-E25-28	2	3.44 ± 0.35	2.20 ± 0.050	2.82 ± 1.56
2-W19-3	1	32.9 ± 3.92		32.9 ± ---
2-W19-9	1	21.4 ± 2.76		21.4 ± ---
2-W19-11	1	31.6 ± 3.84		31.6 ± ---
2-W19-15	1	9.87 ± 1.78		9.87 ± ---
2-W19-16	1	9.26 ± 1.75		9.26 ± ---
2-W22-20	1	1.61 ± 1.00		1.61 ± ---
2-W22-21	1	2.72 ± 1.12		2.72 ± ---
6-27-8	1	1.85 ± 0.151		1.85 ± ---
6-32-22	1	3.87 ± 0.325		3.87 ± ---
6-32-43	1	5.51 ± 0.440		5.51 ± ---
6-35-70	1	47.2 ± 5.40		47.2 ± ---
6-37-43	1	10.7 ± 0.900		10.7 ± ---
6-38-70	1	0.948 ± 0.980		0.948 ± ---
6-41-1	1	0.173 ± 0.0145		0.173 ± ---
6-41-23	1	3.76 ± 0.324		3.76 ± ---
6-46-4	1	0.146 ± 0.0123		0.146 ± ---
6-47-50[c]	1	0.00607 ± 0.000413		0.00607 ± ---
6-49-55A	1	0.0477 ± 0.00391		0.0477 ± ---
6-49-57	1	0.201 ± 0.0161		0.201 ± ---
6-50-53	2	0.0437 ± 0.00376	0.0417 ± 0.0035	0.0427 ± 0.00364

(a) Maximum and minimum concentrations ±2 sigma counting error. Average concentrations ±2 standard error of the calculated mean. Single sample shown as maximum.
(b) See Figures 3.10, 3.11, and 3.12 for well locations.
(c) Wells that sample a confined aquifer or a composite of a confined and unconfined aquifer.

TABLE A. 20. Maximum, Minimum, and Average Nitrate (NO_3^-) Concentrations in Ground-Water Samples in 1987

Well Name[a]	No. of Samples	Concentration (ppb) Maximum	Minimum	Average[b]		
100-B River	1	636		636	±	---
1-B3-1	6	55,600	29,800	37,400	±	8,320
1-B4-1	5	25,200	10,100	13,400	±	5,810
1-B4-2	4	11,400	9,590	10,500	±	880
1-B4-3	4	20,700	9,710	13,100	±	5,340
1-B4-4	4	9,300	8,320	8,870	±	476
1-B5-1	5	10,800	9,470	9,930	±	512
1-B9-1	5	26,900	21,100	24,800	±	2,230
1-D2-5	4	99,800	72,200	82,900	±	13,400
1-D5-12	5	77,700	62,600	67,800	±	5,810
1-D8-3	4	27,300	23,700	25,500	±	1,750
1-F5-1	6	15,500	5,730	12,000	±	3,150
1-F5-3	5	6,980	2,420	<3,400	±	1,750
1-F5-4	5	68,600	52,500	62,300	±	6,190
1-F5-6	4	1,740	<500	<1,330	±	603
1-F7-1	5	105,000	86,300	96,000	±	7,190
1-F8-1	10	218,000	141,000	171,000	±	14,800
1-F8-2	9	99,300	92,300	95,500	±	1,570
1-H3-1	10	98,000	52,300	66,700	±	7,880
1-H3-2A	11	29,900	15,600	20,300	±	2,450
1-H3-2B	11	24,400	14,700	19,500	±	1,920
1-H3-2C	10	9,180	3,260	5,290	±	1,550
1-H4-3	13	1,020,000	246,000	592,000	±	153,000
1-H4-4	15	512,000	9,720	302,000	±	85,900
1-H4-5	10	39,900	28,700	32,400	±	2,460
1-H4-6	10	40,700	31,500	37,300	±	1,610
1-H4-7	11	44,700	5,090	29,400	±	5,860
1-H4-8	10	36,800	27,800	31,900	±	2,040
1-H4-9	12	253,000	51,800	156,000	±	38,400
1-H4-10	10	26,200	10,400	20,900	±	2,680
1-H4-11	11	32,600	21,800	27,300	±	1,720
1-H4-12A	11	171,000	22,900	83,000	±	24,400
1-H4-12B	11	85,900	29,300	57,200	±	10,400
1-H4-12C	11	6,140	2,640	4,850	±	648
1-H4-13	11	40,300	12,100	23,100	±	4,400
1-H4-14	11	20,500	17,100	19,000	±	583
1-H4-15A	11	45,000	25,400	29,500	±	3,250
1-H4-15B	11	28,500	23,200	25,100	±	915
1-H4-16	7	18,900	5,320	12,700	±	3,800
1-H4-17	5	48,500	42,100	44,800	±	2,460
1-H4-18	6	63,800	20,100	30,500	±	14,100

TABLE A.20. (contd)

Well Name[a]	No. of Samples	Concentration (ppb) Maximum	Minimum	Average[b]		
1-K-11	4	54,600	48,200	50,700	±	3,110
1-K-19	9	68,900	36,300	58,600	±	7,320
1-K-20	5	24,100	20,700	22,000	±	1,310
1-K-22	7	3,910	3,130	3,520	±	218
1-K-27	5	9,090	7,000	8,250	±	804
1-K-28	4	27,100	22,000	23,900	±	2,480
1-K-29	5	13,700	8,450	10,900	±	2,020
1-K-30	5	58,500	44,600	52,200	±	5,350
1-N-2	4	34,400	31,000	32,700	±	1,650
1-N-3	1	26,600		26,600	±	---
1-N-4	4	33,600	16,400	27,300	±	8,360
1-N-5	3	50,100	22,500	34,000	±	18,800
1-N-6	2	23,800	23,800	23,800	±	0
1-N-7	1	36,600		36,600	±	---
1-N-14	6	42,500	30,400	38,300	±	3,900
1-N-15	4	34,400	24,700	27,600	±	4,710
1-N-16	3	<2,500	851	<1,950	±	1,130
1-N-18	4	<2,500	<500	<1,500	±	972
1-N-19	4	28,500	11,100	17,600	±	8,460
1-N-20	4	27,800	10,400	16,200	±	8,460
1-N-21	8	19,100	13,000	16,200	±	1,510
1-N-22	4	17,000	<2,500	<6,800	±	7,050
1-N-23	8	26,300	6,790	12,800	±	4,840
1-N-24	3	8,980	5,460	7,060	±	2,400
1-N-25	4	14,800	3,110	7,670	±	5,680
1-N-27	4	34,900	18,800	26,100	±	7,820
1-N-28	5	64,300	17,500	35,200	±	18,000
1-N-29	6	33,400	18,000	22,300	±	4,970
1-N-30	4	35,700	21,800	29,200	±	6,760
1-N-31	4	65,500	25,500	36,200	±	19,400
1-N-32	5	50,800	15,300	33,300	±	13,700
1-N-33	8	54,300	32,100	40,300	±	5,510
1-N-36	5	50,100	22,100	37,300	±	10,800
1-N-37	3	64,300	34,400	50,000	±	20,400
1-N-39	5	63,300	40,200	52,600	±	8,880
1-N-41	1	34,100		34,100	±	---
1-N-42	1	30,200		30,200	±	---
1-N-45	4	80,700	26,600	48,900	±	26,300
1-N-49	4	62,100	43,000	52,000	±	9,280
1-N-50	3	40,200	28,900	34,000	±	7,710
1-N-51	3	28,900	24,000	26,400	±	3,340
1-N-52	4	26,100	20,300	22,200	±	2,820
1-N-58	1	1,720		1,720	±	---
1-N-59	1	1,580		1,580	±	---
1-N-60	1	1,590		1,590	±	---
1-N-61	1	1,290		1,290	±	---

TABLE A.20. (contd)

Well Name[a]	No. of Samples	Concentration (ppb) Maximum	Minimum	Average[b]		
2-E13-5	4	11,400	10,100	10,900	±	632
2-E13-14	3	14,600	11,900	13,500	±	1,840
2-E16-2	12	7,020	1,360	<3,970	±	1,050
2-E17-1	16	417,000	246,000	357,000	±	20,400
2-E17-2	11	258,000	85,500	153,000	±	29,700
2-E17-5	16	276,000	75,200	140,000	±	33,300
2-E17-6	9	11,700	<500	<2,300	±	2,520
2-E17-8	11	358,000	67,000	235,000	±	47,700
2-E17-9	16	171,000	114,000	140,000	±	9,620
2-E17-12	12	117,000	24,200	62,800	±	16,400
2-E17-13	12	151,000	33,500	91,100	±	25,800
2-E19-1	1	<500		<500	±	---
2-E23-1	2	7,200	7,140	7,170	±	75
2-E23-2	2	<2,500	<500	<1,500		---
2-E24-1	13	572,000	227,000	388,000	±	60,600
2-E24-2	8	204,000	149,000	178,000	±	13,700
2-E24-4	12	4,620	<2,500	<3,330	±	391
2-E24-7	3	13,900	12,800	13,300	±	751
2-E24-8	15	35,000	4,140	7,980	±	3,880
2-E24-11	4	470,000	228,000	318,000	±	118,000
2-E24-12	16	209,000	46,600	82,300	±	20,700
2-E24-13	4	4,210	2,640	3,140	±	763
2-E25-2	3	<2,500	1,580	<1,910	±	628
2-E25-6	4	3,290	1,530	<2,250	±	855
2-E25-7	1	2,040		2,040	±	---
2-E25-9	4	<2,500	1,340	<1,940	±	564
2-E25-11	12	55,000	28,000	38,000	±	4,750
2-E25-13	4	443,000	128,000	322,000	±	153,000
2-E25-17	12	26,500	7,750	16,400	±	2,830
2-E25-18	16	26,700	9,550	16,700	±	2,800
2-E25-19	13	257,000	62,700	160,000	±	38,800
2-E25-20	16	229,000	132,000	169,000	±	12,300
2-E25-21	14	12,400	5,720	9,250	±	1,270
2-E25-22	13	7,040	4,300	5,250	±	513
2-E25-23	9	4,030	2,300	<2,820	±	389
2-E25-24	9	5,300	1,970	<3,010	±	748
2-E25-25	3	1,080	785	922	±	201
2-E25-26	3	1,450	1,220	1,350	±	157
2-E25-27	3	6,090	4,080	5,010	±	1,370
2-E25-28	3	1,410	1,120	1,310	±	198
2-E26-1	2	5,090	<500	<2,800	±	5,750
2-E26-2	4	3,400	1,140	<2,390	±	1,100
2-E26-3	3	<2,500	1,110	<1,790	±	949
2-E26-4	4	3,710	1,680	<2,600	±	987
2-E26-6	4	<2,500	687	<2,050	±	881
2-E26-8[c]	2	<2,500	<500	<1,500		---
2-E27-1	2	2,930	2,830	2,880	±	125

TABLE A.20. (contd)

Well Name[a]	No. of Samples	Concentration (ppb) Maximum	Minimum	Average[b]		
2-E27-5	3	6,690	6,520	6,600	±	116
2-E27-7	3	10,700	<2,500	<5,480	±	5,600
2-E28-1	2	8,070	4,650	6,360	±	4,290
2-E28-5	2	3,210	2,900	3,060	±	388
2-E28-7	1	9,960		9,960	±	---
2-E28-17	1	27,100		27,100	±	---
2-E28-18	12	73,300	36,100	50,600	±	5,930
2-E28-21	16	44,700	30,700	40,700	±	2,160
2-E28-23	4	11,400	9,270	10,200	±	1,040
2-E32-1	4	10,700	504	8,080	±	4,960
2-E33-1	3	54,200	14,000	40,200	±	27,400
2-E33-2	1	39,400		39,400	±	---
2-E33-3	3	60,800	37,800	47,600	±	15,700
2-E33-5	3	37,900	34,600	35,900	±	2,250
2-E33-8	2	8,880	8,250	8,570	±	789
2-E33-9	4	10,200	1,660	7,700	±	4,150
2-E33-10	6	10,500	5,400	6,630	±	1,640
2-E33-12[c]	2	<2,500	<500	<1,500		---
2-E33-14	2	19,500	12,400	16,000	±	8,900
2-E33-18	3	17,200	15,700	16,500	±	1,020
2-E33-20	4	9,730	2,740	5,210	±	3,400
2-E33-21	2	3,980	3,940	3,960	±	50
2-E33-24	2	18,000	16,100	17,100	±	2,380
2-E34-1	2	22,800	19,400	21,100	±	4,260
2-W6-1	3	223,000	198,000	209,000	±	17,100
2-W10-1	1	425,000		425,000	±	---
2-W10-4	4	245,000	180,000	218,000	±	31,600
2-W10-5	1	106,000		106,000	±	---
2-W10-8	7	7,610	1,820	<3,360	±	1,620
2-W10-9	7	397,000	311,000	361,000	±	24,100
2-W11-3	1	94,600		94,600	±	---
2-W11-9	2	51,800	7,120	29,500	±	56,000
2-W11-23	4	451,000	408,000	434,000	±	20,900
2-W11-24	4	333,000	221,000	285,000	±	54,400
2-W12-1	3	353,000	345,000	349,000	±	5,460
2-W14-2	5	103,000	81,200	89,500	±	8,380
2-W14-5	8	146,000	28,900	83,600	±	29,100
2-W14-6	7	89,100	20,100	40,800	±	19,300
2-W14-10	11	103,000	64,200	89,300	±	6,800
2-W15-2	1	2,900		2,910	±	---
2-W15-3	4	145,000	124,000	134,000	±	10,200
2-W15-4	7	707,000	520,000	603,000	±	52,300
2-W15-6	4	12,000	8,680	10,300	±	1,610
2-W15-7	1	54,900		54,900	±	---
2-W15-10	7	107,000	100,000	103,000	±	1,960
2-W15-11	7	152,000	121,000	137,000	±	8,670
2-W18-3	2	83,100	51,700	67,400	±	39,300

TABLE A.20. (contd)

Well Name[a]	No. of Samples	Concentration (ppb) Maximum	Minimum	Average[b]		
2-W18-7	1	6,400		6,400	±	---
2-W18-9	4	6,900	5,200	6,200	±	826
2-W18-15	14	2,780	541	<1,770	±	459
2-W18-17	3	8,030	<2,500	<5,580	±	3,770
2-W18-18	5	3,010	<500	<1,060	±	965
2-W18-20	4	3,880	<2,500	<3,010	±	671
2-W19-1	1	1,570		1,570	±	---
2-W19-2	6	585,000	317,000	460,000	±	86,400
2-W19-3	15	113,000	71,400	100,000	±	5,780
2-W19-4	1	7,790		7,790	±	---
2-W19-5	6	5,520	929	4,170	±	1,480
2-W19-9	16	136,000	13,900	92,000	±	17,400
2-W19-11	16	141,000	<2,500	<111,000	±	15,600
2-W19-12	4	7,490	3,170	5,050	±	2,100
2-W19-13	16	99,900	18,400	26,200	±	9,850
2-W19-14	7	67,700	9,040	21,300	±	16,400
2-W19-15	17	127,000	2,170	83,300	±	15,100
2-W19-16	17	97,100	4,440	52,900	±	9,490
2-W19-17	12	55,200	10,400	14,800	±	7,350
2-W19-18	11	303,000	167,000	235,000	±	28,100
2-W19-19	10	1,500,000	82,800	1,160,000	±	253,000
2-W19-20	14	1,070,000	101,000	902,000	±	128,000
2-W19-21	7	3,020	1,260	<2,400	±	492
2-W19-23	8	575,000	105,000	482,000	±	117,000
2-W19-24	7	1,500,000	77,700	1,140,000	±	398,000
2-W19-25	8	728,000	149,000	621,000	±	144,000
2-W19-26	6	1,200,000	621,000	795,000	±	187,000
2-W19-27	6	3,860	<2,500	<3,170	±	439
2-W21-1	2	43,700	36,200	40,000	±	9,400
2-W22-1	1	3,490		3,490	±	---
2-W22-2	1	2,660		2,660	±	---
2-W22-7	2	<2,500	1,620	<2,060	±	1,100
2-W22-9	2	7,320	6,420	6,870	±	1,130
2-W22-12	6	3,920	2,810	3,290	±	358
2-W22-20	3	131,000	123,000	128,000	±	5,460
2-W22-21	4	14,200	11,200	13,100	±	1,460
2-W22-22	15	4,080	<500	<1,960	±	580
2-W22-26	2	12,700	9,000	10,900	±	4,640
2-W23-1	5	43,500	3,260	17,400	±	15,500
2-W23-2	4	36,400	26,700	31,600	±	4,710
2-W23-3	5	7,660	4,190	6,330	±	1,330
2-W23-4	2	<2,500	592	<1,550	±	2,390
2-W23-7	1	51,200		51,200	±	---
2-W23-9	6	409,000	77,100	210,000	±	107,000
2-W23-10	10	233,000	138,000	202,000	±	19,500
2-W23-11	7	19,400	<2,500	<4,950	±	4,730
2-W26-3	4	2,880	813	<2,170	±	1,000

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TABLE A.20. (contd)

Well Name[a]	No. of Samples	Concentration (ppb) Maximum	Minimum	Average[b]		
2-W26-6	4	4,300	2,510	3,200	±	870
2-W27-1	8	128,000	78,200	107,000	±	12,400
3-1-1	9	22,500	1,570	8,990	±	4,700
3-1-2	9	18,300	3,300	8,970	±	3,370
3-1-3	7	9,050	2,020	5,370	±	1,970
3-1-4	9	6,030	899	3,560	±	1,150
3-1-5	9	7,230	997	2,790	±	1,400
3-1-6	9	18,200	1,130	6,540	±	3,840
3-1-7	6	9,060	1,820	4,200	±	2,340
3-1-8	7	7,020	1,020	2,890	±	1,680
3-1-9	4	<500	<500	<500		---
3-1-10	6	12,100	1,250	4,390	±	3,500
3-1-11	9	2,510	1,210	1,880	±	292
3-1-12	6	7,770	1,360	3,010	±	2,070
3-1-13	8	10,600	3,520	6,280	±	1,760
3-1-14	6	12,400	1,670	4,360	±	3,460
3-1-15	6	22,600	1,970	12,700	±	6,650
3-1-16A	6	13,300	2,010	5,400	±	3,640
3-1-16B	5	<500	<500	<500		---
3-1-16C	5	1,800	<500	<901	±	500
3-1-16D	1	<500		<500	±	---
3-1-17A	9	5,870	1,570	2,450	±	966
3-1-17B	5	<500	<500	<500		---
3-1-17C	5	<500	<500	<500		---
3-1-18A	6	22,800	20,800	21,600	±	645
3-1-18B	5	<500	<500	<500		---
3-1-18C	5	<500	<500	<500		---
3-1-19	8	2,510	1,290	1,740	±	303
3-2-1	9	24,000	8,870	15,100	±	3,400
3-2-2	4	9,820	3,190	5,980	±	3,220
3-2-3	4	23,700	7,260	14,800	±	7,990
3-3-1	4	22,300	10,100	15,500	±	5,930
3-3-2	4	12,100	<500	<8,110	±	5,640
3-3-3	4	11,700	9,170	10,200	±	1,230
3-3-6	4	16,000	12,000	14,800	±	1,940
3-3-7	9	16,500	10,700	13,200	±	1,300
3-3-9	4	28,500	10,600	18,800	±	8,700
3-3-10	9	27,000	9,170	19,300	±	4,010
3-3-11	4	17,400	11,600	14,300	±	2,820
3-3-12	4	17,800	12,600	14,800	±	2,530
3-4-1	9	18,700	12,200	15,000	±	1,460
3-4-7	9	19,600	14,300	17,200	±	1,190
3-4-9	4	23,600	13,400	18,400	±	4,960
3-4-10	4	16,500	12,900	14,700	±	1,750
3-4-11	6	18,900	13,700	15,400	±	1,680

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TABLE A.20. (contd)

Well Name[a]	No. of Samples	Concentration (ppb) Maximum	Minimum	Average[b]		
3-5-1	4	59,000	45,700	51,000	±	6,460
3-6-1	8	29,300	27,000	28,400	±	571
3-8-1	5	21,400	16,800	19,600	±	1,770
3-8-2	9	24,600	21,700	23,100	±	652
3-8-3	9	12,800	10,700	11,700	±	472
3-8-4	3	26,500	21,600	23,400	±	3,340
4-S1-7B	4	<2,500	<500	<1,500		---
4-S1-7C	5	28,600	24,500	27,200	±	1,580
4-S1-8A	3	29,200	25,600	27,500	±	2,460
4-S1-8B	5	27,800	25,500	26,600	±	885
6-1-18	4	22,000	18,800	20,200	±	1,560
6-2-3	3	32,200	28,800	30,300	±	2,320
6-2-7	4	48,600	28,300	36,000	±	9,870
6-2-33A	4	3,330	2,810	3,130	±	253
6-3-45	4	7,020	918	<3,910	±	2,970
6-4-E6	4	13,100	12,000	12,700	±	535
6-8-17	4	36,300	31,400	33,800	±	2,380
6-8-25	3	20,800	19,500	20,100	±	887
6-8-32	3	5,830	3,610	4,810	±	1,510
6-9-E2	4	2,760	1,470	2,060	±	627
6-10-E12	5	22,900	18,600	20,800	±	1,650
6-10-54A	4	16,300	12,600	13,800	±	1,800
6-13-64	4	12,200	887	<4,520	±	5,500
6-14-E6T	2	21,100	<500	<10,800	±	25,800
6-14-38	3	4,760	3,080	3,720	±	1,150
6-14-47	5	<2,500	<500	<1,480	±	769
6-15-15B	4	21,200	18,700	19,700	±	1,220
6-15-26	4	23,600	23,500	23,600	±	49
6-17-5	4	67,800	63,300	65,800	±	2,190
6-17-47	3	<2,500	<500	<1,830		---
6-17-70	4	44,500	7,880	34,100	±	17,800
6-19-43	5	12,000	8,560	10,300	±	1,320
6-19-58	4	<2,500	<500	<1,500		---
6-19-88	4	3,240	1,760	<2,500	±	719
6-20-E5A	3	24,600	24,100	24,400	±	341
6-20-E5AP[c]	2	18,300	<2,500	<10,400	±	19,800
6-20-E5AQ[c]	2	<2,500	<500	<1,500		---
6-20-E5AR[c]	2	<2,500	<500	<1,500		---
6-20-E12	4	38,400	<2,500	<27,700	±	17,400
6-20-E12P[c]	2	<2,500	<500	<1,500		---
6-20-20	4	42,000	36,000	38,700	±	2,920
6-20-39[c]	4	4,470	3,310	4,100	±	564
6-20-82	4	22,700	<500	<15,300	±	10,800

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TABLE A.20. (contd)

Well Name[a]	No. of Samples	Concentration (ppb) Maximum	Minimum	Average[b]		
6-21-6	4	41,900	36,900	38,600	±	2,430
6-22-70	4	10,900	10,700	10,800	±	97
6-23-34	4	22,100	18,200	20,400	±	1,900
6-24-1P[c]	2	<2,500	<500	<1,500		---
6-24-1Q[c]	2	<2,500	<500	<1,500		---
6-24-1R[c]	2	<2,500	<500	<1,500		---
6-24-1S[c]	2	<2,500	<500	<1,500		---
6-24-1T	2	<2,500	600	<1,550	±	2,380
6-24-33	5	26,400	22,700	24,400	±	1,420
6-24-34A	4	24,400	19,400	22,100	±	2,430
6-24-34B	5	27,700	20,700	24,500	±	2,690
6-24-34C	4	28,000	21,700	24,300	±	3,060
6-24-35	4	21,800	18,700	20,700	±	1,510
6-24-46	5	8,400	6,210	7,130	±	842
6-25-33A	4	6,540	4,040	5,130	±	1,220
6-25-34A	4	27,600	24,100	26,400	±	1,700
6-25-34B	4	28,900	23,900	27,000	±	2,430
6-25-34C	3	25,800	24,600	25,300	±	819
6-25-55	4	16,700	14,000	15,000	±	1,310
6-25-70	4	13,300	12,000	12,600	±	632
6-26-15A	4	43,100	36,300	39,700	±	3,300
6-26-33	4	29,100	24,000	27,200	±	2,480
6-26-34	4	30,600	24,600	27,500	±	2,920
6-26-35A	4	28,500	22,800	25,200	±	2,770
6-26-35C	4	23,200	19,400	21,200	±	1,850
6-26-89	2	4,110	<2,500	<3,310	±	2,020
6-27-8	4	62,900	37,600	44,300	±	12,300
6-28-40	2	13,200	12,500	12,900	±	877
6-28-40P[c]	2	<2,500	<500	<1,500		---
6-28-52A	4	10,600	<500	<3,530	±	4,910
6-29-4	3	33,400	30,300	31,500	±	2,120
6-29-78	4	8,140	7,470	7,800	±	326
6-31-31	4	8,740	7,650	8,320	±	530
6-31-31P	2	<2,500	<500	<1,500		---
6-32-22	3	35,400	30,300	32,100	±	3,480
6-32-43	2	40,900	38,200	39,600	±	3,380
6-32-62	4	28,500	26,800	27,600	±	826
6-32-70B	6	20,200	16,300	18,100	±	1,260
6-32-72	5	8,900	<500	<3,420	±	3,230
6-32-77	5	6,140	5,020	5,690	±	431
6-33-42	2	40,800	34,200	37,500	±	8,270
6-33-56	2	9,910	9,770	9,840	±	175
6-34-39A	4	3,850	<2,500	<3,220	±	656
6-34-41B	4	14,100	10,100	12,100	±	1,940
6-34-42	2	19,600	15,900	17,800	±	4,640
6-34-51	2	9,400	8,480	8,940	±	1,150
6-34-88	4	19,300	15,800	18,000	±	1,700
6-35-9	3	38,500	35,400	37,100	±	2,120

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TABLE A.20. (contd)

Well Name[a]	No. of Samples	Concentration (ppb) Maximum	Minimum	Average[b]		
6-35-66	5	25,500	21,600	23,600	±	1,500
6-35-70	2	32,900	29,400	31,200	±	4,390
6-35-78A	5	<2,500	<500	<1,300		---
6-36-46P[c]	2	<2,500	<500	<1,500		---
6-36-46Q[c]	2	<2,500	<500	<1,500		---
6-36-61A	5	22,400	18,700	20,800	±	1,420
6-36-61B	4	<2,500	<500	<1,020	±	972
6-36-93	2	37,700	34,600	36,200	±	3,880
6-37-E4	6	27,200	23,300	25,700	±	1,260
6-37-43	5	11,700	<2,500	<9,140	±	3,540
6-37-82A	2	47,100	42,000	44,600	±	6,390
6-38-15	4	56,100	53,500	54,400	±	1,260
6-38-65	3	189,000	147,000	166,000	±	28,700
6-38-70	4	262,000	227,000	238,000	±	17,000
6-39-0	5	44,100	35,900	39,300	±	3,150
6-39-39	2	2,790	<2,500	<2,650	±	363
6-39-79	6	3,230	1,240	1,850	±	642
6-40-1	8	43,800	35,100	39,600	±	2,160
6-40-33A	3	<500	<500	<500		---
6-40-62	5	47,200	43,200	45,600	±	1,540
6-41-1	4	43,700	34,100	39,500	±	4,670
6-41-23	4	21,700	16,700	18,200	±	2,430
6-42-2	6	42,700	32,400	37,800	±	3,320
6-42-12A	4	63,000	41,000	47,000	±	10,700
6-42-40A	4	25,500	<2,500	<13,400	±	11,200
6-42-40B	4	<2,500	<500	<1,510	±	972
6-42-40C[c]	2	<2,500	<500	<1,500		---
6-43-3	6	42,300	31,400	37,100	±	3,520
6-43-88	5	26,700	6,900	17,400	±	7,620
6-44-4	4	5,030	1,530	<2,690	±	1,700
6-44-64	5	50,400	47,000	49,100	±	1,310
6-45-2	6	39,700	26,100	35,100	±	4,390
6-45-42	4	7,970	6,510	7,330	±	710
6-45-69A	2	25,800	25,500	25,700	±	376
6-46-4	6	30,500	25,100	27,800	±	1,740
6-46-21B	4	18,300	15,700	16,500	±	1,260
6-47-5	14	32,200	12,300	25,600	±	3,020
6-47-35A	4	20,500	11,000	16,000	±	4,620
6-47-46A	5	15,200	12,900	14,000	±	885
6-47-50[c]	3	9,160	6,750	8,150	±	1,640
6-47-60	5	24,800	21,100	22,900	±	1,420
6-48-7	3	6,350	4,590	5,630	±	1,200
6-48-18	3	7,040	6,660	6,830	±	259
6-48-71	3	24,900	23,500	24,200	±	955
6-49-13E	5	6,560	4,330	5,790	±	858
6-49-28	4	<2,500	<500	<2,000		---
6-49-55A	6	253,000	198,000	228,000	±	17,700
6-49-57	7	70,000	46,800	61,700	±	6,490

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TABLE A.20. (contd)

Well Name[a]	No. of Samples	Concentration (ppb) Maximum	Minimum	Average[b]		
6-49-79	4	44,400	40,600	42,800	±	1,850
6-49-100C	3	12,500	<2,500	<5,830	±	6,820
6-50-28B	4	4,040	<2,500	<3,320	±	748
6-50-30	4	<2,500	<500	<1,500		---
6-50-42	4	4,810	2,690	3,720	±	1,030
6-50-45[c]	2	<2,500	<500	<1,500		---
6-50-48B[c]	1	<500		<500	±	---
6-50-53	7	507,000	298,000	420,000	±	58,500
6-50-85	5	26,200	24,500	25,400	±	654
6-51-46	2	<2,500	<2,500	<2,500		---
6-51-63	4	18,100	15,900	16,800	±	1,070
6-51-75	4	5,250	2,820	3,980	±	1,180
6-52-19	4	12,300	4,400	6,460	±	3,840
6-52-46A[c]	1	<2,500		<2,500	±	---
6-52-48[c]	2	<2,500	<2,500	<2,500		---
6-53-35	4	50,200	727	<14,100	±	24,000
6-53-50[c]	2	<2,500	<2,500	<2,500		---
6-53-103[c]	2	<2,500	<2,500	<2,500		---
6-54-34	4	13,600	10,100	11,500	±	1,700
6-54-37A	4	<2,500	<500	<2,000		---
6-54-42	4	<2,500	<500	<2,000		---
6-54-45A	3	6,980	<500	<3,330	±	4,420
6-54-57	2	<2,500	<500	<1,500		---
6-55-40	4	<2,500	685	<2,050	±	882
6-55-44	4	<2,500	<500	<2,000		---
6-55-50A	4	3,660	<500	<2,320	±	1,540
6-55-50C	5	3,200	1,340	<2,220	±	715
6-55-50D	4	7,770	<2,500	<4,950	±	2,560
6-55-70	5	2,500	<500	<1,300	±	769
6-55-76	5	7,820	<500	<4,370	±	2,820
6-55-89	4	4,620	3,360	3,940	±	612
6-56-43	4	<2,500	<500	<2,000		---
6-56-53[c]	2	<2,500	<2,500	<2,500		---
6-57-25A	4	3,380	3,200	3,280	±	88
6-57-29A	4	2,960	2,460	2,760	±	243
6-57-83A	3	5,930	<2,500	<3,840	±	2,340
6-58-24	3	4,450	3,290	4,000	±	792
6-59-32	4	4,690	4,170	4,390	±	253
6-59-58	4	<2,500	<500	<1,570	±	972
6-59-80B	4	<2,500	<500	<2,000		---
6-60-32	4	5,960	5,280	5,560	±	330
6-60-57	4	<2,500	<500	<1,500		---
6-60-60	4	<2,500	<500	<1,500		---
6-61-37	4	4,640	4,190	4,420	±	219
6-61-41	4	3,200	2,280	2,760	±	447
6-61-62	4	51,700	39,700	44,300	±	5,830
6-61-66	4	5,230	3,900	4,680	±	646
6-62-31	3	44,500	37,900	41,400	±	4,500

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TABLE A.20. (contd)

Well Name[a]	No. of Samples	Concentration (ppb) Maximum	Minimum	Average[b]		
6-62-43F	4	3,730	3,380	3,540	±	170
6-63-25A	4	21,500	18,000	19,800	±	1,700
6-63-51	4	7,350	3,360	5,770	±	1,940
6-63-55	4	3,800	1,630	2,530	±	1,050
6-63-58	4	25,100	8,030	12,400	±	8,300
6-63-90	5	5,660	5,210	5,390	±	173
6-64-27	4	44,300	40,900	42,600	±	1,650
6-64-62	4	29,600	25,800	27,500	±	1,850
6-65-50	4	3,430	2,010	<2,640	±	690
6-65-59	4	3,820	1,080	2,790	±	1,330
6-65-72	5	23,200	21,200	22,500	±	769
6-65-83	5	4,700	4,330	4,540	±	142
6-66-23	3	43,800	42,800	43,300	±	682
6-66-38	4	<2,500	<500	<2,000		---
6-66-39	4	<2,500	<500	<2,000		---
6-66-58	4	3,520	1,250	<2,470	±	1,100
6-66-64	4	26,500	14,200	17,700	±	5,980
6-66-103	4	<2,500	<500	<1,520	±	972
6-67-51	4	<2,500	863	<1,700	±	796
6-67-86	5	2,960	2,530	2,760	±	165
6-67-98	4	5,390	4,590	5,020	±	389
6-68-105	4	<2,500	1,950	<2,240	±	267
6-69-38	4	<2,500	542	<1,610	±	952
6-70-68	5	4,370	2,880	3,440	±	573
6-71-30	5	29,200	25,100	27,300	±	1,580
6-71-52	5	7,140	6,450	6,820	±	265
6-71-77	5	9,370	6,810	7,950	±	985
6-72-73	2	4,850	3,900	4,380	±	1,190
6-72-88	4	9,530	4,640	7,520	±	2,380
6-72-92	2	6,730	6,210	6,470	±	652
6-73-61	5	9,500	7,050	8,270	±	942
6-74-44	5	8,220	2,750	5,300	±	2,100
6-77-36	5	70,800	46,900	63,200	±	9,190
6-77-54	3	8,100	7,940	8,000	±	109
6-78-62	2	7,730	7,480	7,610	±	313
6-80-43P[c]	2	<2,500	<500	<1,500		---
6-80-43Q	2	2,500	<500	<1,500	±	2,510
6-80-43R	2	<2,500	<500	<1,500		---
6-80-43S	2	9,090	8,240	8,670	±	1,070
6-81-58	4	<2,500	1,130	<1,800	±	666
6-83-47	2	5,930	5,820	5,880	±	138
6-84-35AO	2	11,900	4,600	8,250	±	9,150
6-87-55	3	21,200	20,500	20,800	±	478
6-89-35	3	11,600	9,410	10,400	±	1,490
6-90-45	3	7,090	5,570	6,090	±	1,040
6-96-49	5	16,600	12,400	13,900	±	1,620
6-97-43	5	24,800	19,600	22,000	±	2,000
6-97-51A	5	21,700	20,200	21,100	±	577

9 2 1 2 5 5 6 0 3 8 1

TABLE A.20. (contd)

Well Name[a]	No. of Samples	Concentration (ppb) Maximum	Minimum	Average[b]		
6-101-48B	5	2,680	821	<1,890	±	715
6-S3-E12	5	25,600	21,900	23,600	±	1,420
6-S3-25	2	<500	<500	<500		---
6-S6-E4B	4	17,900	15,000	16,700	±	1,410
6-S6-E4D	8	26,600	23,800	25,300	±	695
6-S6E14A[c]	2	7,160	6,170	6,670	±	1,240
6-S7-34	4	<2,500	<500	<1,800	±	972
6-S8-19	3	6,490	6,160	6,280	±	225
6-S11E12A	2	20,700	<500	<10,600	±	25,300
6-S11E12AP[c]	3	20,000	<500	<7,670	±	13,300
6-S12-3	4	12,200	10,900	11,600	±	632
6-S12-29	4	18,700	16,600	17,700	±	1,020
6-S14-20A	4	4,290	2,780	3,300	±	734
6-S18-51[c]	4	21,800	1,030	<7,150	±	10,100
6-S19-11	2	9,560	9,130	9,350	±	539
6-S19-E13	9	23,400	11,200	20,700	±	2,740
6-S24-19	2	<2,500	<500	<1,500		---
6-S27-E14	12	28,100	20,000	24,100	±	1,460
6-S28-E0	4	10,600	9,640	10,200	±	467
6-S29-E12	4	29,900	20,100	24,400	±	4,760
6-S30E15A	8	15,000	9,900	11,700	±	1,270
6-S31-1	2	3,480	3,430	3,460	±	63

(a) See Figures 3.10, 3.11, and 3.12 for well locations.

(b) Average concentrations ±2 standard error of the calculated mean. First part of year had detection limit of 500 ppb, second part of year had detection limit of 2,500 ppb. If a less-than-detection-limit value was used in calculating the mean, the mean is flagged as less than (<). No estimate of standard error is given for a single sample or if all samples were below detection.

(c) Wells that sample a confined aquifer or a composite of a confined and unconfined aquifer.

TABLE A.21. Maximum, Minimum, and Average Cyanide Concentrations in Ground-Water Samples in 1987

Well Name[a,b]	No. of Samples	Concentration (ppb) Maximum	Minimum	Average[c]
2-E33-1	3	15.9	<10	<12.0 ± 4.03
2-E33-3	3	38.7	<10	<19.6 ± 19.6
2-E33-5	3	26.4	15.8	20.7 ± 7.23
2-W12-1	1	34.0		34.0 ---
2-W14-2	2	115	62.8	88.9 ± 65.4
2-W18-7	1	15.2		15.2 ---
6-38-70	2	22.9	16.3	19.6 ± 8.27
6-40-1	2	10.5	<10	<10.3 ± 0.626
6-41-1	1	10.1		10.1 ---
6-44-64	1	17		17 ---
6-49-55A	2	342	271	307 ± 89.0
6-49-57	6	61.9	19.0	41.5 ± 13.8
6-50-53	6	1120	405	783 ± 231
6-50-85	1	<10		<10 ---

(a) See Figures 3.10, 3.11, and 3.12 for well locations.
(b) Samples were collected from an additional 207 wells in the 100, 200 (see Figure 3.18), 300, 400, and 600 Areas and found to be below the detection limit of 10 ppb for cyanide.
(c) Average concentrations ±2 standard error of the calculated mean. If a less than detection limit value was used in calculating the mean, the mean is flagged as less than (<). No estimate of standard error is given for a single sample.

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TABLE A.22. Maximum, Minimum, and Average Chromium Concentrations in Ground-Water Samples in 1987

Well Name[a,b]	No. of Samples	Concentration (ppb) Maximum	Minimum	Average[c]
1-B3-1	2	62	47	54.5 ± 18.8
1-B4-1	3	13	10	11.0 ± 2.05
1-B4-4	2	12	11	11.5 ± 1.25
1-B5-1	1	27		27 ---
1-B9-1	3	19	16	17.7 ± 2.05
1-D2-5	2	219	205	212 ± 17.5
1-D5-12	3	1,690	1,560	1,610 ± 88.7
1-D8-3	2	151	94	123 ± 71.4
1-F8-1	4	10	<10	<10 ---
1-F8-2	1	21		21 ---
1-H3-1	20	79	31	60.1 ± 6.10
1-H3-2A	22	98	18	41.0 ± 7.67
1-H3-2B	22	147	14	34.0 ± 11.5
1-H3-2C	20	13	<10	<10.4 ± 0.363
1-H4-3	24	426	210	313 ± 26.7
1-H4-4	26	437	24	271 ± 44.0
1-H4-5	20	262	133	185 ± 16.1
1-H4-6	20	89	36	54.3 ± 6.07
1-H4-7	21	206	98	132 ± 10.3
1-H4-8	20	141	94	107 ± 5.18
1-H4-9	22	164	106	133 ± 7.38
1-H4-10	20	96	15	68.8 ± 12.9
1-H4-11	22	167	60	103 ± 12.7
1-H4-12A	22	306	46	204 ± 33.4
1-H4-12B	21	276	137	197 ± 17.3
1-H4-12C	22	258	<10	<147 ± 28.0
1-H4-13	22	48	<10	<27.0 ± 4.24
1-H4-14	22	331	<10	<238 ± 31.8
1-H4-15A	22	205	60	146 ± 18.3
1-H4-15B	22	180	99	149 ± 9.34
1-H4-16	13	16	<10	<10.5 ± 0.923
1-H4-17	8	166	33	70.9 ± 33.0
1-H4-18	12	285	237	257 ± 8.46
1-K-11	2	29	<10	<19.5 ± 23.8
1-K-19	3	101	97	99.3 ± 2.73
1-K-20	3	146	137	141 ± 6.14
1-K-22	3	231	186	203 ± 30.7
1-N-3	2	11	<10	<10.5 ± 1.25
1-N-4	2	21	<10	<15.5 ± 13.8
1-N-58	2	14	<10	<12.0 ± 5.01
1-N-59	2	12	<10	<11.0 ± 2.51

9 2 1 2 5 5 6 0 3 8 4

TABLE A.22. (contd)

Well Name[a,b]	No. of Samples	Concentration (ppb) Maximum	Minimum	Average[c]		
1-N-60	2	15	<10	<12.5	±	6.26
1-N-61	2	28	<10	<19.0	±	22.6
2-E13-14	1	42		42		---
2-E33-1	3	13	11	11.7	±	1.36
2-E33-3	3	13	10	11.7	±	2.05
2-E33-5	3	11	<10	<10.3	±	0.682
2-W6-1	1	46		46		---
2-W10-4	4	69	64	66.8	±	2.43
2-W10-9	3	152	136	144	±	10.9
2-W12-1	1	64		64		---
2-W14-2	5	71	<10	<24.6	±	23.5
2-W15-10	3	13	10	11.7	±	2.05
2-W15-11	3	35	30	32.3	±	3.41
2-W19-24	2	30	<10	<20.0	±	25.1
2-W27-1	4	18	11	13.8	±	3.40
3-1-9	8	18	<10	<12.9	±	1.99
3-1-10	12	13	<10	<10.3	±	0.500
3-1-11	20	11	<10	<10.1	±	0.100
3-1-13	13	16	<10	<10.6	±	0.948
3-1-14	12	13	<10	<10.3	±	0.500
3-1-16A	10	11	<10	<10.1	±	0.200
3-1-16B	10	14	<10	<10.5	±	0.803
3-1-16C	10	33	<10	<15.4	±	4.98
3-1-17B	10	19	<10	<12.0	±	1.91
3-1-18A	12	17	<10	<10.6	±	1.17
3-1-18B	10	32	<10	<16.4	±	5.62
3-1-18C	10	24	<10	<13.1	±	3.30
3-1-19	18	34	10	<12.4	±	2.93
3-4-11	12	23	<10	<12.0	±	2.37
6-23-34	8	11	<10	<10.1	±	0.248
6-25-33A	7	16	<10	<10.9	±	1.68
6-26-35A	7	13	<10	<10.4	±	0.839
6-32-70B	1	23		23		---
6-35-9	2	11	<10	<10.5	±	1.25
6-35-66	1	24		24		---
6-36-61A	1	15		15		---
6-37-E4	1	14		14		---
6-41-1	1	10		10		---
6-43-3	1	11		11		---
6-46-4	1	11		11		---
6-49-57	6	11	<10	<10.5	±	0.323

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TABLE A.22. (contd)

Well Name[a,b]	No. of Samples	Concentration (ppb) Maximum	Minimum	Average[c]	
6-65-72	1	10		10	---
6-65-83	1	26		26	---
6-67-86	1	18		18	---
6-71-52	1	19		19	---
6-73-61	1	17		17	---
6-81-58	1	17		17	---
6-83-47	2	45	44	44.5	± 1.25
6-96-49	1	83		83	---
6-97-43	1	191		191	---
6-97-51A	1	110		110	---

(a) See Figures 3.10, 3.11, and 3.12 for well locations.
(b) Samples were collected from an additional 183 wells (sampling locations identified in Figure 3.19) and found to be below the detection limit of 10 ppb for chromium).
(c) Average concentrations ±2 standard error of the calculated mean. If a less-than-detection limit value was used in calculating the mean, the mean is flagged as less than (<). No estimate of standard error is given for a single sample or if all samples were below detection.

9 2 1 2 5 5 6 0 3 8 6

TABLE A.23. Maximum, Minimum, and Average Carbon Tetrachloride Concentrations in Ground-Water Samples in 1987

Well Name[b,c]	No. of Samples	Concentration (ppb)[a] Maximum	Minimum	Average		
1-H4-3	13	2	<5	2	±	---
2-W6-1	1	220		220	±	---
2-W10-4	4	2,310	1,280	1,950	±	501
2-W10-8	3	13	12	12.7	±	0.682
2-W10-9	3	1,960	1,220	1,540	±	505
2-W14-2	5	1,220	800	976	±	162
2-W14-5	4	630	310	431	±	156
2-W14-6	3	650	380	547	±	184
2-W15-4	3	2,290	1,540	1,840	±	512
2-W15-10	3	3,410	2,220	2,790	±	812
2-W15-11	3	4,520	2,730	3,490	±	1,220
2-W18-7	1	16		16	±	---
2-W18-15	2	119	98	109	±	26.3
2-W18-23	1	850		850	±	---
2-W18-24	2	670	610	640	±	75.2
2-W19-3	3	86	36	58.3	±	34.1
2-W19-9	4	73.4	55	63.6	±	8.94
2-W19-11	4	100	43	72.5	±	27.7
2-W19-13	4	24	17	21.0	±	3.40
2-W19-15	4	76	54	65.3	±	10.7
2-W19-16	4	115	89	105	±	12.6
2-W19-20	2	38.7	36	37.4	±	3.38
2-W19-24	1	26		26	±	---
2-W22-20	3	12	10	11.0	±	1.36
3-1-2	7	3	<5	3	±	---
3-8-2	7	3	<10	2.50	±	1.00
6-23-34	4	6.9	<5	6.9	±	---
6-24-34A	4	5.3	<5	5.3	±	---
6-24-34B	5	5.9	<5	5.9	±	---
6-35-70	2	3	<10	3	±	---
6-35-78A	2	3	<10	3	±	---
6-38-70	3	52	35	44.0	±	11.6
6-39-79	4	380	112	243	±	130

(a) Average concentrations ±2 standard error of the calculated mean. Averages and standard errors calculated from values reported as other than less than detection. Contractual detection limit was 10 ppb for most of the year, 5 ppb for the last quarter. Concentrations less than the contractual detection limits were occasionally reported.

(b) See Figures 3.10, 3.11, and 3.12 for well locations.

(c) Samples were collected from an additional 245 wells (sampling locations identified in Figure 3.20) and found to be below the detection limit for carbon tetrachloride.

TABLE A.24. Radionuclide Concentrations Measured in Columbia River Water at Priest Rapids Dam in 1987

Radionuclide[b]	No. of Samples	Concentration (pCi/L)[a] Maximum		Minimum		Average		Drinking Water Standard[c]
Composite System								
Gross Alpha	12	0.92	± 0.46	0.19	± 0.28	0.44	± 0.16	15
Gross Beta	12	2.1	± 1.4	0.19	± 0.92	0.92	± 0.52	50
^{3}H	12	110	± 10	50	± 10	70	± 10	20,000
^{89}Sr	12	0.10	± 0.08	-0.06	± 0.12	0.015	± 0.041	20
^{90}Sr	12	0.18	± 0.04	0.10	± 0.03	0.14	± 0.02	8
^{234}U	12	0.29	± 0.05	0.17	± 0.04	0.24	± 0.02	—[d]
^{235}U	12	0.028	± 0.022	0.004	± 0.006	0.013	± 0.006	—
^{238}U	12	0.37	± 0.06	0.15	± 0.04	0.21	± 0.03	—
U-Total	12	0.57	± 0.07	0.33	± 0.05	0.46	± 0.04	—
Continuous System								
^{60}Co P	24	0.0038	± 0.009	-0.0070	± 0.007	-0.0006	± 0.0015	100
D	24	0.0074	± 0.008	-0.0066	± 0.013	-0.0004	± 0.0026	
^{95}Nb P	24	0.0043	± 0.003	-0.004	± 0.004	0.0007	± 0.0012	300
D	24	0.0071	± 0.013	-0.0072	± 0.0072	0.0006	± 0.0024	
^{95}Zr P	24	0.0043	± 0.0034	-0.004	± 0.004	0.0007	± 0.0012	200
D	24	0.010	± 0.021	-0.012	± 0.019	-0.0010	± 0.0037	
^{106}Ru P	24	0.020	± 0.065	-0.054	± 0.046	-0.013	± 0.010	30
D	24	0.034	± 0.064	-0.10	± 0.095	-0.032	± 0.021	
^{129}I D	4	0.000012	± 0.000001	0.000004	± 0.0000004	0.000007	± 0.000004	1
^{131}I P	24	0.011	± 0.007	-0.005	± 0.007	0.008	± 0.002	
D	24	0.039	± 0.031	0.001	± 0.0096	0.013	± 0.006	3
^{134}Cs P	24	0.0023	± 0.0035	-0.004	± 0.0057	-0.0004	± 0.0011	
D	24	0.0052	± 0.0074	-0.005	± 0.011	0.0006	± 0.0021	20,000
^{137}Cs P	24	0.0026	± 0.0018	-0.010	± 0.006	0.0017	± 0.0016	
D	24	0.0085	± 0.010	-0.012	± 0.012	-0.0014	± 0.0026	200
^{144}Ce P	24	0.0081	± 0.017	-0.057	± 0.051	-0.011	± 0.006	—
D	24	0.056	± 0.071	-0.085	± 0.069	-0.013	± 0.012	
^{238}Pu P	4	0.0000008	± 0.0000020	-0.0000006	± 0.0000036	0.0000002	± 0.0000014	—
D	4	0.00003	± 0.00004	-0.000005	± 0.00005	0.000012	± 0.000024	
$^{239,240}Pu$ P	4	0.000028	± 0.000007	0.000004	± 0.000002	0.000019	± 0.000012	—
D	4	0.00014	± 0.00007	0.00007	± 0.00004	0.00011	± 0.00004	

(a) Maximum and minimum values ±2 sigma counting error. Average ±2 standard error of the calculated mean.
(b) Radionuclides measured using the continuous system show the particulate (P) and dissolved (D) fractions separately. Other radionuclides are based on samples collected by the composite system (see text).
(c) From State of Washington and EPA (see Table C.2, Appendix C).
(d) Dashes indicate no DWS.

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TABLE A.25. Radionuclide Concentrations Measured in Columbia River Water at the 300 Area in 1987

Radionuclide[b]	No. of Samples	Concentration (pCi/L)[a] Maximum		Minimum		Average		Drinking Water Standard[c]
Composite System								
Gross Alpha	4	0.79	± 0.41	0.43	± 0.35	0.59	± 0.26	15
Gross Beta	4	2.8	± 1.5	1.2	± 1.3	2.1	± 1.0	50
^{3}H	4	200	± 10	130	± 10	170	± 40	20,000
^{89}Sr	4	0.20	± 0.12	-0.011	± 0.12	0.097	± 0.12	20
^{90}Sr	4	0.15	± 0.03	0.092	± 0.044	0.13	± 0.04	8
^{234}U	4	0.33	± 0.05	0.25	± 0.05	0.30	± 0.05	—[d]
^{235}U	4	0.021	± 0.013	0.004	± 0.007	0.009	± 0.010	—
^{238}U	4	0.26	± 0.05	0.24	± 0.05	0.25	± 0.03	—
U-Total	4	0.61	± 0.07	0.49	± 0.07	0.56	± 0.07	—
Continuous System								
^{60}Co P	24	0.0048	± 0.0053	-0.0026	± 0.0046	0.00017	± 0.0012	100
D	24	0.021	± 0.015	-0.0047	± 0.009	0.0032	± 0.0030	
^{95}Nb P	24	0.0047	± 0.0053	-0.0037	± 0.0038	0.00075	± 0.0010	300
D	24	0.0072	± 0.007	-0.0060	± 0.0085	0.0010	± 0.0019	
^{95}Zr P	24	0.0048	± 0.008	-0.0053	± 0.0059	0.0002	± 0.0016	200
D	24	0.013	± 0.019	-0.015	± 0.011	0.0024	± 0.0034	
^{106}Ru P	24	0.0098	± 0.017	-0.028	± 0.043	-0.0099	± 0.0074	30
D	24	0.043	± 0.046	-0.087	± 0.067	-0.022	± 0.018	
^{129}I D	4	0.00013	± 0.00001	0.000079	± 0.000007	0.00011	± 0.00003	1
^{131}I P	24	0.0079	± 0.0061	0.00009	± 0.0034	0.0033	± 0.0013	3
D	24	0.017	± 0.020	0.0013	± 0.0160	0.0083	± 0.0031	
^{134}Cs P	24	0.0035	± 0.0056	-0.0024	± 0.0020	0.00024	± 0.00094	20,000
D	24	0.0050	± 0.0068	-0.012	± 0.0094	-0.00035	± 0.0021	
^{137}Cs P	24	0.00093	± 0.0023	-0.0058	± 0.0054	-0.0015	± 0.0010	200
D	24	0.0031	± 0.0039	-0.014	± 0.010	-0.0019	± 0.0022	
^{144}Ce P	24	0.0028	± 0.04	-0.016	± 0.015	-0.0054	± 0.0034	—
D	24	0.045	± 0.051	-0.041	± 0.081	-0.85	± 0.0087	
^{238}Pu P	4	0.000001	± 0.000004	0.0000005	± 0.0000035	0.0000007	± 0.0000017	—
D	4	0.000009	± 0.00002	-0.00001	± 0.00005	-0.0000003	± 0.00002	
$^{239,240}Pu$ P	4	0.000033	± 0.000008	0.000008	± 0.000006	0.00002	± 0.00001	—
D	4	0.00006	± 0.00005	0.00004	± 0.00002	0.00005	± 0.00002	

(a) Maximum and minimum values ±2 sigma counting error. Average ±2 standard error of the calculated mean.
(b) Radionuclides measured using the continuous system show the particulate (P) and dissolved (D) fractions separately. Other radionuclides are based on samples collected by the composite system (see text).
(c) From State of Washington and EPA (see Table C.2, Appendix C).
(d) Dashes indicate no DWS.

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TABLE A.26. Radionuclide Concentrations Measured in Columbia River Water at the Richland Pumphouse in 1987

Radionuclide[b]	No. of Samples	Concentration (pCi/L)[a] Maximum		Minimum		Average		Drinking Water Standard[c]
Composite System								
Gross Alpha	12	0.89	± 0.43	0.05	± 0.26	0.53	± 0.21	15
Gross Beta	12	2.4	± 1.4	0.21	± 1.17	1.1	± 0.5	50
^{3}H	12	180	± 10	70	± 10	130	± 10	20,000
^{89}Sr	12	0.11	± 0.07	-0.05	± 0.11	0.040	± 0.035	20
^{90}Sr	12	0.18	± 0.04	0.10	± 0.03	0.13	± 0.02	8
^{234}U	12	0.45	± 0.06	0.14	± 0.03	0.27	± 0.05	—[d]
^{235}U	12	0.037	± 0.017	0.003	± 0.011	0.013	± 0.007	—
^{238}U	12	0.36	± 0.05	0.18	± 0.04	0.22	± 0.03	—
U-Total	12	0.84	± 0.08	0.33	± 0.05	0.51	± 0.08	—
Continuous System								
^{60}Co P	26	0.0051	± 0.007	-0.0039	± 0.0047	0.0012	± 0.0015	100
D	26	0.010	± 0.013	-0.0087	± 0.018	0.0018	± 0.0029	
^{95}Nb P	26	0.0049	± 0.005	-0.0016	± 0.0024	0.0015	± 0.0012	300
D	26	0.011	± 0.012	-0.0060	± 0.0069	0.0028	± 0.0028	
^{95}Zr P	26	0.0057	± 0.010	-0.0070	± 0.0089	0.0001	± 0.0020	200
D	26	0.0086	± 0.017	-0.019	± 0.019	-0.0012	± -0.0039	
^{106}Ru P	26	0.025	± 0.068	-0.045	± 0.033	-0.016	± 0.011	30
D	26	0.063	± 0.070	-0.14	± 0.10	-0.028	± 0.027	
^{129}I D	4	0.00013	± 0.00001	0.000080	± 0.000007	0.00010	± 0.00002	1
^{131}I P	26	0.013	± 0.0092	-0.0093	± 0.015	0.003	± 0.002	3
D	26	0.030	± 0.027	-0.0025	± 0.013	0.011	± 0.005	
^{134}Cs P	26	0.0034	± 0.0039	-0.0098	± 0.0086	-0.0003	± 0.0014	20,000
D	26	0.012	± 0.0093	-0.0065	± 0.0074	0.0007	± 0.0024	
^{137}Cs P	26	0.0038	± 0.0072	-0.0076	± 0.0064	-0.0011	± 0.0015	200
D	26	0.0085	± 0.0064	-0.019	± 0.010	-0.0044	± 0.0032	
^{144}Ce P	26	0.0055	± 0.015	-0.018	± 0.014	-0.0067	± 0.0043	—
D	26	0.0055	± 0.059	-0.049	± 0.050	-0.021	± 0.008	
^{238}Pu P	4	0.000004	± 0.000004	0.0000007	± 0.000005	0.000002	± 0.000002	—
D	4	0.00002	± 0.00003	-0.000004	± 0.00002	0.000008	± 0.00002	
$^{239,240}Pu$ P	4	0.00006	± 0.00001	0.000017	± 0.000008	0.00004	± 0.00002	—
D	4	0.00010	± 0.00005	0.00005	± 0.00004	0.00008	± 0.00003	

(a) Maximum and minimum values 2 sigma counting error. Average ±2 standard error of the calculated mean.
(b) Radionuclides measured using the continuous system show the particulate (P) and dissolved (D) fractions separately. Other radionuclides are based on samples collected by the composite system (see text).
(c) From State of Washington and EPA (see Table C.2, Appendix C).
(d) Dashes indicate no DWS.

9 2 1 2 5 5 6 0 3 9 0

TABLE A.27. Columbia River Water Quality Data for 1987

Analysis	Units	Vernita Bridge (Upstream) No. of Samples	Maximum	Minimum	Annual Average[a]	Richland Pumphouse (Downstream) No. of Samples	Maximum	Minimum	Annual Average[a]	State Standard[b]
PNL Environmental Monitoring										
pH	pH units	12	8.3	7.3	NA	12	8.3	7.2	NA	6.5-8.5
Fecal coliform	#/100 mL	12	64	2	5[c]	12	240	2	22[c]	100
Total coliform	#/100 mL	12	2400	2	110[c]	12	240	2	49[c]	
Biological oxygen demand	mg/L	12	8.3	0.4	2.48 ± 1.25	12	3.0	0.5	2.0 ± 0.5	
Nitrate	mg/L	12	0.17	0.02	0.09 ± 0.03	12	0.77	0.05	0.2 ± 0.1	
USGS Sampling Program[d]										
Temperature[e]	°C	365	20.2	3.0	11.7	365	20.4	2.8	12.0	20 (maximum)
Dissolved oxygen	mg/L	6	13.3	9.6	11.2 ± 1.4	4	13.6	9.5	11.3 ± 2.0	6 (minimum)
Turbidity	NTU[f]	6	2.6	0.1	1.2 ± 0.8	4	10.0	0.7	3.8 ± 4.3	5 + background
pH	pH units	6	8.4	7.9	NA	4	8.2	8.0	NA	6.5 - 8.5
Fecal coliform	#/100 mL	6	7	<1	1.5[c]	4	5	1	1.5[c]	100
Suspended solids, 105°C	mg/L	4	16	7	7.8 ± 6.2	4	11	<1	6.5 ± 5.8	
Dissolved solids, 180°C	mg/L	6	92	70	77 ± 7	4	95	61	76 ± 14	
Specific conductance	µmhos/cm	6	161	127	138 ± 11	4	150	127	134 ± 11	
Hardness, as $CaCO_3$	mg/L	6	76	59	67 ± 7	4	75	59	65 ± 7	
Phosphorus, total	mg/L	6	0.03	0.01	0.02 ± 0.01	4	0.03	0.01	0.025 ± 0.01	
Chromium, dissolved	µg/L	3	1	<1	<1	3	<10	<1	<7	
Nitrogen, Kjeldahl	mg/L	6	0.7	<0.2	0.4 ± 0.1	4	0.8	<0.2	0.5 ± 0.25	
Total organic carbon	mg/L	4	40	1.2	11.2 ± 19.2	4	97	1.4	35 ± 45	
Iron, dissolved	µg/L	4	11	3	5.3 ± 3.9	4	14	4	8 ± 4.5	
Ammonia, dissolved (as N)	mg/L	6	0.07	<0.01	0.03 ± 0.02	4	0.04	<0.01	0.02 ± 0.01	

(a) Average values ±2 standard error of the calculated mean.
(b) See Appendix C.
(c) Annual median.
(d) Provisional data subject to revision.
(e) Maximum and minimum represent daily averages.
(f) Nephelometric Turbidity Units.
NA Not Applicable.

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TABLE A.28. Radionuclide Concentrations in Onsite Ponds in 1987

Location	Radionuclide	No. of Samples	Concentration, pCi/L[a] Maximum	Minimum	Average
West Lake	Gross Alpha	4	267 ± 15	85 ± 8	186 ± 89
	Gross Beta	4	490 ± 87	95 ± 19	286 ± 195
	^{3}H	4	570 ± 140	430 ± 140	500 ± 110
	^{90}Sr	4	2.8 ± 0.3	1.8 ± 0.2	2.2 ± 0.5
	^{137}Cs	4	1.6 ± 3.0	0.0 ± 1.0	0.9 ± 1.4
Gable Pond	Gross Alpha	3	0.8 ± 0.4	0.6 ± 0.4	0.7 ± 0.3
	Gross Beta	3	12.3 ± 2.5	4.9 ± 1.8	9.0 ± 5.2
	^{3}H	3	230 ± 180	12 ± 220	160 ± 180
	^{90}Sr	3	1.4 ± 0.1	0.5 ± 0.1	0.9 ± 0.6
	^{137}Cs	3	50 ± 5	0.9 ± 0.9	21 ± 34
B Pond	Gross Alpha	4	0.9 ± 0.4	0.2 ± 0.3	0.4 ± 0.4
	Gross Beta	4	4.3 ± 1.7	2.3 ± 1.4	3.0 ± 1.2
	^{3}H	4	160 ± 180	-60 ± 220	50 ± 140
	^{90}Sr	4	0.4 ± 0.1	0.1 ± 0.1	0.3 ± 0.2
	^{137}Cs	4	1.8 ± 1.9	0.3 ± 1.9	0.9 ± 1.2
FFTF Pond	Gross Alpha	3	1.3 ± 1.3	0.1 ± 0.3	0.5 ± 0.9
	Gross Beta	3	18 ± 3	13 ± 3	16 ± 4
	^{3}H	3	9,510 ± 360	2,410 ± 220	5,560 ± 4,850
	^{137}Cs	3	1.1 ± 2.0	-0.3 ± 1.8	0.4 ± 1.4
	^{22}Na	3	1.5 ± 1.5	0.5 ± 0.8	1.0 ± 0.9

(a) Maximum and minimum values ±2 sigma counting error. Averages ±2 standard error of the calculated mean.

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TABLE A.29. Radionuclide Concentrations in Milk Samples in 1987 (pCi/L)[a]

Location[b]	^{3}H No. of Samples	^{3}H Maximum	^{3}H Average	^{90}Sr No. of Samples	^{90}Sr Maximum	^{90}Sr Average
Wahluke East Area Composite	13	250 ± 130	85 ± 220	4	0.6 ± 0.6	0.12 ± 1.0
Sagemoor Area Composite	13	330 ± 140	160 ± 280	NS	—[c]	—
Riverview Area[d]	12	270 ± 180	96 ± 310	3	6.7 ± 0.8	2.8 ± 7.1
Benton City Area	13	260 ± 140	120 ± 210	NS	—	—
Sunnyside Area	13	310 ± 140	97 ± 290	4	0.9 ± 1.0	0.6 ± 1.2
Moses Lake Area	13	310 ± 180	170 ± 300	NS	—	—

Location[b]	^{90}Sr No. of Samples	^{90}Sr Maximum	^{90}Sr Average	^{129}I No. of Samples	^{129}I Maximum	^{129}I Average
Wahluke East Area Composite	4	1.3 ± 0.4	0.9 ± 0.7	2	0.038 ± 0.004	0.022 ± 0.056
Sagemoor Area Composite	4	1.3 ± 0.4	1.0 ± 0.6	2	0.015 ± 0.001	0.014 ± 0.002
Riverview Area[d]	3	1.3 ± 0.3	0.8 ± 1.0	2	0.034 ± 0.002	0.020 ± 0.050
Benton City Area	4	1.7 ± 0.5	1.2 ± 0.9	1	—	0.014 ± 0.001
Sunnyside Area	4	1.4 ± 0.3	0.8 ± 1.0	2	0.031 ± 0.003	0.017 ± 0.049
Moses Lake Area	4	1.8 ± 1.0	1.3 ± 1.0	2	0.0013 ± 0.0003	0.0008 ± 0.002

Location[b]	^{131}I No. of Samples	^{131}I Maximum	^{131}I Average	^{137}Cs No. of Samples	^{137}Cs Maximum	^{137}Cs Average
Wahluke East Area Composite	13	0.22 ± 0.25	0.04 ± 0.34	13	5.7 ± 4.2	1.1 ± 6.1
Sagemoor Area Composite	26	0.23 ± 0.22	0.03 ± 0.30	26	8.6 ± 3.6	1.2 ± 7.3
Riverview Area[d]	12	0.14 ± 0.24	0.01 ± 0.35	12	12. ± 4.0	3.6 ± 9.1
Benton City Area	13	0.23 ± 0.26	-0.03 ± 0.34	13	5.0 ± 3.0	2.1 ± 5.1
Sunnyside Area	26	0.23 ± 0.26	0.01 ± 0.35	26	11. ± 4.0	2.9 ± 7.6
Moses Lake Area	13	0.37 ± 0.22	0.05 ± 0.37	13	9.1 ± 4.4	1.3 ± 9.3

(a) Maximum values ±2 sigma counting error. Averages ±2 standard error of the calculated mean.
(b) Refer to Figure 3.39.
(c) Dashes indicate no sample was analyzed.
(d) Irrigation water obtained from the Columbia River downstream of Hanford.
NS No sample.

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TABLE A.30. Radionuclide Concentrations in Leafy Vegetables in 1987

Location[b]	^{90}Sr, pCi/g, wet weight[a]			^{137}Cs, pCi/g, wet weight[a]		
	No. of Samples	Maximum	Average	No. of Samples	Maximum	Average
Wahluke East Area	3	0.006 ± 0.003	0.004 ± 0.005	3	0.010 ± 0.008	0.009 ± 0.009
Sagemoor Area	3	0.003 ± 0.003	0.003 ± 0.002	3	0.003 ± 0.007	0.001 ± 0.009
Riverview Area[c]	3	0.003 ± 0.004	0.003 ± 0.003	3	0.008 ± 0.007	0.006 ± 0.010
Benton City Area	3	0.040 ± 0.007	0.020 ± 0.042	3	0.003 ± 0.009	0.001 ± 0.010
Sunnyside Area	3	0.016 ± 0.004	0.007 ± 0.016	3	0.014 ± 0.007	0.004 ± 0.018

(a) Maximum concentrations ±2 sigma counting error. Averages ±2 standard error of the calculated mean.
(b) Refer to Figure 3.39.
(c) Irrigated with Columbia River water.

TABLE A.31. Radionuclide Concentrations in Vegetables in 1987

Type/Location[b]	^{90}Sr, pCi/g, wet weight[a]			^{137}Cs, pCi/g, wet weight[a]		
	No. of Samples	Maximum	Average	No. of Samples	Maximum	Average
Tomatoes						
Riverview Area[c]	3	0.002 ± 0.002	0.002 ± 0.002	3	0.001 ± 0.004	-0.002 ± 0.009
Carrots						
Riverview Area[c]	3	0.013 ± 0.004	0.007 ± 0.010	3	0.008 ± 0.005	0.003 ± 0.012
Potatoes						
Riverview Area[c]	3	0.009 ± 0.003	0.007 ± 0.004	3	0.006 ± 0.006	0.001 ± 0.013
Sagemoor Area	3	0.006 ± 0.002	0.005 ± 0.002	3	0.005 ± 0.005	0.003 ± 0.008
Wahluke East Area	3	0.004 ± 0.003	0.003 ± 0.003	3	0.013 ± 0.005	0.003 ± 0.022
Sunnyside Area	3	0.004 ± 0.002	0.002 ± 0.003	3	0.001 ± 0.008	-0.003 ± 0.012

(a) Maximum values ±2 sigma counting error. Averages ±2 standard error of the calculated mean.
(b) Refer to Figure 3.39.
(c) Irrigated with Columbia River water.

9 2 1 2 5 5 6 0 3 9 4

TABLE A.32. Radionuclide Concentrations in Fruit in 1987

Type/ Location[b]	^{90}Sr, pCi/g, wet weight[a]			^{137}Cs, pCi/g, wet weight[a]			^{3}H, pCi/L, water[a]		
	No. of Samples	Maximum	Average	No. of Samples	Maximum	Average	No. of Samples	Maximum	Average
Apples									
Riverview Area[c]	3	0.003 ± 0.002	0.002 ± 0.003	3	0.008 ± 0.006	0.001 ± 0.015	3	75 ± 140	30 ± 170
Sagemoor Area	3	0.001 ± 0.002	0.001 ± 0.002	3	0.010 ± 0.009	0.003 ± 0.016	3	230 ± 140	150 ± 250
Cold Creek Area	3	0.002 ± 0.003	0.001 ± 0.002	3	0.006 ± 0.007	-0.006 ± 0.027	3	2 ± 130	-24 ± 150
Sunnyside Area	3	0.001 ± 0.002	0.001 ± 0.002	3	0.010 ± 0.007	0.007 ± 0.012	3	240 ± 140	180 ± 230
Wahluke Area	3	0.003 ± 0.002	0.002 ± 0.003	3	0.006 ± 0.006	0.001 ± 0.017	3	3 ± 140	36 ± 150
Cherries									
Sagemoor Area	3	0.003 ± 0.002	0.002 ± 0.003	3	0.006 ± 0.005	0.005 ± 0.006	3	92 ± 130	31 ± 230
Sunnyside Area	3	0.003 ± 0.003	0.003 ± 0.003	3	-0.001 ± 0.004	-0.003 ± 0.009	3	110 ± 130	18 ± 250
Grapes									
Riverview Area [c]	3	0.007 ± 0.002	0.005 ± 0.004	3	0.009 ± 0.010	0.004 ± 0.014	3	34 ± 140	-14 ± 180
Sagemoor Area	3	0.002 ± 0.003	0.002 ± 0.002	3	0.007 ± 0.006	-0.001 ± 0.017	3	74 ± 140	-6 ± 270
Cold Creek Area	3	0.007 ± 0.003	0.004 ± 0.006	3	0.007 ± 0.006	0.003 ± 0.011	3	310 ± 140	210 ± 280
Sunnyside Area	3	0.005 ± 0.003	0.003 ± 0.004	3	0.009 ± 0.006	0.001 ± 0.023	3	27 ± 140	-42 ± 230
Melons									
Riverview Area[c]	3	0.003 ± 0.002	0.002 ± 0.003	3	0.003 ± 0.0030	0.002 ± 0.006	3	15 ± 130	-23 ± 180

(a) Maximum values ±2 sigma counting error. Averages ±2 standard error of the calculated mean.
(b) Refer to Figure 3.39.
(c) Irrigated with Columbia River water.

TABLE A.33. Radionuclide Concentrations in Local Wine in 1987

Location[b]	^{3}H, pCi/g[a]			^{137}Cs, pCi/g[a]		
	No. of Samples	Maximum	Average	No. of Samples	Maximum	Average
Sagemoor	3	269 ± 139	168 ± 145	6	4.4 ± 3.5	-0.4 ± 4.2
Sunnyside	3	278 ± 140	199 ± 169	6	2 ± 13	-1.9 ± 5.1

(a) Maximum values ±2 sigma counting error. Averages ±2 standard error of the calculated mean.
(b) Refer to Figure 3.39.

TABLE A.34. Radionuclide Concentrations in Wheat and Alfalfa in 1987

Type/ Location[b]	^{90}Sr, pCi/g, dry weight[a]			^{137}Cs, pCi/g, dry weight[a]			$^{239,240}Pu$, pCi/g, dry weight[a]		
	No. of Samples	Maximum	Average	No. of Samples	Maximum	Average	No. of Samples	Maximum	Average
Wheat									
Wahluke East Area	3	0.023 ± 0.004	0.022 ± 0.006	3	0.002 ± 0.006	0.001 ± 0.007	NS	---	---
Sagemoor Area	3	0.010 ± 0.005	0.009 ± 0.006	3	0.003 ± 0.006	0.001 ± 0.009	3	0.00003 ± 0.00008	0.00001 ± 0.00006
Riverview Area[c]	3	0.014 ± 0.004	0.011 ± 0.012	3	0.004 ± 0.006	0.003 ± 0.007	NS	---	---
Moses Lake Area	3	0.009 ± 0.004	0.007 ± 0.004	3	0.006 ± 0.006	0.003 ± 0.013	NS	---	---
Alfalfa									
Wahluke East Area	3	0.025 ± 0.005	0.023 ± 0.007	3	0.009 ± 0.016	0.003 ± 0.019	NS	---	---
Sagemoor Area	3	0.12 ± 0.01	0.12 ± 0.02	3	0.037 ± 0.023	0.014 ± 0.070	NS	---	---
Riverview Area[c]	3	0.036 ± 0.050	0.035 ± 0.005	3	0.036 ± 0.012	0.015 ± 0.044	NS	---	---
Benton City Area	3	0.059 ± 0.006	0.044 ± 0.028	3	0.005 ± 0.014	-0.004 ± 0.032	NS	---	---
Sunnyside Area	3	0.080 ± 0.009	0.071 ± 0.021	3	0.013 ± 0.016	-0.001 ± 0.034	NS	---	---
Moses Lake Area	3	0.17 ± 0.01	0.16 ± 0.02	3	0.017 ± 0.019	0.005 ± 0.027	NS	---	---

(a) Maximum values ±2 sigma counting error. Averages ±2 standard error of the calculated mean.
(b) Refer to Figure 3.39.
(c) Irrigated with Columbia River water.
NS No Sample

TABLE A.35. Radionuclide Concentrations in Beef, Chicken, and Eggs in 1987

Type/Location[b]	^{90}Sr, pCi/g, wet weight[a]			^{137}Cs, pCi/g, wet weight[a]		
	No. of Samples	Maximum	Average	No. of Samples	Maximum	Average
Beef						
Sagemoor Area	1	---	0.001 ± 0.002	1	---	0.005 ± 0.005
Sunnyside Area	1	---	0.005 ± 0.003	1	---	0.14 ± 0.006
Chicken						
Sagemoor Area	2	0.003 ± 0.003	0.001 ± 0.005	2	0.003 ± 0.017	0.001 ± 0.016
Eggs						
Sagemoor Area	2	0.003 ± 0.002	0.002 ± 0.005	2	0.001 ± 0.006	0.001 ± 0.007

(a) Maximum values ±2 sigma counting error. Averages ±2 standard error of the calculated mean unless only one sample.
(b) Refer to Figure 3.39.

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TABLE A.36. Concentrations of Cesium-137 in Deer Muscle and Plutonium-239,240 in Deer Liver in 1987

		^{137}Cs, pCi/g, wet weight[a]			$^{239,240}Pu$, pCi/g, wet weight[a]		
Location	Type	No. of Samples	Maximum	Average	No. of Samples	Maximum	Average
Random (road kills)	Muscle	3	0.019 ± 0.007	0.008 ± 0.018	NS	—[b]	—
	Liver	NS	—	—	3	0.00083 ± 0.0014	0.00037 ± 0.00073
200 Area Ponds	Muscle	1	—	0.007 ± 0.008	NS	—	—
	Liver	NS	—	—	1	—	0.00002 ± 0.00004

(a) Maximum values ±2 sigma counting error. Averages ±2 standard error of the calculated mean unless only one sample.
(b) Dashes indicate no analysis or no calculation.
NS No sample.

TABLE A.37. Radionuclide Concentrations in Columbia River Fish in 1987

	^{60}Co, pCi/g, wet weight[a]			^{90}Sr, pCi/g, wet weight[a]			^{137}Cs, pCi/g, wet weight[a]		
Type/Location[b]	No. of Samples	Maximum	Average	No. of Samples	Maximum	Average	No. of Samples	Maximum	Average
Whitefish Muscle									
Upstream of Site Boundary	5	0.023 ± 0.022	0.006 ± 0.062	5	0.001 ± 0.002	0.001 ± 0.003	5	0.033 ± 0.035	0.016 ± 0.043
100-D Area Vicinity	10	0.053 ± 0.035	0.011 ± 0.065	10	0.004 ± 0.003	0.001 ± 0.003	10	0.056 ± 0.031	0.022 ± 0.067
Whitefish Carcass									
Upstream of Site Boundary	NS	—	—	5	0.021 ± 0.005	0.018 ± 0.006	NS	—	—
100-D Area Vicinity	NS	—	—	10	0.035 ± 0.005	0.024 ± 0.015	NS	—	—
Bass Muscle									
100-F Sloughs	5	0.017 ± 0.017	0.002 ± 0.035	5	0.006 ± 0.003	0.003 ± 0.005	5	0.066 ± 0.026	0.046 ± 0.044
Bass Carcass									
100-F Sloughs	NS	—	—	5	0.066 ± 0.031	0.049 ± 0.036	NS	—	—

(a) Maximum values ±2 sigma counting error. Averages ±2 standard error of the calculated mean.
(b) Refer to Figure 3.43.
NS No sample.

9 2 1 2 5 5 6 0 3 9 7

TABLE A.38. Radionuclide Concentrations in Muscle Tissue of Upland Gamebirds in 1987

Type/ Location[b]	^{60}Co, pCi/g, wet weight[a] No. of Samples	Maximum	Average	^{137}Cs, pCi/g, wet weight[a] No. of Samples	Maximum	Average
Pheasant						
100 Areas	9	0.028 ± 0.016	0.006 ± 0.013	9	0.033 ± 0.030	0.003 ± 0.017
300 Area	1	---	0.002 ± 0.025	1	---	0.002 ± 0.027

(a) Maximum values ±2 sigma counting error. Averages ±2 standard error of the calculated mean unless only one sample.
(b) Refer to Figure 3.43.

TABLE A.39. Radionuclide Concentrations in Muscle Tissue of Mallard Ducks in 1987

Location[b]	No. of Samples	^{137}Cs, pCi/g, wet weight[a] Maximum	Minimum	Average
200 Area B Pond	4	2.2 ± 0.1	0.37 ± 0.05	1.2 ± 0.9
300 Area Pond	4	0.93 ± 0.09	0.01 ± 0.02	0.41 ± 0.45

(a) Maximum and minimum values ±2 sigma counting error. Average ±2 standard error of the calculated mean.
(b) Refer to Figure 3.43

TABLE A.40. Radionuclide Concentrations in Bone and Muscle Tissue of Rabbits in 1987

Type/Location[b]	^{90}Sr (Bone), pCi/g, wet weight[a] No. of Samples	Maximum	Average	^{137}Cs (Muscle), pCi/g, wet weight[a] No. of Samples	Maximum	Average
Cottontail						
100 Area	3	460 ± 8	260 ± 310	3	0.044 ± 0.030	0.023 ± 0.033
Jack Rabbit						
200 Area	2	40 ± 1	21 ± 5	2	0.067 ± 0.029	0.031 ± 0.077

(a) Maximum values ±2 sigma counting error. Averages ±2 standard error of the calculated mean.
(b) Refer to Figure 3.43.

9 2 1 2 5 5 6 0 3 9 8

TABLE A.41. Strontium-90 (^{90}Sr) Concentrations in Soil

Location	Map Location[b]	pCi/g (dry weight)[a] 1982	1983	1984	1985	1986	1987
ON SITE							
1 Mile NE of 100-N Area	1	0.20 ± 0.03	0.70 ± 0.023	0.29 ± 0.017	0.28 ± 0.058	0.24 ± 0.01	—[c]
1 Mile E of 100-N Area	2	0.15 ± 0.06	0.85 ± 0.026	0.22 ± 0.010	0.44 ± 0.091	0.22 ± 0.01	0.31 ± 0.01
100 Area Fire Station	3	0.28 ± 0.04	1.7 ± 0.033	0.45 ± 0.020	0.57 ± 0.11	0.34 ± 0.01	0.33 ± 0.01
200-East NC	4	0.93 ± 0.13	2.7 ± 0.047	0.20 ± 0.19	1.2 ± 0.23	0.61 ± 0.01	1.1 ± 0.1
E of 200-East	5	0.33 ± 0.09	0.78 ± 0.033	0.73 ± 0.48	0.90 ± 0.18	0.39 ± 0.01	0.34 ± 0.02
200-East SE	6	0.29 ± 0.05	1.3 ± 0.028	0.44 ± 0.060	0.20 ± 0.042	0.27 ± 0.01	0.24 ± 0.02
SW of BC Cribs	7	0.13 ± 0.10	0.79 ± 0.033	0.12 ± 0.050	0.39 ± 0.079	0.11 ± 0.01	0.02 ± 0.01
S of 200-East	8	0.18 ± 0.05	0.38 ± 0.020	0.50 ± 0.11	0.14 ± 0.030	0.54 ± 0.01	0.11 ± 0.01
E of 200-West	9	0.48 ± 0.11	2.6 ± 0.048	0.33 ± 0.020	0.61 ± 0.12	0.56 ± 0.01	0.38 ± 0.02
2 Miles S of 200-West	10	0.06 ± 0.005	0.28 ± 0.015	0.14 ± 0.020	0.37 ± 0.078	0.23 ± 0.02	—
NE of FFTF	11	0.042 ± 0.035	0.52 ± 0.020	0.18 ± 0.021	0.17 ± 0.039	—	0.09 ± 0.01
SE of FFTF	12	0.047 ± 0.045	0.54 ± 0.019	0.032 ± 0.054	0.20 ± 0.042	0.44 ± 0.01	—
N of 300 Area	13	0.22 ± 0.030	0.73 ± 0.023	0.58 ± 0.029	0.32 ± 0.068	0.18 ± 0.02	0.24 ± 0.01
Hanford Townsite	14	0.24 ± 0.080	1.9 ± 0.048	0.31 ± 0.029	0.25 ± 0.052	—	0.29 ± 0.01
Wye Barricade	15	0.21 ± 0.030	0.81 ± 0.026	0.31 ± 0.040	0.31 ± 0.062	—	0.18 ± 0.01
ONSITE AVERAGE		0.25 ± 0.12	1.1 ± 0.40	0.32 ± 0.10	0.42 ± 0.15	0.31 ± 0.11	0.31 ± 0.16
OFF SITE							
Riverview	16	0.12 ± 0.040	0.90 ± 0.044	0.039 ± 0.012	0.074 ± 0.019	0.06 ± 0.01	0.19 ± 0.01
Byers Landing	17	0.02 ± 0.01	0.30 ± 0.020	0.064 ± 0.008	0.18 ± 0.016	0.17 ± 0.01	0.08 ± 0.01
Sagemoor	18	0.006 ± 0.003	0.28 ± 0.017	0.25 ± 0.046	0.081 ± 0.019	0.11 ± 0.02	0.04 ± 0.01
Taylor Flats No. 2	19	0.23 ± 0.060	0.23 ± 0.039	0.042 ± 0.008	0.046 ± 0.013	0.36 ± 0.02	0.10 ± 0.01
W End Fir Road	20	0.07 ± 0.007	1.20 ± 0.031	0.14 ± 0.015	0.091 ± 0.022	0.12 ± 0.02	0.05 ± 0.01
Ringold	21	0.08 ± 0.040	1.80 ± 0.032	0.24 ± 0.014	0.20 ± 0.042	0.26 ± 0.02	0.21 ± 0.01
Berg Ranch	22	0.20 ± 0.090	0.92 ± 0.023	0.20 ± 0.019	0.15 ± 0.033	0.20 ± 0.01	0.20 ± 0.01
Wahluke Slope No. 2[d]	23	0.10 ± 0.030	0.65 ± 0.023	0.16 ± 0.017	0.21 ± 0.046	0.10 ± 0.01	0.07 ± 0.01
Vernita Bridge[d]	24	0.11 ± 0.070	0.52 ± 0.017	0.17 ± 0.015	0.31 ± 0.064	0.09 ± 0.01	—
Yakima Barricade[d]	25	0.09 ± 0.003	0.59 ± 0.023	0.13 ± 0.017	0.54 ± 0.109	—	0.06 ± 0.01
Rattlesnake Springs[d]	26	0.17 ± 0.040	0.89 ± 0.033	0.075 ± 0.009	0.33 ± 0.069	0.18 ± 0.01	0.12 ± 0.01
ALE[d]	27	0.30 ± 0.060	1.60 ± 0.032	0.36 ± 0.039	0.61 ± 0.12	—	0.40 ± 0.03
Prosser Barricade[d]	28	0.29 ± 0.020	1.10 ± 0.027	0.36 ± 0.020	0.45 ± 0.092	0.17 ± 0.01	—
S of 300 Area[d]	29	0.24 ± 0.150	1.4 ± 0.039	0.35 ± 0.015	0.51 ± 0.10	0.31 ± 0.01	—
Benton City	30	0.21 ± 0.030	0.42 ± 0.018	0.36 ± 0.031	0.12 ± 0.027	0.25 ± 0.01	0.24 ± 0.01
Sunnyside	31	0.12 ± 0.030	1.60 ± 0.040	0.31 ± 0.029	0.26 ± 0.055	0.05 ± 0.01	0.25 ± 0.02
Walla Walla	32				0.31 ± 0.015	0.14 ± 0.08	0.02 ± 0.01
McNary Dam	33				0.29 ± 0.019	0.18 ± 0.08	0.07 ± 0.06
Moses Lake	34					0.08 ± 0.01	0.06 ± 0.02
Washtucna	35					0.40 ± 0.02	0.12 ± 0.12
Connell	36					0.32 ± 0.02	0.12 ± 0.11
Othello	37					0.27 ± 0.02	0.15 ± 0.08
Yakima	38					0.04 ± 0.01	0.06 ± 0.04
OFFSITE AVERAGE		0.15 ± 0.045	1.0 ± 0.29	0.20 ± 0.059	0.26 ± 0.080	0.18 ± 0.05	0.12 ± 0.03

(a) Individual results ±2 sigma counting error. Averages ±2 standard error of the calculated mean.
(b) Locations are identified in Figure 3.50.
(c) Locations sampled every other year indicated by dashed line.
(d) Perimeter location on Site near Site boundary.

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TABLE A.42. Cesium-137 (^{137}Cs) Concentrations in Soil

Location	Map Location[b]	pCi/g (dry weight)[a] 1982	1983	1984	1985	1986	1987
ON SITE							
1 Mile NE of 100-N Area	1	0.67 ± 0.08	0.48 ± 0.04	0.70 ± 0.05	0.76 ± 0.065	0.81 ± 0.05	—[c]
1 Mile E of 100-N Area	2	0.54 ± 0.04	0.77 ± 0.05	0.67 ± 0.04	0.62 ± 0.057	0.55 ± 0.04	1.1 ± 0.1
100 Area Fire Station	3	0.99 ± 0.06	1.40 ± 0.07	0.98 ± 0.06	1.2 ± 0.082	1.6 ± 0.1	1.3 ± 0.1
200-East NC	4	22 ± 0.37	28 ± 0.33	21 ± 0.23	23 ± 1.4	9.6 ± 0.2	16 ± 0.1
E of 200-East	5	1.5 ± 0.10	1.30 ± 0.07	1.4 ± 0.06	3.0 ± 0.20	1.4 ± 0.1	0.69 ± 0.04
200-East SE	6	1.8 ± 0.08	0.16 ± 0.03	0.54 ± 0.04	0.55 ± 0.048	0.37 ± 0.03	0.61 ± 0.04
SW of BC Cribs	7	0.31 ± 0.06	0.31 ± 0.03	0.06 ± 0.02	0.14 ± 0.022	0.12 ± 0.02	0.01 ± 0.02
S of 200-East	8	0.54 ± 0.07	0.15 ± 0.03	0.14 ± 0.02	0.56 ± 0.053	0.71 ± 0.04	0.13 ± 0.03
E of 200-West	9	3.2 ± 0.10	5.70 ± 0.15	0.59 ± 0.04	2.0 ± 0.069	3.1 ± 0.1	1.3 ± 0.1
2 Miles S of 200 West	10	0.21 ± 0.06	0.07 ± 0.02	0.17 ± 0.03	0.30 ± 0.030	0.50 ± 0.04	---
NE of FFTF	11	0.13 ± 0.02	0.18 ± 0.03	0.12 ± 0.02	0.080 ± 0.028	---	0.33 ± 0.03
SE of FFTF	12	0.19 ± 0.03	0.20 ± 0.04	0.08 ± 0.02	0.083 ± 0.022	0.04 ± 0.02	---
N of 300 Area	13	0.85 ± 0.05	0.53 ± 0.04	0.43 ± 0.04	0.46 ± 0.052	0.54 ± 0.45	1.2 ± 0.1
Hanford Townsite	14	0.96 ± 0.08	1.00 ± 0.07	0.91 ± 0.05	1.1 ± 0.086	---	1.1 ± 0.1
Wye Barricade	15	1.1 ± 0.06	0.84 ± 0.05	0.68 ± 0.04	1.3 ± 0.098	---	0.59 ± 0.04
ONSITE AVERAGE		2.4 ± 2.9	2.8 ± 3.7	1.9 ± 2.8	2.3 ± 3.0	1.5 ± 1.4	2.0 ± 2.6
OFF SITE							
Riverview	16	0.49 ± 0.07	1.2 ± 0.07	0.077 ± 0.021	0.21 ± 0.026	0.17 ± 0.04	0.86 ± 0.05
Byers Landing	17	0.28 ± 0.07	0.59 ± 0.05	0.20 ± 0.03	0.19 ± 0.035	0.50 ± 0.04	0.23 ± 0.03
Sagemoor	18	0.06 ± 0.04	0.14 ± 0.03	1.0 ± 0.06	0.10 ± 0.023	0.32 ± 0.04	0.12 ± 0.02
Taylor Flats No. 2	19	0.61 ± 0.05	2.2 ± 0.07	0.084 ± 0.031	0.085 ± 0.028	1.2 ± 0.1	0.60 ± 0.06
W End Fir Road	20	0.35 ± 0.05	0.25 ± 0.03	0.12 ± 0.03	0.14 ± 0.025	0.25 ± 0.03	0.23 ± 0.04
Ringold	21	0.83 ± 0.06	1.6 ± 0.08	0.44 ± 0.044	1.1 ± 0.046	0.40 ± 0.04	1.0 ± 0.1
Berg Ranch	22	0.83 ± 0.05	0.61 ± 0.05	0.49 ± 0.046	0.58 ± 0.052	0.60 ± 0.05	0.31 ± 0.04
Wahluke Slope No. 2[d]	23	0.34 ± 0.07	0.25 ± 0.03	0.29 ± 0.03	0.47 ± 0.047	0.30 ± 0.03	0.16 ± 0.03
Vernita Bridge[d]	24	0.55 ± 0.05	0.27 ± 0.03	0.46 ± 0.037	0.20 ± 0.03	---	---
Yakima Barricade[d]	25	0.42 ± 0.04	0.70 ± 0.033	0.10 ± 0.028	1.1 ± 0.066	---	0.08 ± 0.02
Rattlesnake Springs[d]	26	0.70 ± 0.05	0.52 ± 0.05	0.14 ± 0.03	0.46 ± 0.037	0.37 ± 0.04	0.32 ± 0.04
ALE[d]	27	1.1 ± 0.10	1.5 ± 0.07	0.55 ± 0.04	1.6 ± 0.069	---	1.1 ± 0.1
Prosser Barricade[d]	28	1.2 ± 0.06	0.77 ± 0.05	0.15 ± 0.03	0.73 ± 0.045	0.32 ± 0.03	---
S of 300 Area[d]	29	1.1 ± 0.06	1.1 ± 0.06	1.1 ± 0.06	0.88 ± 0.072	0.68 ± 0.04	---
Benton City	30	0.75 ± 0.05	0.54 ± 0.05	0.53 ± 0.04	0.87 ± 0.064	0.79 ± 0.05	0.65 ± 0.04
Sunnyside	31	0.41 ± 0.06	1.1 ± 0.06	1.5 ± 0.071	0.29 ± 0.036	0.09 ± 0.03	0.29 ± 0.04
Walla Walla	32				0.29 ± 0.024	0.25 ± 0.03	0.07 ± 0.02
McNary Dam	33				0.52 ± 0.040	0.28 ± 0.03	0.30 ± 0.47
Moses Lake	34					0.24 ± 0.03	0.16 ± 0.09
Washtucna	35					1.2 ± 0.1	0.38 ± 0.17
Connell	36					1.7 ± 0.1	0.35 ± 0.61
Othello	37					0.26 ± 0.2	0.76 ± 0.42
Yakima	38					0.11 ± 0.1	0.16 ± 0.06
OFFSITE AVERAGE		0.63 ± 0.15	0.85 ± 0.28	0.44 ± 0.21	0.56 ± 0.19	0.80 ± 0.68	0.38 ± 0.12

(a) Individual results ±2 sigma counting error. Averages ±2 standard error of the calculated mean.
(b) Locations are identified in Figure 3.50.
(c) Locations sampled every other year indicated by dashed line.
(d) Perimeter location on Site near Site boundary.

9 2 1 2 5 5 6 0 4 0 0

TABLE A.43. Plutonium-239,240 ($^{239,240}Pu$) Concentrations in Soil

Location	Map Location[b]	pCi/g (dry weight)[a] 1982	1983	1984	1985	1986	1987
ON SITE							
1 Mile NE of 100-N Area	1	0.015 ± 0.003	0.012 ± 0.0030	0.015 ± 0.0020	0.016 ± 0.0016	0.015 ± 0.001	—[c]
1 Mile E of 100-N Area	2	0.026 ± 0.003	0.0069 ± 0.0014	0.016 ± 0.0027	0.013 ± 0.0011	0.012 ± 0.001	0.023 ± 0.002
100 Area Fire Station	3	0.016 ± 0.003	0.0022 ± 0.0015	0.021 ± 0.0017	0.024 ± 0.0016	0.030 ± 0.002	0.017 ± 0.001
200-East NC	4	0.059 ± 0.009	0.051 ± 0.0065	0.033 ± 0.0040	0.030 ± 0.0019	0.015 ± 0.002	0.031 ± 0.002
E of 200-East	5	0.015 ± 0.002	0.011 ± 0.002	0.012 ± 0.0015	0.026 ± 0.0017	0.011 ± 0.001	0.009 ± 0.001
200-East SE	6	0.024 ± 0.004	0.028 ± 0.0050	0.0091 ± 0.0017	0.022 ± 0.0016	0.008 ± 0.001	0.012 ± 0.001
SW of BC Cribs	7	0.012 ± 0.001	0.0076 ± 0.0012	0.0034 ± 0.0019	0.024 ± 0.0022	0.004 ± 0.001	0.001 ± 0.001
S of 200-East	8	0.012 ± 0.001	0.0088 ± 0.0017	0.0056 ± 0.0031	0.0041 ± 0.0014	0.007 ± 0.001	0.003 ± 0.001
E of 200-West	9	0.78 ± 0.016	0.83 ± 0.027	0.074 ± 0.0040	0.33 ± 0.0069	0.34 ± 0.001	0.17 ± 0.01
2 Miles S of 200-West	10	0.004 ± 0.002	0.0006 ± 0.00095	0.0036 ± 0.0019	0.0094 ± 0.0011	0.013 ± 0.001	—
NE of FFTF	11	0.002 ± 0.001	0.0029 ± 0.0007	0.0021 ± 0.0007	0.0025 ± 0.0005	—	0.006 ± 0.001
SE of FFTF	12	0.005 ± 0.002	0.0042 ± 0.0018	0.0087 ± 0.0011	0.0021 ± 0.0005	0.001 ± 0.001	—
N of 300 Area	13	0.016 ± 0.003	0.013 ± 0.002	0.0064 ± 0.0029	0.010 ± 0.0011	0.008 ± 0.001	0.014 ± 0.001
Hanford Townsite	14	0.015 ± 0.003	0.021 ± 0.004	0.016 ± 0.0030	0.0059 ± 0.0009	—	0.019 ± 0.002
Wye Barricade	15	0.018 ± 0.003	0.017 ± 0.0022	0.014 ± 0.0020	0.017 ± 0.0015	—	0.011 ± 0.001
ONSITE AVERAGE		0.062 ± 0.10	0.068 ± 0.11	0.016 ± 0.0090	0.035 ± 0.042	0.038 ± 0.005	0.026 ± 0.027
OFF SITE							
Riverview	16	0.006 ± 0.002	0.021 ± 0.005	0.0018 ± 0.0018	0.0052 ± 0.0098	0.003 ± 0.001	0.015 ± 0.001
Byers Landing	17	0.002 ± 0.0009	0.012 ± 0.002	0.0066 ± 0.0040	0.0027 ± 0.0006	0.008 ± 0.001	0.003 ± 0.001
Sagemoor	18	0.003 ± 0.0009	0.0079 ± 0.0015	0.019 ± 0.0021	0.0018 ± 0.0005	0.006 ± 0.001	0.002 ± 0.001
Taylor Flats No. 2	19	0.016 ± 0.003	0.031 ± 0.005	0.0014 ± 0.0005	0.0008 ± 0.0003	0.021 ± 0.003	0.019 ± 0.002
W End Fir Road	20	0.005 ± 0.001	0.0059 ± 0.0017	0.0022 ± 0.0015	0.0017 ± 0.0005	0.004 ± 0.001	0.003 ± 0.001
Ringold	21	0.013 ± 0.002	0.028 ± 0.005	0.0075 ± 0.0012	0.017 ± 0.0016	0.006 ± 0.001	0.017 ± 0.002
Berg Ranch	22	0.012 ± 0.002	0.014 ± 0.003	0.0097 ± 0.0015	0.011 ± 0.0011	0.012 ± 0.002	0.006 ± 0.001
Wahluke Slope No. 2[d]	23	0.006 ± 0.002	0.010 ± 0.002	0.0061 ± 0.0029	0.0087 ± 0.0015	0.006 ± 0.001	0.003 ± 0.001
Vernita Bridge[d]	24	0.009 ± 0.002	0.015 ± 0.0026	0.0060 ± 0.0024	0.0095 ± 0.0010	0.003 ± 0.001	—
Yakima Barricade[d]	25	0.011 ± 0.001	0.014 ± 0.002	0.0016 ± 0.0011	0.022 ± 0.0015	—	0.002 ± 0.001
Rattlesnake Springs[d]	26	0.019 ± 0.002	0.026 ± 0.0049	0.0032 ± 0.0016	0.0085 ± 0.0009	0.006 ± 0.001	0.006 ± 0.001
ALE[d]	27	0.03 ± 0.002	0.031 ± 0.005	0.0091 ± 0.0014	0.034 ± 0.0021	—	0.024 ± 0.002
Prosser Barricade[d]	28	0.033 ± 0.004	0.020 ± 0.004	0.0039 ± 0.0016	0.019 ± 0.0019	0.008 ± 0.001	—
S of 300 Area[d]	29	0.019 ± 0.003	0.022 ± 0.0013	0.022 ± 0.0023	0.018 ± 0.0015	0.015 ± 0.001	—
Benton City	30	0.024 ± 0.003	0.015 ± 0.0017	0.0099 ± 0.0015	0.019 ± 0.0020	0.016 ± 0.001	0.014 ± 0.001
Sunnyside	31	0.009 ± 0.002	0.026 ± 0.005	0.025 ± 0.0026	0.015 ± 0.0016	0.002 ± 0.001	0.006 ± 0.001
Walla Walla	32				0.013 ± 0.0012	0.005 ± 0.001	0.002 ± 0.002
McNary Dam	33				0.015 ± 0.0023	0.007 ± 0.001	0.006 ± 0.008
Moses Lake	34					0.016 ± 0.001	0.002 ± 0.001
Washtucna	35					0.024 ± 0.002	0.006 ± 0.003
Connell	36					0.027 ± 0.002	0.007 ± 0.011
Othello	37					0.004 ± 0.001	0.013 ± 0.011
Yakima	38					0.002 ± 0.001	0.003 ± 0.003
OFFSITE AVERAGE		0.013 ± 0.005	0.019 ± 0.004	0.0084 ± 0.0037	0.012 ± 0.0046	0.009 ± 0.003	0.007 ± 0.002

(a) Individual results ±2 sigma counting error. Averages ±2 standard error of the calculated mean.
(b) Locations are identified in Figure 3.50.
(c) Locations sampled every other year indicated by dashed line.
(d) Perimeter location on Site near Site boundary.

9 2 1 2 5 5 6 0 4 0 1

TABLE A.44. Uranium Concentrations in Soil

Location	Map Location[b]	pCi/g (dry weight)[a] 1982	1983	1984	1985	1986	1987
ON SITE							
1 Mile NE of 100-N	1	0.23 ± 0.08	0.39 ± 0.109	0.42 ± 0.11	0.49 ± 0.16	0.19 ± 0.06	—[c]
1 Mile E of 100-N	2	0.22 ± 0.08	0.28 ± 0.077	0.32 ± 0.088	0.40 ± 0.13	0.45 ± 0.13	0.34 ± 0.10
100 Area Fire Station	3	0.32 ± 0.11	0.22 ± 0.061	0.45 ± 0.12	0.44 ± 0.15	0.53 ± 0.15	0.35 ± 0.10
200-East NC	4	0.45 ± 0.16	0.25 ± 0.071	0.36 ± 0.098	0.39 ± 0.13	0.28 ± 0.08	0.23 ± 0.06
E of 200-East	5	0.32 ± 0.11	0.26 ± 0.07	0.32 ± 0.08	0.46 ± 0.15	0.47 ± 0.13	0.31 ± 0.09
200-East SE	6	0.37 ± 0.13	0.20 ± 0.057	0.37 ± 0.070	0.39 ± 0.13	0.03 ± 0.08	0.25 ± 0.07
SW of BC Cribs	7	0.27 ± 0.09	0.28 ± 0.078	1.0 ± 0.15	0.33 ± 0.11	0.32 ± 0.09	0.19 ± 0.05
S of 200-East	8	0.30 ± 0.11	0.18 ± 0.05	0.46 ± 0.22	0.34 ± 0.11	0.32 ± 0.09	0.22 ± 0.06
E of 200-West	9	0.73 ± 0.26	0.53 ± 0.15	0.53 ± 0.29	0.43 ± 0.14	0.48 ± 0.13	0.39 ± 0.11
2 Miles S of 200-West	10	0.39 ± 0.14	0.26 ± 0.074	0.34 ± 0.092	0.47 ± 0.16	0.49 ± 0.14	—
NE of FFTF	11	0.30 ± 0.10	0.25 ± 0.068	0.30 ± 0.082	0.39 ± 0.13	—	0.24 ± 0.07
SE of FFTF	12	0.28 ± 0.10	0.16 ± 0.046	0.27 ± 0.073	0.40 ± 0.13	0.37 ± 0.11	—
N of 300 Area	13	0.99 ± 0.35	0.50 ± 0.14	0.76 ± 0.20	3.9 ± 1.1	0.66 ± 0.19	3.8 ± 1.1
Hanford Townsite	14	0.32 ± 0.11	0.24 ± 0.067	0.34 ± 0.093	0.35 ± 0.12	—	0.42 ± 0.12
Wye Barricade	15	0.38 ± 0.13	0.19 ± 0.053	0.65 ± 0.10	0.29 ± 0.097	—	0.19 ± 0.05
ONSITE AVERAGE		0.39 ± 0.11	0.28 ± 0.061	0.46 ± 0.11	0.82 ± 0.66	0.40 ± 0.08	0.58 ± 0.59
OFF SITE							
Riverview	16	0.14 ± 0.05	0.37 ± 0.10	0.32 ± 0.085	0.44 ± 0.14	0.26 ± 0.07	0.30 ± 0.08
Byers Landing	17	0.55 ± 0.19	0.32 ± 0.09	0.43 ± 0.11	0.39 ± 0.13	0.26 ± 0.07	0.10 ± 0.03
Segemoor	18	0.31 ± 0.11	0.38 ± 0.11	0.50 ± 0.13	0.58 ± 0.18	0.31 ± 0.08	0.24 ± 0.07
Taylor Flats No. 2	19	0.59 ± 0.21	0.47 ± 0.13	1.0 ± 0.26	1.3 ± 0.36	0.44 ± 0.12	0.97 ± 0.27
W End Fir Road	20	0.28 ± 0.10	0.47 ± 0.13	0.54 ± 0.14	0.73 ± 0.22	0.32 ± 0.09	0.55 ± 0.15
Ringold	21	0.43 ± 0.15	0.37 ± 0.10	0.78 ± 0.21	0.84 ± 0.26	1.1 ± 0.3	0.67 ± 0.19
Berg Ranch	22	0.26 ± 0.09	0.24 ± 0.07	0.41 ± 0.11	0.43 ± 0.14	0.28 ± 0.08	0.38 ± 0.11
Wahluke Slope No. 2[d]	23	0.36 ± 0.13	0.35 ± 0.10	0.43 ± 0.12	0.35 ± 0.12	0.21 ± 0.06	0.17 ± 0.05
Vernita Bridge[d]	24	0.38 ± 0.13	0.37 ± 0.10	0.92 ± 0.26	0.73 ± 0.22	0.34 ± 0.09	—
Yakima Barricade[d]	25	0.23 ± 0.08	0.26 ± 0.071	0.21 ± 0.056	0.35 ± 0.12	—	0.27 ± 0.08
Rattlesnake Springs[d]	26	0.30 ± 0.11	0.25 ± 0.07	0.26 ± 0.069	0.44 ± 0.14	0.26 ± 0.07	0.28 ± 0.08
ALE[d]	27	0.35 ± 0.12	0.28 ± 0.08	0.25 ± 0.067	0.46 ± 0.15	—	0.45 ± 0.13
Prosser Barricade[d]	28	0.20 ± 0.07	0.25 ± 0.07	0.36 ± 0.06	0.80 ± 0.24	0.25 ± 0.07	—
S of 300 Area[d]	29	0.506 ± 0.177	0.31 ± 0.08	1.0 ± 0.29	0.66 ± 0.21	0.56 ± 0.16	—
Benton City	30	0.56 ± 0.19	0.44 ± 0.12	0.91 ± 0.24	0.64 ± 0.20	0.45 ± 0.12	0.39 ± 0.11
Sunnyside	31	0.17 ± 0.06	0.20 ± 0.05	0.26 ± 0.071	0.26 ± 0.090	0.31 ± 0.09	0.29 ± 0.08
Walla Walla	32				0.20 ± 0.071	0.35 ± 0.10	0.62 ± 0.17
McNary Dam	33				0.15 ± 0.055	0.41 ± 0.12	0.32 ± 0.09
Moses Lake	34					0.11 ± 0.03	0.19 ± 0.05
Washtucna	35					0.20 ± 0.06	0.24 ± 0.07
Connell	36					0.25 ± 0.07	0.32 ± 0.09
Othello	37					0.21 ± 0.06	0.24 ± 0.06
Yakima	38					0.48 ± 0.14	0.41 ± 0.11
OFFSITE AVERAGE		0.35 ± 0.078	0.32 ± 0.048	0.54 ± 0.15	0.54 ± 0.14	0.35 ± 0.09	0.36 ± 0.07

(a) Individual results ±2 sigma counting error. Averages ±2 standard error of the calculated mean.
(b) Locations are identified in Figure 3.50.
(c) Locations sampled every other year indicated by dashed line.
(d) Perimeter location on Site near Site boundary.

9 2 1 2 5 5 6 0 4 0 2

TABLE A.45. Plutonium Ratios for Samples of Surface Soil Collected Off Site in 1986 and 1987

Location	Map Location[b]	^{240}Pu to ^{239}Pu Ratios[a] 1986	1987
Pasco Airport	1	0.179	0.183 0.179
Taylor Flats Rd.	2	0.170	0.164 0.175
Merrills Corner	3	0.177	0.179 0.181
Eltopia	4	0.177	0.182 0.177
Mesa	5	0.172	0.180 0.182
Basin City	6	0.177	0.179 0.174
Hollingsworth Rd.	7	0.170	0.171 0.171
Ringold Canal	8	0.173	0.174 0.156
Walla Walla	32	0.168	0.148 0.170
McNary	33	0.182	0.186 0.191 0.191
Moses Lake	34	0.153	0.169 0.179
Washtucna	35	0.175	0.189 0.190
Connell	36	0.181	0.188 0.184
Othello	37	0.178	0.176 0.179
Yakima	38	0.144	0.175 0.180
Average (1986 and 1987)[c]		0.176 ±	0.003

(a) Uncertainties (±2 standard deviations) are less than 2% of ratio values.
(b) Location numbers 1 through 8 are identified in Figure 3.51. Location numbers 32 through 38 are shown in Figure 3.50.
(c) Average ±2 standard error of calculated mean.

9 2 1 2 5 5 6 0 4 0 3

TABLE A.46. Strontium-90 (^{90}Sr) Concentrations in Vegetation

Location	Map Location[b]	pCi/g (dry weight)[a] 1982	1983	1984	1985	1986	1987
ON SITE							
1 Mile NE of 100-N Area	1	0.03 ± 0.002	0.11 ± 0.017	0.069 ± 0.007	0.078 ± 0.072	NS	—[c]
1 Mile E of 100-N Area	2	0.05 ± 0.005	0.29 ± 0.018	0.12 ± 0.012	0.012 ± 0.0012	0.14 ± 0.01	0.038 ± 0.008
100-Area Fire Station	3	0.05 ± 0.007	0.37 ± 0.020	0.11 ± 0.011	0.17 ± 0.017	0.14 ± 0.01	0.010 ± 0.005
200-East NC	4	0.10 ± 0.020	0.63 ± 0.024	0.39 ± 0.020	0.41 ± 0.018	0.38 ± 0.01	0.13 ± 0.01
E of 200-East	5	0.14 ± 0.009	0.91 ± 0.030	0.20 ± 0.030	0.25 ± 0.019	0.18 ± 0.01	0.24 ± 0.02
200-East SE	6	0.03 ± 0.003	0.91 ± 0.031	0.20 ± 0.013	0.53 ± 0.018	8.2 ± 0.1	0.086 ± 0.010
SW of BC Cribs	7	0.05 ± 0.003	0.34 ± 0.016	0.11 ± 0.030	0.41 ± 0.016	NS	0.071 ± 0.009
S of 200-East	8	0.17 ± 0.005	0.53 ± 0.017	1.1 ± 0.066	0.44 ± 0.022	0.14 ± 0.01	0.089 ± 0.010
E of 200-West	9	0.07 ± 0.005	0.47 ± 0.022	0.13 ± 0.020	1.1 ± 0.026	0.13 ± 0.01	0.10 ± 0.01
2 Miles S of 200-West	10	0.05 ± 0.003	0.34 ± 0.016	0.19 ± 0.007	0.89 ± 0.035	0.14 ± 0.01	—
NE of FFTF	11	0.009 ± 0.002	1.2 ± 0.037	0.022 ± 0.006	0.28 ± 0.015	—	0.025 ± 0.005
SE of FFTF	12	0.02 ± 0.002	1.7 ± 0.040	0.088 ± 0.009	0.28 ± 0.019	NS	—
N of 300 Area	13	0.008 ± 0.001	0.93 ± 0.029	0.023 ± 0.004	0.13 ± 0.016	0.26 ± 0.01	0.021 ± 0.004
Hanford Townsite	14	0.06 ± 0.003	0.29 ± 0.015	0.044 ± 0.006	0.18 ± 0.013	—	0.067 ± 0.009
Wye Barricade	15	0.04 ± 0.008	0.16 ± 0.012	0.016 ± 0.007	0.15 ± 0.012	—	0.012 ± 0.004
ONSITE AVERAGE		0.058 ± 0.024	0.61 ± 0.22	0.19 ± 0.14	0.36 ± 0.16	1.1 ± 1.8	0.075 ± 0.004
OFF SITE							
Riverview	16	0.01 ± 0.002	1.1 ± 0.033	0.015 ± 0.010	0.069 ± 0.085	0.039 ± 0.004	0.018 ± 0.005
Byers Landing	17	0.008 ± 0.002	0.12 ± 0.006	0.018 ± 0.008	0.057 ± 0.089	0.074 ± 0.006	0.007 ± 0.005
Sagemoor	18	0.01 ± 0.004	-0.006 ± 0.017	0.067 ± 0.012	0.097 ± 0.011	NS	0.046 ± 0.008
Taylor Flats No. 2	19	0.06 ± 0.003	0.037 ± 0.024	0.063 ± 0.010	0.10 ± 0.010	0.054 ± 0.006	0.064 ± 0.010
W End Fir Road	20	0.009 ± 0.014	0.086 ± 0.020	0.047 ± 0.016	0.076 ± 0.088	0.062 ± 0.005	0.040 ± 0.007
Ringold	21	0.018 ± 0.019	0.85 ± 0.026	0.051 ± 0.010	0.066 ± 0.0081	0.059 ± 0.005	0.012 ± 0.005
Berg Ranch	22	0.04 ± 0.002	0.023 ± 0.027	0.092 ± 0.026	0.050 ± 0.079	NS	0.036 ± 0.009
Wahluke Slope No. 2[d]	23	0.01 ± 0.004	0.018 ± 0.016	0.048 ± 0.013	0.15 ± 0.012	NS	0.038 ± 0.008
Vernita Bridge[d]	24	0.03 ± 0.003	0.10 ± 0.011	0.073 ± 0.011	0.21 ± 0.011	NS	—
Yakima Barricade[d]	25	0.05 ± 0.01	0.04 ± 0.008	0.022 ± 0.003	0.21 ± 0.011	—	0.034 ± 0.007
Rattlesnake Springs[d]	26	0.024 ± 0.004	0.69 ± 0.026	0.087 ± 0.011	1.7 ± 0.033	0.14 ± 0.01	0.073 ± 0.009
ALE[d]	27	0.05 ± 0.005	0.017 ± 0.023	0.082 ± 0.007	0.095 ± 0.090	—	0.036 ± 0.006
Prosser Barricade[d]	28	0.05 ± 0.02	0.021 ± 0.022	0.12 ± 0.009	NS	0.084 ± 0.07	—
S of 300 Area[d]	29	0.03 ± 0.004	0.05 ± 0.011	0.047 ± 0.005	0.091 ± 0.014	0.10 ± 0.01	—
Benton City	30	0.05 ± 0.008	0.12 ± 0.013	0.055 ± 0.018	0.30 ± 0.013	0.14 ± 0.01	0.045 ± 0.009
Sunnyside	31	0.005 ± 0.003	0.18 ± 0.018	0.037 ± 0.008	0.061 ± 0.075	0.044 ± 0.00	0.061 ± 0.008
Walla Walla	32						0.039 ± 0.008
McNary Dam	33						0.007 ± 0.003
Moses Lake	34						0.023 ± 0.008
Washtucna	35						0.091 ± 0.011
Connell	36						0.024 ± 0.005
Othello	37						0.053 ± 0.007
Yakima	38						0.024 ± 0.006
OFFSITE AVERAGE		0.031 ± 0.0095	0.20 ± 0.16	0.057 ± 0.015	0.22 ± 0.21	0.080 ± 0.023	0.036 ± 0.010

(a) Individual results ±2 sigma counting error. Averages ±2 standard error of the calculated mean.
(b) Locations are identified in Figure 3.50.
(c) Locations sampled every other year indicated by dashed line.
(d) Perimeter location on Site near Site boundary.
NS No sample.

9 2 1 2 5 5 6 0 4 0 4

TABLE A.47. Cesium-137 (^{137}Cs) Concentrations in Vegetation

Location	Map Location[b]	pCi/g (dry weight)[a] 1982	1983	1984	1985	1986	1987
ON SITE							
1 Mile NE of 100-N Area	1	0.04 ± 0.06	0.003 ± 0.012	0.0097 ± 0.014	0.015 ± 0.011	0.027 ± 0.017	--[c]
1 Mile E of 100-N Area	2	0.09 ± 0.07	0.026 ± 0.008	0.0032 ± 0.013	0.003 ± 0.025	0.007 ± 0.022	0.21 ± 0.03
100-Area Fire Station	3	0.04 ± 0.07	0.015 ± 0.008	0.015 ± 0.012	0.016 ± 0.014	0.034 ± 0.0177	0.11 ± 0.02
200-East NC	4	0.23 ± 0.05	0.18 ± 0.014	0.24 ± 0.020	0.36 ± 0.042	0.20 ± 0.03	0.32 ± 0.03
E of 200-East	5	0.37 ± 0.13	0.069 ± 0.010	0.069 ± 0.013	0.12 ± 0.030	0.11 ± 0.03	0.11 ± 0.02
200-East SE	6	0.08 ± 0.05	0.053 ± 0.009	0.079 ± 0.017	0.078 ± 0.020	0.10 ± 0.02	0.11 ± 0.02
SW of BC Cribs	7	0.05 ± 0.02	0.0085 ± 0.0055	0.018 ± 0.013	0.038 ± 0.016	0.011 ± 0.017	0.052 ± 0.018
S of 200-East	8	0.05 ± 0.04	0.019 ± 0.007	0.022 ± 0.011	0.068 ± 0.015	0.029 ± 0.017	0.035 ± 0.020
E of 200-West	9	-0.03 ± 0.04	0.03 ± 0.009	0.055 ± 0.016	0.052 ± 0.017	0.032 ± 0.020	0.054 ± 0.019
2 Miles S of 200-West	10	0.0004 ± 0.06	0.025 ± 0.009	0.011 ± 0.012	0.019 ± 0.023	0.029 ± 0.020	--
NE of FFTF	11	-0.03 ± 0.04	0.02 ± 0.008	0.0064 ± 0.11	0.048 ± 0.020	--	0.056 ± 0.023
SE of FFTF	12	0.01 ± 0.02	0.03 ± 0.009	-0.0095 ± 0.015	0.032 ± 0.018	0.017 ± 0.012	--
N of 300 Area	13	0.02 ± 0.05	0.010 ± 0.006	0.011 ± 0.009	0.024 ± 0.016	0.17 ± 0.51	0.053 ± 0.016
Hanford Townsite	14	0.07 ± 0.02	0.011 ± 0.011	0.010 ± 0.020	0.038 ± 0.022	--	0.097 ± 0.022
Wye Barricade	15	0.035 ± 0.045	-0.01 ± 0.016	0.0037 ± 0.011	0.035 ± 0.015	--	0.053 ± 0.020
ONSITE AVERAGE		0.072 ± 0.055	0.035 ± 0.023	0.034 ± 0.033	0.062 ± 0.045	0.071 ± 0.051	0.10 ± 0.05
OFF SITE							
Riverview	16	-0.006 ± 0.03	0.021 ± 0.007	-0.0001 ± 0.014	-0.0054 ± 0.011	1.1 ± 0.1	0.049 ± 0.016
Byers Landing	17	-0.08 ± 0.06	0.013 ± 0.011	0.024 ± 0.012	0.017 ± 0.011	1.9 ± 0.1	0.049 ± 0.023
Sagemoor	18	0.05 ± 0.03	0.012 ± 0.012	0.003 ± 0.012	0.013 ± 0.014	1.2 ± 0.1	0.035 ± 0.017
Taylor Flats No. 2	19	0.02 ± 0.04	0.025 ± 0.012	0.016 ± 0.013	0.011 ± 0.022	1.7 ± 0.1	0.030 ± 0.015
W End Fir Road	20	-0.07 ± 0.04	0.021 ± 0.010	0.095 ± 0.021	0.022 ± 0.021	1.2 ± 0.1	0.012 ± 0.013
Ringold	21	-0.0005 ± 0.08	0.020 ± 0.008	-0.0008 ± 0.013	0.0083 ± 0.013	1.5 ± 0.1	0.031 ± 0.014
Berg Ranch	22	-0.05 ± 0.04	0.014 ± 0.009	0.027 ± 0.011	0.0073 ± 0.014	0.009 ± 0.013	0.11 ± 0.03
Wahluke Slope No. 2[d]	23	-0.04 ± 0.07	0.02 ± 0.008	-0.0012 ± 0.012	0.023 ± 0.013	0.026 ± 0.024	0.075 ± 0.025
Vernita Bridge[d]	24	0.09 ± 0.03	0.014 ± 0.010	0.005 ± 0.010	0.0061 ± 0.015	0.009 ± 0.022	--
Yakima Barricade[d]	25	0.02 ± 0.02	0.012 ± 0.010	0.00 ± 0.013	0.0027 ± 0.015	--	0.018 ± 0.013
Rattlesnake Springs[d]	26	0.03 ± 0.02	0.004 ± 0.009	0.0054 ± 0.013	0.016 ± 0.014	0.81 ± 0.05	0.047 ± 0.017
ALE[d]	27	0.03 ± 0.02	0.0093 ± 0.0095	-0.0006 ± 0.012	0.022 ± 0.013	--	0.049 ± 0.020
Prosser Barricade[d]	28	0.006 ± 0.02	0.011 ± 0.008	0.012 ± 0.012	NS	0.004 ± 0.025	--
S of 300 Area[d]	29	0.02 ± 0.01	0.005 ± 0.012	0.0032 ± 0.013	0.013 ± 0.020	0.018 ± 0.023	--
Benton City	30	0.06 ± 0.08	0.022 ± 0.007	0.0041 ± 0.011	0.093 ± 0.021	1.4 ± 0.1	0.002 ± 0.016
Sunnyside	31	0.04 ± 0.02	0.006 ± 0.009	0.018 ± 0.012	0.018 ± 0.015	0.34 ± 0.03	0.004 ± 0.023
Walla Walla	32					0.006 ± 0.020	0.029 ± 0.015
McNary Dam	33					0.014 ± 0.019	0.042 ± 0.020
Moses Lake	34					0.85 ± 0.05	0.079 ± 0.023
Washtucna	35					0.98 ± 0.05	0.023 ± 0.018
Connell	36					0.027 ± 0.017	0.029 ± 0.014
Othello	37					0.002 ± 0.019	0.012 ± 0.017
Yakima	38					0.21 ± 0.03	0.011 ± 0.015
OFFSITE AVERAGE		0.023 ± 0.023	0.014 ± 0.0041	0.0078 ± 0.0055	0.018 ± 0.012	0.64 ± 0.29	0.039 ± 0.012

(a) Individual results ±2 sigma counting error. Averages ±2 standard error of the calculated mean.
(b) Locations are identified in Figure 3.50.
(c) Locations sampled every other year indicated by dashed line.
(d) Perimeter location on Site near Site boundary.
NS No sample.

TABLE A.48. Plutonium-239,240 ($^{239,240}Pu$) Concentrations in Vegetation

Location	Map Location[b]	pCi/g (dry weight)[a] 1982	1983	1984	1985	1986	1987
ON SITE							
1 Mile NE of 100-N	1	-0.0009 ± 0.0006	0.00000 ± 0.00000	0.0005 ± 0.00015	0.00013 ± 0.00015	NS	---[c]
1 Mile E of 100-N	2	0.0012 ± 0.0010	0.00022 ± 0.00045	0.00012 ± 0.00030	0.00036 ± 0.00020	0.00048 ± 0.00026	0.00061 ± 0.00027
100 Area Fire Station	3	0.0002 ± 0.0004	0.032 ± 0.0020	0.00012 ± 0.00025	0.00032 ± 0.00018	0.00041 ± 0.00029	0.00064 ± 0.00032
200-East NC	4	0.00062 ± 0.00067	0.00028 ± 0.00039	0.00042 ± 0.00022	0.00067 ± 0.00026	0.00070 ± 0.00042	0.0021 ± 0.0005
E of 200-East	5	0.0008 ± 0.0007	0.00066 ± 0.00048	0.00074 ± 0.00066	0.0075 ± 0.0011	0.0010 ± 0.0003	0.0010 ± 0.0003
200-East SE	6	0.0001 ± 0.0006	0.00046 ± 0.00061	0.00093 ± 0.00066	0.0018 ± 0.00043	0.0021 ± 0.0005	0.0012 ± 0.0004
SW of BC Cribs	7	0.0004 ± 0.0006	0.00016 ± 0.00018	0.00054 ± 0.00061	0.00096 ± 0.00032	NS	0.00077 ± 0.00033
S of 200-East	8	0.0005 ± 0.0006	0.00020 ± 0.00025	0.00044 ± 0.00037	0.0025 ± 0.00051	0.0017 ± 0.0004	0.00062 ± 0.00032
E of 200-West	9	0.004 ± 0.0008	0.0044 ± 0.0010	0.0065 ± 0.0018	0.0060 ± 0.00083	0.0044 ± 0.0012	0.0082 ± 0.0015
2 Miles S of 200-West	10	0.00074 ± 0.00067	0.0021 ± 0.00084	0.0001 ± 0.00020	0.00059 ± 0.00028	0.00094 ± 0.00036	—
NE of FFTF	11	0.0006 ± 0.0010	0.00022 ± 0.00026	0.00036 ± 0.00039	0.00047 ± 0.00023	—	0.00012 ± 0.00012
SE of FFTF	12	-0.0003 ± 0.0004	0.00070 ± 0.00069	0.00083 ± 0.00063	0.00049 ± 0.00030	NS	—
N of 300 Area	13	0.003 ± 0.0007	0.00046 ± 0.00034	0.0022 ± 0.0011	0.00026 ± 0.00014	0.00053 ± 0.00025	0.00021 ± 0.00019
Hanford Townsite	14	0.0004 ± 0.0003	0.0007 ± 0.0010	0.00055 ± 0.00035	0.00042 ± 0.00022	—	0.00016 ± 0.00013
Wye Barricade	15	0.0006 ± 0.0008	0.00026 ± 0.00024	0.00078 ± 0.00088	0.0012 ± 0.00038	—	0.00018 ± 0.00014
ONSITE AVERAGE		0.00087 ± 0.00065	0.0028 ± 0.0042	0.0010 ± 0.00085	0.0016 ± 0.0012	0.0014 ± 0.0009	0.0013 ± 0.0013
OFF SITE							
Riverview	16	0.0005 ± 0.0007	0.00220 ± 0.00086	-0.00013 ± 0.00017	0.00075 ± 0.00039	0.00029 ± 0.00028	0.00010 ± 0.00011
Byers Landing	17	0.00079 ± 0.00063	0.00040 ± 0.00038	0.00010 ± 0.00010	0.00015 ± 0.00013	0.00029 ± 0.00024	0.00037 ± 0.00023
Sagemoor	18	-0.00040 ± 0.0004	0.00020 ± 0.00060	0.00012 ± 0.00014	0.00022 ± 0.00017	NS	0.00005 ± 0.00008
Taylor Flats No. 2	19	0.00004 ± 0.0004	0.00056 ± 0.00038	-0.00010 ± 0.00010	0.00036 ± 0.00028	0.00015 ± 0.00015	0.00028 ± 0.00018
W End Fir Road	20	0.0007 ± 0.0009	0.00021 ± 0.00029	0.00039 ± 0.00048	0.00019 ± 0.00015	0.00007 ± 0.00015	0.00004 ± 0.00018
Ringold	21	0.0001 ± 0.0004	0.00000 ± 0.00000	-0.00007 ± 0.00030	0.00019 ± 0.00017	0.00033 ± 0.00031	0.00001 ± 0.00001
Berg Ranch	22	0.0002 ± 0.0004	0.00050 ± 0.00030	0.00080 ± 0.00059	0.00058 ± 0.00031	NS	0.00023 ± 0.00018
Wahluke Slope No. 2[d]	23	0.003 ± 0.0008	-0.00001 ± 0.00002	0.00017 ± 0.00028	0.00026 ± 0.00021	NS	0.00020 ± 0.00016
Vernita Bridge[d]	24	0.002 ± 0.0009	0.00008 ± 0.00030	0.00035 ± 0.00025	0.00017 ± 0.00028	NS	—
Yakima Barricade[d]	25	0.001 ± 0.0010	0.00038 ± 0.00029	0.00027 ± 0.00044	0.00056 ± 0.00022	—	0.00017 ± 0.00018
Rattlesnake Springs[d]	26	0.0004 ± 0.0003	0.00083 ± 0.00096	0.00022 ± 0.00022	0.00040 ± 0.00021	0.00013 ± 0.00012	0.00037 ± 0.00022
ALE[d]	27	0.0005 ± 0.0006	0.00033 ± 0.00028	0.00074 ± 0.00063	0.00054 ± 0.00025	—	0.00020 ± 0.00014
Prosser Barricade[d]	28	-0.00008 ± 0.0005	0.00034 ± 0.00034	0.00017 ± 0.00031	NS	0.00071 ± 0.00027	—
S of 300 Area[d]	29	0.001 ± 0.0007	0.00014 ± 0.00021	0.00036 ± 0.00067	0.00045 ± 0.00021	0.0026 ± 0.00027	—
Benton City	30	0.001 ± 0.0009	0.00070 ± 0.00050	-0.00015 ± 0.00025	0.0019 ± 0.00048	0.0013 ± 0.00018	0.00005 ± 0.00011
Sunnyside	31	0.001 ± 0.0008	0.00031 ± 0.00029	0.00031 ± 0.00025	0.00017 ± 0.00014	0.0006 ± 0.00011	0.00015 ± 0.00017
Walla Walla	32						0.00008 ± 0.00002
McNary Dam	33						0.00011 ± 0.00014
Moses Lake	34						0.00024 ± 0.00020
Washtucna	35						0.00005 ± 0.00008
Connell	36						0.00007 ± 0.00009
Othello	37						0.00015 ± 0.00016
Yakima	38						0.00010 ± 0.00013
OFFSITE AVERAGE		0.00077 ± 0.00045	0.00045 ± 0.00028	0.00022 ± 0.00017	0.00046 ± 0.00023	0.00047 ± 0.00049	0.00015 ± 0.00008

(a) Individual results ±2 sigma counting error. Averages ±2 standard error of the calculated mean.
(b) Locations are identified in Figure 3.50.
(c) Locations sampled every other year indicated by dashed line.
(d) Perimeter location on Site near Site boundary.
NS No sample.

TABLE A.49. Uranium Concentrations in Vegetation

Location	Map Location[b]	pCi/g (dry weight)[a] 1982	1983	1984	1985	1986	1987
ON SITE							
1 Mile NE of 100-N Area	1	0.01 ± 0.005	0.006 ± 0.003	0.007 ± 0.0034	0.0076 ± 0.0056	NS	—[c]
1 Mile E of 100-N Area	2	0.02 ± 0.007	0.007 ± 0.003	0.0061 ± 0.0030	0.013 ± 0.0074	0.0060 ± 0.0017	0.014 ± 0.004
100-Area Fire Station	3	0.008 ± 0.003	0.007 ± 0.003	0.0067 ± 0.0033	0.016 ± 0.0078	0.0054 ± 0.0016	0.008 ± 0.002
200-East NC	4	0.006 ± 0.002	0.007 ± 0.004	0.0092 ± 0.0037	0.015 ± 0.0076	0.011 ± 0.003	0.014 ± 0.004
E of 200-East	5	0.01 ± 0.005	0.008 ± 0.003	0.0066 ± 0.0042	0.011 ± 0.0064	0.0046 ± 0.0013	0.029 ± 0.08
200-East SE	6	0.006 ± 0.002	0.007 ± 0.003	0.0052 ± 0.0040	0.016 ± 0.0080	0.013 ± 0.004	0.016 ± 0.04
SW of BC Cribs	7	0.01 ± 0.003	0.005 ± 0.003	0.017 ± 0.0077	0.014 ± 0.0077	NS	0.007 ± 0.002
S of 200-East	8	0.01 ± 0.004	0.009 ± 0.004	0.011 ± 0.0054	0.035 ± 0.014	0.0072 ± 0.0021	0.025 ± 0.007
E of 200-West	9	0.01 ± 0.004	0.011 ± 0.004	0.016 ± 0.0065	0.022 ± 0.0096	0.016 ± 0.005	—
2 Miles S of 200-West	10	0.01 ± 0.003	0.007 ± 0.003	0.015 ± 0.0058	0.0096 ± 0.0063	0.0060 ± 0.0017	0.025 ± 0.007
NE of FFTF	11	0.002 ± 0.0008	0.005 ± 0.003	0.014 ± 0.005	0.0081 ± 0.0054	—	0.015 ± 0.004
SE of FFTF	12	0.007 ± 0.002	0.01 ± 0.004	0.0050 ± 0.0027	0.022 ± 0.0098	NS	—
N of 300 Area	13	0.01 ± 0.005	0.018 ± 0.006	0.012 ± 0.0046	0.082 ± 0.027	0.018 ± 0.005	0.016 ± 0.004
Hanford Townsite	14	0.01 ± 0.004	0.011 ± 0.048	0.0032 ± 0.0022	0.015 ± 0.0080	—	0.010 ± 0.003
Wye Barricade	15	0.005 ± 0.002	0.0077 ± 0.0035	0.0045 ± 0.0036	0.021 ± 0.0095	—	0.007 ± 0.002
ONSITE AVERAGE		0.0099 ± 0.0025	0.0083 ± 0.0018	0.0093 ± 0.0026	0.021 ± 0.0099	0.0097 ± 0.0030	0.0016 ± 0.004
OFF SITE							
Riverview	16	0.02 ± 0.006	0.014 ± 0.005	0.021 ± 0.0076	0.0099 ± 0.0060	0.015 ± 0.004	0.018 ± 0.005
Byers Landing	17	0.04 ± 0.010	0.015 ± 0.006	0.022 ± 0.0078	0.19 ± 0.058	0.021 ± 0.006	0.020 ± 0.006
Sagemoor	18	0.02 ± 0.006	0.013 ± 0.005	0.012 ± 0.0050	0.019 ± 0.0086	NS	0.012 ± 0.003
Taylor Flats No. 2	19	0.03 ± 0.009	0.016 ± 0.006	0.011 ± 0.0044	0.022 ± 0.0096	0.016 ± 0.005	0.031 ± 0.009
W End Fir Road	20	0.03 ± 0.010	0.02 ± 0.007	0.036 ± 0.012	0.038 ± 0.014	0.0092 ± 0.0027	0.023 ± 0.006
Ringold	21	0.03 ± 0.010	0.027 ± 0.009	0.025 ± 0.0085	0.041 ± 0.015	0.011 ± 0.003	0.049 ± 0.014
Berg Ranch	22	0.02 ± 0.060	0.012 ± 0.005	0.017 ± 0.0066	0.0097 ± 0.0063	NS	0.014 ± 0.004
Wahluke Slope No. 2[d]	23	0.01 ± 0.005	0.011 ± 0.005	0.0088 ± 0.0039	0.015 ± 0.0079	NS	0.018 ± 0.005
Vernita Bridge[d]	24	0.01 ± 0.005	0.013 ± 0.005	0.011 ± 0.0045	0.020 ± 0.0090	NS	—
Yakima Barricade[d]	25	0.01 ± 0.003	0.0078 ± 0.0035	0.0037 ± 0.0020	0.020 ± 0.0090	—	0.009 ± 0.001
Rattlesnake Springs[d]	26	0.004 ± 0.001	0.012 ± 0.005	0.0042 ± 0.0022	0.013 ± 0.0068	0.0097 ± 0.0028	0.012 ± 0.003
ALE[d]	27	0.008 ± 0.003	0.0055 ± 0.0029	0.0057 ± 0.0025	0.0075 ± 0.0054	—	0.016 ± 0.004
Prosser Barricade[d]	28	0.01 ± 0.003	0.011 ± 0.005	0.0042 ± 0.0023	NS	0.0097 ± 0.0028	—
S of 300 Area[d]	29	0.006 ± 0.002	0.0118 ± 0.0056	0.014 ± 0.0053	0.036 ± 0.014	0.014 ± 0.004	—
Benton City	30	0.01 ± 0.004	0.015 ± 0.006	0.014 ± 0.0056	0.013 ± 0.0074	0.021 ± 0.006	0.018 ± 0.005
Sunnyside	31	0.01 ± 0.005	0.009 ± 0.004	0.0013 ± 0.0014	0.0086 ± 0.0057	0.0060 ± 0.0017	0.014 ± 0.004
Walla Walla	32						0.016 ± 0.004
McNary Dam	33						0.014 ± 0.004
Moses Lake	34						0.016 ± 0.004
Washtucna	35						0.015 ± 0.004
Connell	36						0.014 ± 0.004
Othello	37						0.013 ± 0.004
Yakima	38						0.011 ± 0.003
OFFSITE AVERAGE		0.017 ± 0.0052	0.013 ± 0.0028	0.013 ± 0.0049	0.041 ± 0.041	0.013 ± 0.003	0.018 ± 0.004

(a) Individual results ±2 sigma counting error. Averages ±2 standard error of the calculated mean.
(b) Locations are identified in Figure 3.50.
(c) Locations sampled every other year indicated by dashed line.
(d) Perimeter location on Site near Site boundary.
NS No sample.

TABLE A.50. Environmental Dosimeter Measurements - Perimeter and Community Locations

Location	Map Location[b]	No. of Samples	Dose Rate, mrem/yr[a] Maximum	Minimum	Average[c]
PERIMETER STATIONS					
Prosser Barricade	1	13	88	74	81 ± 3
ALE	2	13	91	70	82 ± 3
Rattlesnake Springs	3	13	95	72	87 ± 4
Yakima Barricade	4	13	95	76	89 ± 3
Vernita Bridge	5	13	95	73	83 ± 3
Wahluke Slope No. 2	6	13	93	75	84 ± 3
Berg Ranch	7	13	95	53	85 ± 6
Sagehill	8	13	87	44	77 ± 7
Ringold	9	13	97	52	83 ± 7
Fir Road	10	13	88	74	82 ± 3
Pettett	11	13	91	71	78 ± 3
Sagemoor	12	13	88	71	80 ± 3
Byers Landing	13	13	91	77	82 ± 3
RRC No. 64	14	13	82	69	76 ± 2
Horn Rapids Rd., Mi. 12	15	13	88	70	79 ± 3
Horn Rapids, Substation	16	13	84	68	78 ± 3
Perimeter Average					82 ± 5
NEARBY COMMUNITIES					
Benton City	17	12	74	63	69 ± 2
Othello	18	13	80	41	67 ± 6
Connell	19	13	86	45	72 ± 6
Pasco	20	13	81	63	73 ± 3
Richland	21	13	78	63	72 ± 3
Eltopia	22	13	83	42	72 ± 6
Prosser	23	13	77	64	71 ± 2
Mattawa	24	13	74	63	70 ± 2
Kennewick	25	13	87	71	79 ± 3
Nearby Average					72 ± 4
DISTANT COMMUNITIES					
Walla Walla	26	13	85	43	74 ± 6
McNary	27	13	96	49	78 ± 6
Sunnyside	28	14	78	62	72 ± 3
Moses Lake	29	14	78	56	66 ± 4
Washtucna	30	13	85	71	77 ± 3
Yakima	31	13	72	63	68 ± 2
Distant Average					72 ± 5

(a) Monthly integrated readings in mR were converted to annual dose equivalent rates.
(b) Locations are identified in Figure 3.54.
(c) Averages ±2 times the standard error of the calculated mean.

9 2 1 2 5 5 6 0 4 0 8

TABLE A.51. Immersion Dose Rates Measured in the Columbia River in 1987

Location[b]	Number of Measurements	Dose Rate, mrem/h[a] Maximum	Minimum	Average[c]
Coyote Rapids	2	0.006	0.006	0.006 ± 0.0006
Richland Pumphouse	2	0.007	0.005	0.006 ± 0.002

(a) Quarterly integrated readings in mR were converted to hourly dose equivalent rates.
(b) Locations are identified in Figure 3.56.
(c) Averages ±2 times the standard error of calculated mean.

TABLE A.52. Environmental Dosimeter Measurements at Publicly Accessible Onsite Locations in 1987

Location	Map Location[b]	No. of Measurements	Dose Rate, mrem/h[a] Maximum	Minimum	Average[c]
100-N Area Shoreline					
100-N Trench Springs	1	13	0.039	0.024	0.032 ± 0.003
Below 100-N Main Stack	2	13	0.025	0.011	0.018 ± 0.002
Upstream Tip 100-N Berm	3	13	0.028	0.016	0.021 ± 0.002
Downstream 100-N Outfall	4	13	0.033	0.018	0.024 ± 0.003
300 Area Perimeter Fence					
377 South Fence	5	12	0.063[d]	0.008	0.011 ± 0.001
3705 West Fence	6	13	0.039[d]	0.008	0.011 ± 0.001
400 Area (FFTF) Perimeter Fence					
400-East	7	13	0.009	0.008	0.009 ± 0.0003

(a) Monthly integrated readings in mR were converted to hourly dose equivalent rates.
(b) Locations are identified in Figure 3.57.
(c) Averages ±2 times the standard error of the calculated mean.

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TABLE A.53. Environmental Dosimeter Measurements Along the Hanford Reach of the Columbia River in 1987

Location	Map Location[b]	No. of Measurements	Dose Rate, mrem/h[a] Maximum	Minimum	Average[c]
Upriver 100-B Area	1	3	0.010	0.008	0.009 ± 0.001
Below 100-B Retention Basin	2	3	0.018	0.015	0.016 ± 0.002
Above 100-K Boat Ramp	3	3	0.010	0.009	0.009 ± 0.001
Downriver from 100-D Area	4	2	0.012	0.011	0.011 ± 0.002
Downriver Opposite 100-D Area	5	3	0.009	0.008	0.008 ± 0.001
Lower End Locke Island	6	3	0.010	0.009	0.009 ± 0.001
White Bluffs Slough	7	3	0.017	0.013	0.015 ± 0.003
White Bluffs Ferry Landing	8	3	0.010	0.009	0.009 ± 0.001
Below 100-F Area	9	3	0.010	0.008	0.009 ± 0.001
100-F Floodplain	10	3	0.016	0.013	0.014 ± 0.002
Hanford Powerline Crossing	11	3	0.011	0.009	0.010 ± 0.001
Hanford Ferry Landing	12	3	0.009	0.008	0.009 ± 0.001
Hanford Peninsula	13	3	0.015	0.012	0.014 ± 0.003
Hanford Railroad Track	14	3	0.013	0.011	0.012 ± 0.002
Savage Island Slough	15	3	0.013	0.011	0.012 ± 0.002
Ringold Island	16	3	0.010	0.009	0.009 ± 0.001
Powerline Crossing	17	3	0.011	0.010	0.010 ± 0.001
North End Wooded Island	18	3	0.009	0.008	0.009 ± 0.001
South End Wooded Island	19	3	0.011	0.010	0.011 ± 0.001
Island Near 300 Area	20	3	0.013	0.010	0.011 ± 0.002
Below Bateman Island	21	2	0.011	0.010	0.011 ± 0.002

(a) Quarterly integrated readings in mR were converted to hourly dose equivalent rates.
(b) Locations are identified in Figure 3.56.
(c) Averages ±2 times the standard error of the calculated mean.

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TABLE A.54. Onsite External Penetrating Dose Measurements in 1987

Location	Map Location[b]	No. of Measurements	Dose Rate, mrem/h[a] Maximum	Minimum	Average[c]
100 Area					
100-K	1	13	0.009	0.008	0.008 ± 0.0003
100-N	2	13	0.011	0.009	0.010 ± 0.0003
100-D	3	13	0.010	0.009	0.009 ± 0.0003
100 Area Fire Station	4	13	0.010	0.008	0.009 ± 0.0003
200 Area					
N of 200-East	5	14	0.011	0.008	0.010 ± 0.0004
E of 200-East	6	13	0.011	0.008	0.010 ± 0.0003
200-E SE	7	13	0.011	0.008	0.010 ± 0.0004
GTE Building	8	13	0.010	0.007	0.009 ± 0.0003
SW of BC Cribs	9	13	0.011	0.008	0.010 ± 0.0004
S of 200-East	10	13	0.011	0.009	0.010 ± 0.0004
300 Area					
300 Pond	11	13	0.010	0.008	0.009 ± 0.0003
3614 A Building	12	13	0.012	0.008	0.009 ± 0.0006
300 S Gate	13	13	0.010	0.008	0.009 ± 0.0003
300 SW Gate	14	13	0.010	0.008	0.009 ± 0.0003
3705 West Fence	15	12	0.039[d]	0.008	0.011 ± 0.0012
377 Building South Fence	16	13	0.063[d]	0.008	0.011 ± 0.0014
400 Area					
400-East	17	13	0.009	0.008	0.009 ± 0.0003
400-West	18	13	0.010	0.008	0.009 ± 0.0004
400-South	19	13	0.010	0.008	0.009 ± 0.0002
400-North	20	13	0.010	0.008	0.009 ± 0.0003
FFTF North	21	13	0.010	0.008	0.009 ± 0.0003
FFTF Southeast	22	13	0.009	0.008	0.009 ± 0.0003
600 Area					
Rt. 11A, Mi. 9	23	12	0.010	0.008	0.009 ± 0.0004
Hanford Townsite	24	13	0.010	0.007	0.009 ± 0.0002
Wye Barricade	25	13	0.010	0.009	0.009 ± 0.0002
Army Loop Camp	26	13	0.010	0.008	0.009 ± 0.0004

(a) Monthly integrated reading in mR were converted to hourly dose equivalent rates.
(b) Locations are identified in Figure 3.58.
(c) Averages ±2 times the standard error of the mean.
(d) Special 2-day integrated readings were obtained when steam generator was moved.

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TABLE A.55. Estimates of Precision Based in Terms of Coefficient of Variation for U.S. Testing Co. 1987 Replicate Sampling and Analysis

Medium	Analysis[a]	Coefficient of Variation (%)[b]
Air	Gross Alpha	36
	Gross Beta	16
	^{90}Sr	27
Water	Gross Alpha	44
	Gross Beta	31
	^{3}H	22
	^{90}Sr	4
	^{234}U	4
	^{238}U	9
Milk	^{3}H	37
	^{40}K	5
	^{90}Sr	9
Wheat	^{40}K	8
	^{90}Sr	18
Soil on Site	^{40}K	1
	^{90}Sr	19
	^{134}Cs	45
	^{137}Cs	26
	^{224}Ra	4
	^{226}Ra	1
	^{235}U	48
	U(nat)	12
	$^{239,240}Pu$	26
Soil off Site	^{40}K	2
	^{90}Sr	37
	^{134}Cs	5
	^{137}Cs	46
	^{224}Ra	7
	^{226}Ra	10
	^{238}U	44
	U(nat)	27
	$^{239,240}Pu$	31

(a) Only analyses greater than the minimum detectable amount are listed.

(b) Coefficient of variation calculated from the standard deviation (calculated from replicates), divided by the mean, and multiplied by 100. The standard deviation was calculated by $s = \sqrt{\sum \frac{d^2}{2n}}$ where d is the range between duplicate pairs and n is the number of pairs (AOAC 1975).

TABLE A.56. Washington State - DSHS and PNL Shared TLD Stations in 1987

Location		Exposure Rate (mR/day)							
		First[a]		Second		Third		Fourth	
		DSHS[b]	PNL	DSHS	PNL	DSHS	PNL	DSHS	PNL
U.S. Ecology	NE Corner	0.25	0.20	0.24	0.22	0.20	0.22	0.25	0.21
	NW Corner	0.26	0.20	0.25	0.22	0.23	0.21	0.27	0.22
	SW Corner	0.32	0.25	0.34	0.26	0.31	0.28	0.34	0.24
WNP-2 1		0.24	0.21	0.24	0.22	0.21	0.23	0.24	0.22
WNP-2 4		0.20	0.18	0.19	0.20	0.19	0.20	0.20	0.19
WNP-2 8		0.27	0.22	0.26	0.24	0.23	0.25	0.26	0.24
200-East SE		0.26	0.22	0.21	0.24	0.20	0.23	0.25	0.23
E 200-East		0.27	0.21	0.23	0.23	0.21	0.24	0.28	0.24
N 200-East		0.26	0.22	0.21	0.23	0.23	0.23	0.26	0.24
Rt 11A, Mi. 9		0.27	0.21	0.20	0.24	0.20	0.22	0.28	0.23
GTE Building		0.23	0.19	0.19	0.22	0.16	0.22	0.22	0.22
S 200-East		0.28	0.23	0.23	0.26	0.20	0.25	0.27	0.24
SW of BC Crib		0.25	0.22	0.20	0.24	0.19	0.23	0.25	0.24
Army Loop Camp		0.28	0.21	0.21	0.22	0.23	0.23	0.26	0.24
Yakima Barricade		0.30	0.22	0.24	0.25	0.20	0.24	0.28	0.26
Wye Barricade		0.27	0.21	0.20	0.21	0.17	0.22	0.23	0.22
Moses Lake		0.20	0.16	0.15	0.18	0.23	0.19	0.23	0.20
Connell		0.19	0.18	0.23	0.22	0.19	0.21	0.21	0.21
Richland		(c)	0.19	0.21	0.20	0.19	0.20	0.20	0.20
Sunnyside		0.22	0.19	0.19	0.20	0.17	0.20	0.20	0.21

(a) First, Second, Third and Fourth refer to the 1987 calendar quarters.
(b) TLD results for DSHS and PNL at the same location in units of milliroentgens per day.
(c) No data.

9 2 1 2 5 5 6 0 4 1 3

TABLE A.57. Surface-Water Split Samples for 1987

Location	Nuclide	Results, pCi/L[a] Washington	Oregon	U.S. Testing Co.
Old Hanford Ferry Landing	Gross Alpha			
	Dissolved	<2	0.9 ± 0.2	<0.23
	Suspended	<1	<0.5	
	Gross Beta			
	Dissolved	4 ± 1	10.9 ± 1.2	1.56 ± 24
	Suspended	<1	1.2 ± 0.6	
	^{3}H	<350	623 ± 125	82 ± 28
	^{89}Sr			
	Dissolved		<0.3	
	Suspended		<0.03	
	^{90}Sr			
	Dissolved		5.2 ± 1.4	0.13 ± 0.03
	Suspended			
	U-Total			
	Nitrates	<0.2		
	Gamma Scan[b]			
	^{60}Co	0.71 ± 0.60		
No. 3 Seep Well, N-Spring	Gross Alpha			
	Dissolved	8.8 ± 2.5	6.2 ± 2.0	0.53 ± 0.35
	Suspended	16.0 ± 4.0	6.0 ± 4.2	
	Gross Beta			
	Dissolved	13,600 ± 110	11,495 ± 20	9,790 ± 630
	Suspended	2,360 ± 20	11,042 ± 20	
	^{3}H	63,600 ± 1,300	64,980 ± 610	66,400 ± 800
	^{89}Sr			
	Dissolved	<1	<0.3	<560
	Suspended	<1		
	^{90}Sr			
	Dissolved	7,010	8,200 ± 1150	7,370 ± 420
	Suspended	850		
	U-Total	30 ± 0.1		
	Nitrates	10 mg/L		
	Gamma Scan[b]			
	^{60}Co	70 ± 5	65 ± 9	Total 233 ± 28
				Dissolved 48 ± 9
	^{131}I	16 ± 3	<30	Total 20 ± 6
				Dissolved <31

9 2 1 2 5 5 6 0 4 1 4

TABLE A.57. (contd)

Location	Nuclide	Results, pCi/L[a] Washington	Oregon	U.S. Testing Co.
	^{103}Ru	70 ± 5	65 ± 12	Total 812 ± 12 Dissolved 45 ± 11
	^{106}Ru	80 ± 2	<130	Total 154 ± 51 Dissolved 49 ± 43
	^{125}Sb	90 ± 10	60 ± 40	Total 122 ± 25 Dissolved 107 ± 20
Monitoring Well, N-Spring	Gross Alpha			
	Dissolved	5.2 ± 2.1	<3.0	<0.28
	Suspended	<1	<3.0	
	Gross Beta			
	Dissolved	12,100 ± 100	12,381 ± 20	9,120 ± 608
	Suspended	120 ± 1	54.4 ± 1.5	
	^{3}H	64,400 ± 1,340	63,780 ± 1,560	65,100 ± 800
	^{89}Sr			
	Dissolved	<1	<0.3	<980
	Suspended	<1		
	^{90}Sr			
	Dissolved	5,860	7,420 ± 231	6,060 ± 370
	Suspended	50		
	U-Total	20 ± 0.1		
	Nitrates	9.5 mg/L		
	Gamma Scan[b]			
	^{214}Bi	30 ± 5		
	^{60}Co	75 ± 5	67 ± 10	Total 74 ± 12 Dissolved 68 ± 10
	^{131}I	13 ± 3	<30	Total 11 ± 5 Dissolved <26
	^{103}Ru	60 ± 5	52 ± 13	Total 72 ± 11 Dissolved 59 ± 10
	^{106}Ru	65 ± 20	<200	Total 83 ± 42 Dissolved 93 ± 41
	^{125}Sb	100 ± 10	60 ± 50	Total 114 ± 21 Dissolved 103 ± 19

(a) Results ±2 standard deviations for values greater than the system minimum detectable amount.
(b) Only nuclides with quantifiable activities above the system minimum detectable activity are listed.

TABLE A.58. Results of Site-Wide Radiological and Nitrate (NO_3^-) Ground-Water Monitoring Quality Control Program[a] in 1987

Constituent (units)	Well Name	Collection Date	Record Sample		Blind (Duplicate) Sample		Rep CV[b]	Audit Sample[c]		Audit CV
^3H (pCi/L)	1-F8-2	14 JAN 87	3,900	± 347	3,890	± 347	0.2			
		17 MAY 87	2,910	± 338	3,130	± 343	5.2			
		02 JUL 87	2,630	± 230	2,530	± 227	2.7	2,530	± 359	1.4
		19 OCT 87	2,340	± 265	2,430	± 268	2.7			
	1-K-22	13 JAN 87	730	± 291	805	± 293	6.9	793	± 315	2.3
		23 APR 87	2,240	± 322	1,190	± 299	43.3	673	± 309	61.7
		28 JUL 87	552	± 176	682	± 179	14.9	1,080	± 347	38.6
		20 OCT 87	728	± 230	590	± 226	14.8			
	1-N-21	15 JAN 87	5,040	± 310	4,740	± 304	4.3	4,950	± 361	0.9
		28 MAY 87	2,320	± 319	2,110	± 314	6.7	2,230	± 342	0.5
		17 SEP 87	2,380	± 268	2,230	± 265	4.6	2,180	± 322	3.9
		22 NOV 87	1,780	± 211	1,750	± 210	1.2	1,450	± 262	13.9
	1-N-23	15 JAN 87	2,230	± 260	1,920	± 253	10.6	2,080	± 330	0.2
		28 MAY 87	6,090	± 392	5,840	± 388	3.0	6,000	± 383	0.4
		17 SEP 87	1,260	± 237	1,450	± 243	9.9	1,170	± 310	10.4
		22 NOV 87	8,200	± 336	7,910	± 330	2.5	7,850	± 330	1.8
	1-N-33	16 JAN 87	198,000	± 1,440	203,000	± 1,460	1.8	200,000		0.2
		01 JUN 87	89,200	± 1,140	84,000	± 1,100	4.2	91,600	± 925	4.0
		10 SEP 87	129,000	± 1,390	126,000	± 1,350	1.7			
		01 NOV 87	218,000	± 1,780	217,000	± 1,770	0.3			
	4-S1-7C	08 JAN 87	82,300	± 1,090	84,100	± 1,100	1.5	79,600		3.1
		07 APR 87	81,000	± 947	76,800	± 915	3.8	81,100	± 843	1.9
		28 JUL 87	79,500	± 1,060	77,800	± 1,060	1.5	93,800	± 960	12.4
		20 NOV 87	81,700	± 954	80,100	± 945	1.4	79,000	± 746	1.7
	6-15-26	28 JAN 87	63,000	± 835	62,900	± 834	0.1	64,600		1.8
		02 JUN 87	60,400	± 933	64,800	± 974	5.0	64,500	± 797	2.1
		03 SEP 87	63,100	± 966	64,200	± 966	1.2	63,700	± 766	0.1
		26 OCT 87	64,700	± 975	64,200	± 979	0.5			
	6-41-1	28 FEB 87	233,000	± 1,280				242,000		2.7
		19 MAY 87	242,000	± 1,840	231,000	± 1,800	3.3	248,000		3.4
		07 AUG 87	245,000	± 1,880	242,000	± 1,850	0.9	270,000		7.3
		27 OCT 87	240,000	± 1,860	242,000	± 1,860	0.6			
	6-S6-E4D	08 JAN 87	38,000	± 766	33,000	± 709	10.0	35,000		1.0
		03 JUN 87	35,000	± 715	35,100	± 722	0.2	36,300	± 636	2.5
		24 JUL 87	35,600	± 724	35,800	± 729	0.4	42,100	± 689	11.6
		26 OCT 87	37,400	± 758	34,700	± 720	5.3			
NO_3^- (ppb)	1-F8-2	14 JAN 87	97,900		94,400		2.6			
		17 MAY 87	99,300		99,100		0.1			
		02 JUL 87	92,400		92,700		0.2			
		19 OCT 87	92,300		92,700		0.3			
	1-K-22	13 JAN 87	3,200		3,130		1.6			
		23 APR 87	3,400		3,560		3.3			
	1-N-21	15 JAN 87	16,900		16,900		0.0			
		28 MAY 87	13,000		13,000		0.0			
		17 SEP 87	15,700		15,700		0.0			
		22 NOV 87	19,000		19,100		0.4			
	1-N-23	15 JAN 87	11,500		11,100		2.5			
		28 MAY87	26,000		26,300		0.8			
		17 SEP 87	6,790		6,810		0.2			
		22 NOV 87	6,950		6,810		1.4			
	1-N-33	16 JAN 87	41,700		41,400		0.5			
		01 JUN 87	32,100		32,200		0.2			
		10 SEP 87	33,500		33,700		0.4			
		01 NOV 87	54,300		53,600		0.9			
	3-6-1	08 JAN 87	29,300		29,200		0.2			
		02 APR 87	27,900		28,100		0.5			
		22 JUL 87	27,000		27,000		0.0			
		20 OCT 87	29,200		29,200		0.0			
	3-8-3	08 JAN 87	11,300		11,200		0.6			
		02 APR 87	11,800		11,700		0.6			
		22 JUL 87	12,800		12,800		0.0			
		20 OCT 87	10,700		12,000		8.1			
	4-S1-7C	08 JAN 87	28,600		28,600		0.0			
		07 APR 87	27,000		27,100		0.3			
	6-15-26	28 JAN 87	23,600		23,600		0.0			
	6-S27-E14	04 JUN 87	26,000		28,100		5.5			
	6-S6-E4D	08 JAN 87	26,500		26,600		0.3			
		03 JUN 87	24,600		24,900		0.9			
		24 JUL 87	23,800		23,800		0.0			
		26 OCT 87	26,000		26,000		0.0			

TABLE A.58. (contd)

Constituent (units)	Well Name	Collection Date	Record Sample			Blind (Duplicate) Sample			Rep CV[b]	Audit Sample[c]			Audit CV
Cobalt-60 (pCi/L)	1-N-21	15 JAN 87	5.68	±	5.08	6.11	±	4.98	5.2				
		17 SEP 87	5.08	±	4.54	5.66	±	5.06	7.6				
		22 NOV 87	5.06	±	4.52	7.90	±	5.97	31.0				
	1-N-23	28 MAY 87	22.2	±	9.47	23.8	±	11.5	4.9	25	±	4.2	5.9
	1-N-33	16 JAN 87	222	±	33.0	203	±	22.1	6.3				
		01 JUN 87	176	±	33.9	174	±	29.7	0.8	190	±	6.9	5.8
		10 SEP 87	221	±	34.0	217	±	32.1	1.3	230	±	7.5	3.5
		01 NOV 87	498	±	46.6	542	±	48.1	6.0				
	6-15-26	03 SEP 87	5.38	±	4.82	9.70	±	6.46	40.5				
	6-S6-E4D	26 OCT 87	10.7	±	6.76	11.0	±	7.30	2.0				
Cesium-137 (pCi/L)	1-K-22	28 JUL 87	6.05	±	4.28	4.82	±	3.64	16.0				
	1-N-21	22 NOV 87	3.18	±	2.84					14	±	14	89.1
Ruthenium-106 (pCi/L)	1-N-23	28 MAY 87	111	±	48.4	60.5	±	59.5	41.6				
	1-N-33	16 JAN 87	175	±	109	78.8	±	65.4	53.6				
		01 JUN 87	173	±	86.3	126	±	52.4	22.2	110	±	32	21.5
		10 SEP 87	108	±	86.0	135	±	89.3	15.7				
Ruthenium-103 (pCi/L)	1-N-33	16 JAN 87	59.2	±	24.1	58.7	±	13.8	0.6				
		01 JUN 87	54.6	±	20.7	47.2	±	13.5	10.3				
Antimony-125 (pCi/L)	1-N-33	16 JAN 87	184	±	44.9	51.2	±	18.8	79.0	140	±	43	12.0
		10 SEP 87	174	±	41.6					140	±	21	15.3
		01 NOV 87	98.8	±	37.0	105	±	32.2	4.3				
Iodine-131 (pCi/L)	1-N-33	16 JAN 87	5,820	±	343	1,290	±	113	90.1	8,500			58.0
Iodine-129 (pCi/L)	6-50-53	04 SEP 87	0.042	±	0.0035	0.044	±	0.0038	3.4				
Uranium (pCi/L)	1-F8-2	14 JAN 87	26.6	±	6.90	67.2	±	17.7	61.2				
		17 MAY 87	61.5	±	16.2	69.0	±	18.7	8.1				
		02 JUL 87	93.8	±	25.0	98.8	±	26.3	3.7				
		19 OCT 87	144	±	37.9	135	±	35.3	4.6				
	1-K-22	13 JAN 87	0.789	±	0.553	0.629	±	0.586	16.0				
		23 APR 87	1.17	±	0.391	0.999	±	0.358	11.1				
		28 JUL 87	0.856	±	0.321	0.870	±	0.327	1.9				
		20 OCT 87	0.994	±	0.348	1.00	±	0.357	0.4				
	2-E33-3	15 MAY 87	1.08	±	0.344	1.04	±	0.329	2.7				
		06 AUG 87	1.17	±	0.400	1.73	±	0.560	27.3	4.6	±	2.8	73.6
	2-W23-2	22 SEP 87	3.95	±	1.13	4.15	±	1.19	3.5				
	3-6-1	08 JAN 87	6.11	±	1.85	5.46	±	1.69	7.9	8.7	±	3.3	28.5
		02 APR 87	5.63	±	1.55	5.73	±	1.56	1.2	13	±	5.5	55.4
		22 JUL 87	6.66	±	1.81	4.38	±	1.21	29.2				
		20 OCT 87	5.87	±	1.62	5.48	±	1.53	4.9				
	3-8-3	08 JAN 87	3.88	±	1.29	7.07	±	2.15	41.2	6.0	±	3.0	6.5
		02 APR 87	2.70	±	0.800	3.92	±	1.14	26.1				
		22 JUL 87	4.33	±	1.24	3.47	±	0.999	15.6				
		20 OCT 87	3.33	±	0.969	3.71	±	1.06	7.6				
	6-S27-E14	04 JUN 87	3.46	±	0.969	3.46	±	1.14	0.0				
	6-S6-E4D	08 JAN 87	3.07	±	1.03	3.12	±	1.08	1.1	7.5	±	5.3	58.8
		03 JUN 87	2.77	±	0.789	2.86	±	0.822	2.3	6.2	±	3.0	53.1
		24 JUL 87	2.59	±	0.777	2.56	±	0.767	0.8	3.4	±	3.1	19.5
		26 OCT 87	2.62	±	0.790	2.91	±	0.864	7.4				
Gross Beta (pCi/L)	4-S1-7C	08 JAN 87	25.7	±	3.77	25.0	±	3.73	2.0	50	±	16	46.3
		07 APR 87	25.9	±	3.81	23.0	±	3.60	8.4	38	±	15	30.7
Strontium-90 (pCi/L)	1-N-21	15 JAN 87	2.91	±	1.24	2.82	±	1.18	2.2	3.6	±	1.6	16.1
		17 SEP 87	8.46	±	1.89	5.14	±	1.36	34.5	11.9	±	2.38	38.6
		22 NOV 87	5.91	±	1.43	6.01	±	1.42	1.2	7.76	±	1.94	18.6
	1-N-23	15 JAN 87	3.97	±	1.25	3.61	±	1.23	6.7	8.87	±	2.21	56.7
	1-N-33	16 JAN 87	658	±	13.5	650	±	13.6	0.9	663	±	19.9	1.0
		10 SEP 87	454	±	35.8	443	±	34.7	1.7				
		01 NOV 87	644	±	89.1	635	±	90.2	1.0				

(a) Individual results ±2 sigma counting errors.
(b) REP CV = standard deviation of original and duplicate divided by their mean times 100
(c) AUDIT CV = standard deviation of audit and mean of original and duplicate divided by their mean times 100.

TABLE A.59. Summary of Analytical Results for Replicate Samples Collected from Well 199-H4-4 During 1987

Constituent	Month	Analysis Values (ppb) UST	HEHF	PNL
Chromium	January	176[a]	160[a]	
	February	419	473	
	March	437	466	
	April	378	396	
	May	26	25	
	June	209	174	
	July	280		281
	August	323, 312		---[b]
	September	336, 337		341
	October	249, 233		214
	November	[c]		[c]
	December	167, 184		180
Sodium	January	69,300	70,000	
	February	179,000	147,000	
	March	181,000	155,000	
	April	168,000	161,000	
	May	12,400	11,900	
	June	88,300	88,600	
	July	135,000		148,000
	August	306, 300		[b]
	September	192,000		199,000
		177,000, 181,000[a]		
	October	115,000, 117,000		119,000
	November	—[c]		---[c]
	December	95,500, 99,700		91,500
Chloroform (A80)	January	<10		6.99
	February	20		6.41[d]
	March	19		19.91
	April	18		18.71 ± 0.63
	May	<10		2.74
	June	<10		10.88 ± 0.78
	July	16.4		13.95
	August	12		14.37
	September	16		18.99
	October	11		11.52
	November	---[c]		---[c]
	December	8		13.1[e]
Nitrate	January	112,000	118,000	118,000[f]
	February	492,000	625,000*	470,000
	March	493,000	500,000	478,000
	April	452,700	507,000	440,000

TABLE A.59. (contd)

Constituent	Month	Analysis Values (ppb) UST	HEHF	PNL
	May	9,720	9,200	9,920
	June	180,000	169,000	180,000
	July	296,000		325,000
	August	374,000, 369,000		364,000
	September	512,000, 499,000		---[g]
	October	231,000, 231,000		220,000
	November	----[c]		---[c]
	December	139,000, 139,000		152,000
Sulfate	January	37,100	40,000	40,700[f]
	February	68,500	78,000	78,200
	March	82,900	79,000	77,700
	April	68,800	74,000	76,200
	May	21,300	19,700	21,200
	June	44,400	39,000	48,000
	July	66,200		61,000
	August	70,700, 70,300		71,000
	September	81,100, 79,100		[g]
	October	60,100, 60,200		61,800
	November	---[c]		---[c]
	December	54,100, 53,800		55,500
Chloride	January	3,670	3,570	3,780[f]
	February	5,900	5,800	5,460
	March	7,070[h]	5,000	5,390
	April	6,650	6,700	5,550
	May	1,280	1,900	2,490
	June	4,480	4,100	4,46
	July	6,130		5,010
	August	6,710, 6,750		5,570
	September	6,890, 6,730		—[g]
	October	6,340, 6,260		5,120
	November	—[c]		—[c]
	December	5,950, 5,950		5,390

(a) Unfiltered samples January-July and September duplicate; otherwise filtered samples.
(b) A mixup in samples caused deletion of August sample.
(c) No November sample collected.
(d) >2.8 Standard deviations difference between analyses (6.3 ppb).
(e) >2.8 Standard deviations difference between analyses (>4.3 ppb).
(f) Analysis done by WHC until July. WHC Lab became PNL in July 1987.
(g) No sample delivered to PNL.
(h) UST had instrument trouble, which caused high chloride results.
* Outlier.

TABLE A.60. Summary of Data from Replicate Samples and Interlaboratory Comparisons for the Ground-Water Monitoring Project During 1987

Constituent	Well Name	Analytical Results (ppb) UST	PNL	Comments
Nitrate	6-49-57	69,900	66,100	
		70,000		
		69,800		
	6-49-55A	251,000	223,000	
		252,000		
		253,000		
Sulfate	6-49-57	38,900	34,500	
		38,900		
		38,800		
	6-49-55A	148,000	113,000	PNL spike recovery 118% indicates initial result was probably too low
		148,000		
		148,000		
Chloride	6-49-57	42,100	3,660	Discrepancy attributed to dilution error.
		41,900		
		41,900		
	6-49-55A	15,000	13,500	
		15,100		
		15,100		
Calcium	6-49-57	24,800	24,900	
		24,100		
		24,400		
	6-50-53	229,000	217,000	
		225,000		
		232,000		
Barium	6-49-57	29	24.6	
		28		
		27		
	6-50-53	71	72.0	
		71		
		70		
Sodium	6-49-57	48,800	47,600	
		46,300		
		46,900		
	6-50-53	59,200	57,400	
		61,600		
		61,100		

TABLE A.60. (contd)

Constituent	Well Name	Analytical Results (ppb) UST	PNL	Comments
Vanadium	6-49-57	30	30	
		30		
		25		
	6-50-53	5	19	Discrepant result
	6-50-532	7		
	6-50-531	<5		
Potassium	6-49-57	5,900	6,200	
		4,800		
		5,300		
	6-50-53	14,900	15,300	
		14,900		
		14,400		
Iron	6-50-53	292	322	
		296		
		283		
	6-49-57	<30	23	
		<30		
		<30		
Magnesium	6-49-57	7,970	7,520	
		7,530		
		7,630		
	6-50-53	64,900	60,300	
		66,600		
		67,100		
Strontium	6-49-57	135	133	
		142		
		131		
	6-50-53	953	970	
		919		
		936		
Cyanide	6-49-57	619		
		499		
		615		
Cyanide	6-50-53	622		Reanalyzed 841
		1120		1140
		1120		1170
Ammonium	6-49-55A	640		
		640		

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APPENDIX B

GLOSSARY, ABBREVIATIONS, CONVERSION TABLE

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APPENDIX B

GLOSSARY, ABBREVIATIONS, CONVERSION TABLE

Activation Product - A material made radioactive by exposure to neutron radiation in a nuclear reactor.

Air Submersion Dose - The radiation dose received from external exposure to radioactive materials present in the surrounding atmosphere.

Airlift - A means of collecting water samples from wells by pumping air down the tube that is inside the well and then forcing water up the annular space between the tube and a larger pipe or the well casing.

Aquifer - A permeable geologic unit that can transmit significant quantities of water.

Background Radiation - The radioactivity in the environment, including cosmic rays from space and radiation that exists elsewhere - in the air, in the earth, and in manmade materials that surround us. In the United States, most people receive 100 to 250 millirems (mrem) of background radiation per year.

Bankstorage - A hydrologic term that describes river water that flows into and is retained in permeable stream banks during periods of high river stage. Flow is reversed during periods of low river stage.

becquerel (Bq) - A unit of activity equal to one nuclear transformation per second (1 Bq = 1 s^{-1}). The former special- named unit of activity, the curie, is related to the becquerel according to 1 Ci = 3.7×10^{10} Bq.

Confined Aquifer - An aquifer that is bounded above and below by less permeable layers. Ground water in the confined aquifer is under a pressure greater than the atmospheric pressure.

Controlled Area - An area to which access is controlled to protect individuals from exposure to radiation or radioactive materials.

Cosmic Radiation - High-energy subatomic particles from outer space, which bombard the earth's atmosphere. Cosmic radiation is part of natural background radiation.

Counting Error - The variability caused by the inherent random nature of radioactive disintegration and the detection process.

Curie (Ci) - A unit of radioactivity equal to 37 billion (3.7×10^{10}) nuclear transformations per second.

Detection Level - The minimum concentration of a substance that can be measured with a 99% confidence that the analytical concentration is greater than zero.

Derived Concentration Guide (DCG) - Concentrations of radionuclides in air and water that could be continuously consumed or inhaled and not exceed an effective dose equivalent of 100 mrem/yr.

Dispersion - The process whereby solutes are spread or mixed as they are transported by ground water as it moves through sediments.

Dosimeter - A portable device for measuring the total accumulated exposure to ionizing radiation.

Effective Dose - See "Effective Dose Equivalent" under "Radiation Dose."

Effluent - The liquid or gaseous waste streams released to the environment from a facility.

Effluent Monitoring - Sampling or measuring specific liquid or gaseous effluent streams for the presence of pollutants.

Exposure - Subjecting a target (usually living tissue) to radiation.

Evapotranspiration - A combination of evaporation from open bodies of water, evaporation from soil surfaces, and transpiration from the soil by plants.

Fallout - Radioactive materials mixed into the earth's atmosphere following a nuclear explosion. Fallout constantly precipitates onto the earth.

"Fence-post" Dose Rate - The dose rate measured or calculated at the point of highest exposure at the boundary of the Hanford Site.

Fission (fissioned) - The splitting or breaking apart of a heavy atom into two new atoms. When a heavy atom, such as uranium, is split, large amounts of energy, radiation, and one or more neutrons are released.

Fission Products - The atoms formed when uranium is split in a nuclear reactor. Many fission products are radioactive.

Fuel Cladding - The metal skin used to retain the fuel pellets and separate the fuel and the coolant in a nuclear reactor.

Glaciofluvial Sediments - A sedimentary deposit consisting of material transported by, suspended in, or laid down by the meltwater streams flowing from melting glacier ice.

Ground Water - Subsurface water that is in the pore spaces of soil and geologic units.

Half-life - The length of time in which any radioactive substance will lose one-half of its radioactivity. The half-life may vary in length from a fraction of a second to thousands of years.

Ion Exchange - The reversible exchange of ions contained in a crystal for different ions in solution without destroying the crystal structure or disturbing the electrical neutrality.

Isotope - Different forms of the same chemical element that are distinguished by having different numbers of neutrons in the nucleus. A single element may have many isotopes. For example, the three isotopes of hydrogen are protium, deuterium, and tritium.

> **Long-lived Isotope** - A radionuclide that decays at such a slow rate that a quantity of it will exist for an extended period (half-life is greater than 3 years).
>
> **Short-lived Isotope** - A radionuclide that decays so rapidly that a given quantity is transformed almost completely into decay products within a short period (half-life of 2 days or less).

Lacustrine Sediments - A sedimentary deposit consisting of material pertaining to, produced by, or formed in a lake or lakes.

Lithology - The description of the physical characteristics of rocks that make up geologic units. This may include such characteristics as color, mineralogic composition, and grain size.

Maximally Exposed Individual - A hypothetical individual who remains in an uncontrolled area and would, when all potential routes of exposure from a facility's operations are considered, receive the greatest possible dose equivalent.

Mean - The average value of a series of measurements.

Median - The middle value in a set of results when the data are ranked in increasing or decreasing order.

Millirem (mrem) - A unit of radiation dose equivalent that is equal to one one-thousandth of a rem. An individual member of the public can receive up to 500 millirems (mrem) per year according to DOE standards. This limit does not include radiation received for medical treatment or the 100 to 250 millirems (mrem) that people receive annually from background radiation.

Minimum Detectable Concentration - The smallest amount or concentration of a radioactive or nonradioactive element that can be reliably detected in a sample.

Noble Gas - Any of a group of chemically and biologically inert gases that includes krypton and xenon. These gases are not retained in the body following inhalation. The principal exposure pathways from radioactive noble gases are direct external dose from the surrounding air (see "Air Submersion Dose"), and from internal irradiation while the inhaled air is in the lung.

Offsite Locations - Sampling and measurement locations outside the Hanford Site boundary.

Onsite Locations - Sampling and measurement locations within the Hanford Site boundary.

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Outfall - The end of a drain or pipe that carries waste water or other effluents into a ditch, pond, or river.

Person-rem - See "Collective Dose Equivalent" under "Radiation Dose."

Plume - The distribution of a pollutant in air or water after being released from a source.

Plutonium - A heavy, radioactive, manmade metallic element. Its most important isotope is fissionable ^{239}Pu, which is produced by the irradiation of ^{238}U. Routine analysis cannot distinguish between the ^{239}Pu and ^{240}Pu isotopes, hence, the term $^{239,240}Pu$.

Primary Cooling Loop - A closed system of piping that provides cooling water to the reactor. Heat energy is transferred to the secondary loop through a heat exchanger.

Radiation - Refers to the process of emitting energy in the form of rays or particles that are thrown off by disintegrating atoms. The rays or particles emitted may consist of alpha, beta, or gamma radiation.

> **Alpha Radiation** - The least penetrating type of radiation. Alpha radiation can be stopped by a sheet of paper or outer dead layer of skin.
>
> **Beta Radiation** - Emitted from a nucleus during fission. Beta radiation can be stopped by an inch of wood or a thin sheet of aluminum.
>
> **External Radiation** - Radiation originating from a source outside the body, such as cosmic radiation or natural and manmade radionuclides.
>
> **Gamma Radiation** - A form of electromagnetic, high-energy radiation emitted from a nucleus. Gamma rays are essentially the same as x-rays and require heavy shieldings, such as concrete or steel, to be stopped.
>
> **Internal Radiation** - Radiation originating from a source within the body as a result of the inhalation, ingestion, or implantation of natural or manmade radionuclides in body tissues.

Radiation Dose - For the purpose of this report, radiation doses are defined as follows:

Absorbed Dose - The amount of energy deposited by radiation in a given amount of material. Absorbed dose is measured in units of "rads" (see "Dose Equivalent").

Collective Dose Equivalent - The sum of the dose equivalents for individuals comprising a defined population. The per capita dose equivalent is the quotient of the collective dose equivalent divided by the population size.

Committed Dose Equivalent - The total dose equivalent accumulated in an organ or tissue in the 50 years following a single intake of radioactive materials into the body.

Cumulative Dose Equivalent - The total dose one could receive in a period of 50 years following release of the radionuclides to the environment, including the dose that could occur as a result of residual radionuclides remaining in the environment beyond the year of release.

Dose Equivalent - The product of the absorbed dose, the quality factor, and any other modifying factors. The dose equivalent is a quantity for comparing the biological effectiveness of different kinds of radiation on a common scale. The unit of dose equivalent is the rem. A millirem (mrem) is one one-thousandth of a rem.

Effective Dose Equivalent - An estimate of the total risk of potential health effects from radiation exposure. It is the sum of the committed effective dose equivalent from internal deposition and the effective dose equivalent from external penetrating radiation received during a calendar year. The committed effective dose equivalent is the sum of the individual organ committed dose equivalents (50 year) multiplied by weighting factors that represent the proportion of the total random risk that each organ would receive from uniform irradiation of the whole body.

Radioactivity - A property possessed by some elements, such as uranium, whereby alpha, beta, or gamma rays are spontaneously emitted.

Radioisotope - A radioactive isotope of a specified element. Carbon-14 is a radioisotope of carbon. Tritium is a radioisotope of hydrogen.

Radionuclide - A radioactive nuclide. There are several hundred known nuclides, both manmade and naturally occurring; nuclides are characterized by the number of neutrons and protons in an atom's nucleus.

Rem - An acronym for Roentgen Equivalent Man; a unit of radiation exposure that indicates the potential impact on human cells.

Sievert - A unit of dose equivalent from the International System of Units (SI) equal to 1 joule per kilogram.

Spent Fuel - Nuclear fuel that has been exposed in a nuclear reactor; this fuel contains uranium, activation products, fission products, and plutonium. Spent fuel is processed in the PUREX Plant.

Standard Deviation - An indication of the dispersion of a set of results around their average.

Standard Error of the Mean - An indication of the dispersion of an estimated mean from the average of other estimates of the same mean.

Thermoluminescent Dosimeters (TLD) - A material that, after being exposed to radiation, luminesces upon being heated. The amount of light emitted is proportional to the amount of radiation (dose) to which it has been exposed.

Unconfined Aquifer - Contains ground water that is not confined above by relatively impermeable rocks. The pressure at the top of the unconfined aquifer is equal to that of the atmosphere. At Hanford, the unconfined aquifer is the uppermost aquifer and is most susceptible to contamination from Site operations.

Uncontrolled Area - An area on or near a nuclear facility to which public access is not restricted.

Water Table - A theoretical surface which is represented by the elevation of water surfaces in wells penetrating only a short distance into the unconfined aquifer.

Whole-Body Dose - A radiation dose that involves exposure of the entire body.

Windrose - A star-shaped diagram showing how often winds of various speeds blow from different directions, usually based on yearly averages.

$\bar{X}/Q'$ (Chi over Que) - A dispersion factor calculated using an atmospheric dispersion model from average annual meteorological data. It is used to estimate the air concentration from the total airborne release of a radionuclide. The resulting estimates of average annual air concentrations at specific locations away from the source can be used to calculate potential doses.

ACRONYMS AND ABBREVIATIONS

ALARA	as low as reasonably achievable
ALE	Arid Lands Ecology (Reserve)
BMI	Battelle Memorial Institute
BWIP	Basalt Waste Isolation Project
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
cfs	cubic feet per second
DOE	U.S. Department of Energy
DOE-RL	U.S. Department of Energy, Richland Operations Office
DCG	Derived Concentration Guide
DWS	Drinking Water Standards
EML	Environmental Measurements Laboratory
EPA	U.S. Environmental Protection Agency
ERDA	U.S. Energy Research and Development Administration (predecessor to DOE)
FFTF	Fast Flux Test Facility
HEDL	Hanford Engineering Development Laboratory
HEHF	Hanford Environmental Health Foundation
ICRP	International Commission on Radiological Protection
MDC	minimum detectable concentration
NERP	National Environmental Research Park
NPDES	National Pollutant Discharge Elimination System
PNL	Pacific Northwest Laboratory
PSD	Prevention of Significant Deterioration
PUREX	Plutonium and Uranium Extraction Plant
QA	Quality Assurance
QC	Quality Control
RCRA	Resource Conservation and Recovery Act
REDOX	Reduction Oxidation Plant
SI	International System of Units (metric)
TLD	thermoluminescent dosimeter
UNC	UNC Nuclear Industries
UO_3 Plant	Uranium Oxide Plant
UST	United States Testing Company, Inc.
USGS	U.S. Geological Survey
WDOE	Washington State Department of Ecology
WDSHS	Washington State Department of Social and Health Services
WHC	Westinghouse Hanford Company

ABBREVIATIONS FOR UNITS OF MEASURE

Radioactivity	
Symbol	Name
Ci	curie
mCi	millicurie (10^{-3} Ci)
µCi	microcurie (10^{-6} Ci)
nCi	nanocurie (10^{-9} Ci)
pCi	picocurie (10^{-12} Ci)
fCi	femtocurie (10^{-15} Ci)
aCi	attocurie (10^{-18} Ci)
Bq	becquerel
Sv	sievert

Volume	
Symbol	Name
cm^3	cubic centimeter
L	liter
mL	milliliter (10^{-3} L)
m^3	cubic meter
ppm	parts per million
ppb	parts per billion

Length	
Symbol	Name
km	kilometer (10^3 m)
m	meter
cm	centimeter (10^{-2} m)
mm	millimeter (10^{-3}m)
µm	micrometer (10^{-6} m)

Mass	
Symbol	Name
g	gram
kg	kilogram (10^3 g)
µg	microgram (10^{-6} g)
ng	nanogram (10^{-9} g)
t	metric ton (or tonne; 10^3 kg)

Area	
Symbol	Name
ha	hectare (10,000 m^2)

Time	
Symbol	Name
yr	year
d	day
h	hour
m	minute
s	second

CONVERSION TABLE

Multiply	By	To Obtain	Multiply	By	To Obtain
in.	2.54	cm	cm	0.394	in.
ft	0.305	m	m	3.28	ft
mi	1.61	km	km	0.621	mi
lb	0.454	kg	kg	2.205	lb
liq qt	0.946	L	L	1.057	liq qt
ft^2	0.093	m^2	m^2	10.76	ft^2
ha	2.47	acres	acres	0.405	ha
mi^2	2.59	km^2	km^2	0.386	mi^2
ft^3	0.028	m^3	m^3	35.7	ft^3
nCi/mi^2	0.386	mCi/km^2	mCi/km^2	2.57	nCi/mi^2
dpm	0.450	pCi	pCi	2.22	dpm
nCi	1000	pCi	pCi	0.001	nCi
pCi/L	10^{-9}	µCi/mL	µCi/mL	10^{9}	pCi/L
pCi/m^3	10^{-12}	Ci/m^3	Ci/m^3	10^{12}	pCi/m^3
pCi/m^3	10^{-12}	mCi/cm^3	mCi/cm^3	10^{12}	pCi/m^3
mCi/km^2	1.0	nCi/m^2	nCi/m^2	1.0	mCi/km^2
becquerel	2.7×10^{-11}	curie	curie	3.7×10^{10}	becquerel
gray	100	rad	rad	0.01	gray
sievert	100	rem	rem	0.01	sievert
ppb	0.001	ppm	ppm	1000	ppb
ppm	1.0	mg/L	mg/L	1.0	ppm

TABLE OF UNIT PREFIXES

Factor	Prefix	Symbol
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{2}	hecto	h
10^{1}	deka	da
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	µ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a

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APPENDIX C

APPLICABLE STANDARDS AND PERMITS AND ENVIRONMENTAL COMPLIANCE DOCUMENTATION

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APPENDIX C

APPLICABLE STANDARDS AND PERMITS AND ENVIRONMENTAL COMPLIANCE DOCUMENTATION

Operations at the Hanford Site must conform to a variety of federal and state standards and permits designed to ensure the radiological, chemical, biological, and physical quality of the environment for either aesthetic or public health considerations. Standards and permits applicable to Hanford operations in 1987 are listed in the following tables. The State of Washington has promulgated water-quality standards for the Columbia River (WDOE 1982). Of interest to Hanford operations is the designation of the Hanford reach of the Columbia River as Class A, Excellent. This designation requires that the water be usable for substantially all needs, including drinking water, recreation, and wildlife. Class A water standards are summarized in Table C.1. Drinking water standards promulgated by EPA (EPA 1976) are summarized in Tables C.2 and C.3. Benton, Franklin, Walla Walla Counties Air Pollution Control Authority air quality standards are shown in Table C.4. Environmental radiation protection standards are published in DOE Order 5480.1A "Environmental Protection, Safety, and Health Protection Programs for DOE Operations," (DOE 1981). These standards are based on guidelines originally recommended by the Federal Radiation Council and other scientific groups, such as the International Commission on Radiological Protection and the National Commission on Radiation Protection and Measurements. In September 1985, DOE issued a revision to this order that incorporates a system for evaluating and controlling radiation exposures to members of the public in uncontrolled areas. The revised standards are shown in Table C.5, which also includes standards pursuant to the Clean Air Act for sources of radionuclide emissions to the air (EPA 1983). These standards govern allowable exposures to ionizing radiation from DOE operations.

The DOE has also prepared draft tables of DCGs that reflect the concentrations of individual nuclides in water or air that would result in an effective dose equivalent of 100 mrem caused by ingestion of water or inhalation. The DCGs are useful reference values but do not generally represent concentrations that ensure compliance with either the DOE or Clean Air Act dose standards (Table C.6).

Permits required for regulated releases to water and air have been issued by the EPA under the National Pollution Discharge Elimination System of the Clean Water Acts and the Prevention of Significant Deterioration requirements of the Clean Air Act. Permits for collecting wildlife for environmental sampling are issued by the Washington State Department of Wildlife and the U.S. Fish and Wildlife Service. Current permits are listed in Table C.7.

Table C.8 lists the Environmental Impact Statements and Environmental Assessments relating to the Hanford Site that were issued during 1987 in final form. These environmental compliance documents were prepared in accordance with federal, state, and regional environmental protection laws.

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TABLE C.1. Washington State Water-Quality Standards for the Hanford Reach of the Columbia River

Parameter	Permissible Levels
Fecal coliform organism	1) ≤100 organisms/100 mL 2) ≤10% of samples may exceed 200 organisms/100 mL
Dissolved oxygen	>8 mg/L
Temperature	1) ≤20°C (68°F) due to human activities 2) When natural conditions exceed 20°C, no temperature increase of greater than 0.3°C allowed. 3) Increases not to exceed 34/(T+9), where T = highest existing temperature in °C outside of dilution zone.
pH	1) 6.5 to 8.5 range 2) <0.5 unit induced variation
Turbidity	≤5 NTU[a] over background turbidity
Toxic, radioactive, or deleterious materials	Concentrations shall be below those of public health significance, or which cause acute or chronic toxic conditions to the aquatic biota, or which may adversely affect any water use.
Aesthetic value	Shall not be impaired by the presence of materials or their effects, excluding those of natural origin, which offend the senses of sight, smell, touch, or taste.

(a) NTU = Nephelometric Turbidity Units.

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TABLE C.2. Radiological Drinking Water Standards: U.S. Environmental Protection Agency, National Interim Primary Drinking Water Regulations and State of Washington, Rules and Regulations of the State Board of Health Regarding Public Water Systems

Contaminant	Limit
Gross alpha (excluding uranium)	15 pCi/L
Combined ^{226}Ra and ^{228}Ra	5 pCi/L
Radium-226 (State of Washington only)	3 pCi/L
Gross beta and gamma radioactivity from manmade radionuclides	Annual average concentration shall not produce an annual dose from manmade radionuclides equivalent to the total body or any internal organ dose greater than 4 mrem/yr. If two or more radionuclides are present, the sum of their annual dose equivalent shall not exceed 4 mrem/yr. Compliance may be assumed if annual average concentrations for gross beta activity, ^{3}H, and ^{90}Sr are less than 50, 20,000, and 8 pCi/L, respectively.

The following list provides the annual average concentrations, with respect to the Columbia River, for selected manmade radionuclides of interest. These radionuclides are assumed to yield an annual dose of 4 mrem to the indicated organ. Data are taken from the National Interim Primary Drinking Water Regulations, Table IV-2A (EPA 1976).

Radionuclide	Critical Organ	Concentration, pCi/L
^{3}H	Whole Body	20,000
^{60}Co	GI (LLI)[a]	100
^{89}Sr	Bone	20
^{89}Sr	Bone Marrow	80
^{90}Sr	Bone Barrow	8
^{95}Zr	GI (LLI)[a]	200
^{95}Nb	GI (LLI)[a]	300
^{106}Ru	GI (LLI)[a]	30
^{129}I	Thyroid	1
^{131}I	Thyroid	3
^{134}Cs	GI(s)[a]	20,000
^{137}Cs	Whole Body	200

(a) Gastrointestinal tract (lower large intestine).

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TABLE C.3. Chemical Drinking Water Standards: U.S. Environmental Protection Agency, National Interim Primary Drinking Water Regulations (EPA 1976) and State of Washington, Public Water Supplies (WDSHS 1983)

Chemical Constituent	Concentration
As	50 µg/L
Ba	1 mg/L
Cd	10 µg/L
CCl_4	5 µg/L
Cr	50 µg/L
Cu	1.0 mg/L
F	2 mg/L
Hg	2 µg/L
NO_3^-	45 mg/L
Pb	50 µg/L
Se	10 µg/L

TABLE C.4. Benton, Franklin, Walla Walla Counties Air Pollution Control Authority Ambient Air Quality Standards[a]

Parameters	Type of Standard[b]	Sampling Period	Permissible Levels
NO_2	Secondary and primary	Annual average	0.05 ppm

(a) Benton, Franklin, Walla Walla Air Pollution Control Authority 1980.
(b) Primary ambient air quality national standards define levels of air quality to protect the public health. Secondary standards define levels of air quality to protect the public welfare from any known or anticipated adverse effects of a pollutant.

TABLE C.5. Radiation Standards for Protection of the Public in the Vicinity of DOE Facilities

DOSE LIMITS

ALL PATHWAYS

The effective dose equivalent for any member of the public from all routine DOE operations [a] (natural background and medical exposures excluded) shall not exceed the values given below[b]:

	Effective Dose Equivalent[c]	
	mrem/yr	(mSv/yr)
Occasional Annual Exposures	500	(5)
Prolonged Period of Exposure[d]	100	(1)

No individual organ shall receive a committed effective dose equivalent of 5 mrem/yr (500 mSv/yr) or greater.

AIR PATHWAYS ONLY (Limits from EPA 1983, 40 CFR 61)

	Dose Equivalent	
	mrem/yr	(mSv/yr)
Whole-Body Dose	25	(0.25)
Any Organ	75	(0.75)

(a) Routine DOE operations implies normal, planned operations and does not include actual or potential accidental or unplanned releases.

(b) Memo from W. A. Vaughan, Assistant Secretary for Environment Safety, and Health, U.S. Department of Energy, to DOE Field Offices, August 5, 1985.

(c) Effective dose equivalent is expressed in rem (or millirem) with the corresponding value in sievert (or millisievert) in parentheses.

(d) For the purposes of these standards, a prolonged exposure is one that lasts, or is predicted to last, longer than 5 years.

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TABLE C.6. Proposed Derived Concentration Guides[a,b]

Radionuclide	Water pCi/L (10^{-9} µCi/mL)	Air pCi/m^3 (10^{-12} µCi/mL)
^{3}H	2,000,000	200,000
$^{14}C(CO_2)$	NS	500,000
^{51}Cr	1,000,000	60,000
^{54}Mn	50,000	2,000
^{60}Co	5,000	80
^{65}Zn	9,000	600
^{85}Kr	NS	60,000[c]
^{89}Sr	20,000	300
^{90}Sr	1,000	9
^{106}Ru	6,000	30
^{129}I	500	70
^{131}I	3,000	400
^{137}Cs	3,000	400
^{144}Ce	7,000	30
^{234}U	500	0.09
^{235}U	600	0.1
^{238}U	600	0.1
^{238}Pu	400	0.03
^{239}Pu	300	0.02

(a) Concentrations of radionuclides in water and air that could be continuously consumed or inhaled, respectively, and not exceed a committed effective dose equivalent of 100 mrem/yr.
(b) Numbers taken from a memo May 6, 1987, from R. E. Gerton, Director, Environment, Safety, and Health Division, DOE to the Hanford contractors.
(c) Derived from DOE Order 5480.1A (DOE 1981).
NS No standard.

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TABLE C.7. Environmental Permits

NPDES Permits

NPDES Permit No. WA-000374-3, issued to the DOE Richland Operations Office by Region 10 of the EPA, covers nonradioactive discharges to the Columbia River from eight outfalls. The following are measurements required for NPDES-permitted discharges at Hanford:

Measurement	Location 100-K Area (2 Discharges)	100-N Area (5 Discharges)	300 Area (1 Discharge)
Flow Rate	X	X	X
Suspended Solids	X	X	X
Temperature	X	X	---
pH	X	X	X
Chlorine	X	X	---
Oil and Grease	---[a]	X	---
Heat Discharged	---	X	---
Settleable Solids	---	---	X
Iron	---	X	---
Ammonia	---	X	---
Chromium	---	X	---

(a) Dashed line indicates no measurement required.

PSD Permits

PSD Permit No. PSD-X80-14, issued to the DOE Richland Operations Office by Region 10 of the EPA, covers emission of NO_x to the atmosphere from the PUREX Plant and the UO_3 Plant. No expiration date.

Wildlife Sampling Permits

Scientific Study or Collection Permit No. 131, issued to Pacific Northwest Laboratory, by Washington State Department of Wildlife, covers the collection of wildlife, including fish, for environmental monitoring purposes. Renewed annually.

Federal Fish and Wildlife Permit No. 671877, issued to Pacific Northwest Laboratory by U.S. Fish and Wildlife Service.

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TABLE C.8. Hanford Site Environmental Impact Statements and Environmental Assessments Issued During 1987

Environmental Impact Statements

U.S. Department of Energy (DOE). 1987. Disposal of Hanford Defense High-Level, Transuranic and Tank Wastes. DOE/EIS-0113, U.S. Department of Energy, Washington DC.

Copies of the NPDES, PSD, and Wildlife Sampling Permits regulations may be obtained from the following organizations:

State of Washington,
Department of Ecology
Olympia, WA 98504

U.S. Environmental Protection Agency
Region 10
1200 Sixth Avenue
Seattle, WA 98101

U.S. Department of Energy
Richland Operations Office
Richland, WA 99352

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APPENDIX D

ANALYTICAL PROCEDURES AND SAMPLING SUMMARY

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APPENDIX D

ANALYTICAL PROCEDURES AND SAMPLING SUMMARY

SURFACE MONITORING: RADIOLOGICAL SAMPLES

All routine environmental surveillance samples are analyzed according to detailed, written analytical procedures that are described in general terms in this section. Minimum detectable concentrations for the various medium/analysis combinations and other analytical information are shown in Table D.1.

AIR SAMPLES

Alpha- and Beta- Emitting Radionuclides are measured by a direct count from the glass fiber filter. Alpha radiation is counted on a low-background, gas-flow proportional counter and beta on a gas-flow proportional counter.

Gamma-Emitting Radionuclides are counted directly from glass fiber filters using a Ge(Li) detector with a multichannel, pulse-height analyzer. Listed below are the nuclides that are scanned during the analysis:

^{7}Be	^{99}Mo	$^{144}CePr$
^{22}Na	^{103}Ru	^{147}Nd
^{24}Na	^{106}Ru	^{152}Eu
^{40}K	^{110M}Ag	^{154}Eu
^{46}Sc	^{113}Sn	^{155}Eu
^{51}Cr	^{124}Sb	^{208}Tl
^{54}Mn	^{125}Sb	^{212}Pb
^{59}Fe	^{131}I	^{212}Bi
^{57}Co	^{133}I	^{214}Pb
^{58}Co	^{135}I	^{214}Bi
^{60}Co	^{134}Cs	^{224}Ra
^{65}Zn	^{137}Cs	^{226}Ra Da
^{76}As	^{133}Ba	^{228}Th Da
^{75}Se	^{140}Ba	^{234}Th
^{85}Kr	$^{140}BaLa$	^{232}Th Da
^{85}Sr	^{139}Ce	^{238}U Da
^{95}Zr	^{141}Ce	
^{95}Nb	^{144}Ce	

Strontium-90 is leached from glass fiber filters with fuming nitric acid, scavenged with barium chromate, precipitated as a carbonate, transferred to a stainless steel planchet, and counted with a low-background, gas-flow proportional counter.

Uranium is leached from glass fiber filters with nitric acid and extracted as tetrapropyl ammonium uranyl trinitrate, then extracted back into water. A portion of the water extract is fused with sodium and lithium fluoride and analyzed by alpha spectrometry.

Plutonium is leached from glass fiber filters with nitric acid and passed through an anion-exchange resin. The Pu on the resin column is eluted with nitric and hydrofluoric acids, electrodeposited on a stainless steel disk, and then counted with an alpha spectrometer.

Tritium in air as titrated water vapor is measured in water vapor collected in silica gel. The water vapor is removed from the gel by heat and vacuum action. It is then collected in a freeze trap. The ^{3}H content of the water vapor is determined with a liquid scintillation spectrometer.

Iodine-131 is collected on activated charcoal and then counted on a Ge(Li) detector with a multichannel, pulse-height analyzer.

Carbon-14 is collected as CO_2 gas using soda lime. The CO_2 is released from the soda-lime sample with acid and injected into a "Benzene Synthesizer" instrument. The CO_2 is quantitatively converted to benzene through a series of catalytic reactions. The benzene product is mixed with scintillation solution and counted on a low-temperature, liquid scintillation counter.

Krypton-85 is removed from the air sample and purified using a specially constructed cryogenic chromatography instrument. The sample is passed through a series of cold traps. The purified ^{85}Kr is then mixed with scintillation solution and counted on a low-temperature, liquid scintillation counter.

WATER SAMPLES

Alpha-Emitting Radionuclides (uranium and plutonium) are extracted into ether from strong nitric acid. The ether phase is evaporated. The residue is plated on a stainless steel planchet and counted with a low-background, gas-flow proportional counter.

Beta-Emitting Radionuclides are counted directly from dried residue using a gas-flow proportional counter.

Gamma-Emitting Radionuclides are counted directly from 500 mL of sample concentrate using a Ge(Li) detector with a multichannel pulse height analyzer.

Strontium-90 in large-volume water samples is precipitated with fuming nitric acid, scavenged with barium chromate, precipitated as a carbonate, transferred to a stainless steel planchet and counted with a low-background, gas-flow proportional counter. After 15 days, the ^{90}Y decay product is separated and then counted with a proportional counter.

Tritium samples can be counted directly with a liquid scintillation spectrometer, or the sample can be enriched by alkaline electrolysis and then counted with a liquid scintillation spectrometer.

Filter-Resin Samples are analyzed for gamma-emitting radionuclides using a Ge(Li) detector with a multichannel, gamma-ray spectrometer. Aliquots of the samples are analyzed by neutron-activation analysis for ^{129}I and by chemical separation and alpha spectrometry for plutonium.

MILK

Gamma-Emitting Radionuclides in milk are counted directly using a Ge(Li) detector with a multichannel, pulse-height analyzer.

Tritium in water distilled from milk is counted directly with a liquid scintillation spectrometer.

Iodine-129 is separated from milk with an anion exchange resin, purified, and analyzed by the neutron-activation method.

Iodine-131 is removed from milk with an anion-exchange resin. The iodine is eluted with sodium hypochlorite, precipitated as palladium iodide, and beta-counted with a low-background, gas-flow proportional counter.

Strontium-89,90 is removed from milk with a cation resin, eluted with sodium chloride, precipitated as a carbonate, and transferred to a stainless steel planchet for counting with a low-background, gas-flow proportional counter.

FOODSTUFFS

Gamma-Emitting Radionuclides in foodstuffs are counted directly on a Ge(Li) detector with a multichannel, pulse-height analyzer.

Tritium in water distilled from farm produce is counted directly with a liquid scintillation spectrometer.

Plutonium in foodstuffs is measured as it is in air-filter samples, after it has been dried, ashed in a furnace, and treated with nitric acid.

Uranium in foodstuffs is measured as it is in water samples. However, the samples are dried, ashed in a furnace, and treated with nitric acid before the ether extraction step.

Strontium-90 is measured as it is in air samples, but samples are dried, ashed in a furnace, and treated with nitric acid before exposure to fuming nitric acid.

VEGETATION AND WILDLIFE

Uranium, Plutonium, Strontium, and Gamma-Emitting Radionuclides are measured using the procedures described for foodstuffs.

SOIL

Gamma-Emitting Radionuclides are counted on a Ge(Li) detector with a multichannel, pulse-height analyzer, after the sample is placed into a marinelli beaker.

Plutonium and Strontium-89,90 are measured after the soil sample is dried, mixed thoroughly, leached with nitric acid, and then precipitated as strontium oxalate. The sample is then precipitated as a carbonate, transferred to a planchet, and

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counted with a low-background, gas-flow proportional counter. After the strontium has been removed from the sample, the plutonium is coprecipitated with calcium oxalate, dissolved, and loaded onto an ion-exchange resin column. The plutonium is eluted from the resin column with nitric and hydrofluoric acids, deposited on a stainless steel disk, and counted with an alpha spectrometer.

Uranium analysis is conducted after the sample is dried, ashed in a furnace, and leached with hot nitric acid. Uranium is extracted from the acid leachate as tetrapropyl ammonium uranyl trinitrate and then extracted back into water. A portion of the water extract is fused with sodium and lithium fluoride and analyzed with a fluorometer.

SURFACE MONITORING: NONRADIOLOGICAL SAMPLES

Surface-Water Samples

Water samples collected to monitor water quality of the Columbia River are analyzed according to standard methods. Most onsite analyses make use of the most applicable methods recommended by the American Public Health Association in their publication *Standard Methods for the Examination of Water and Wastewater: Including Bottom Sediments and Sludges* (APHA 1985). Supplemental USGS samples are analyzed according to approved USGS standard methods.

GROUND-WATER MONITORING: RADIOLOGICAL SAMPLES

All ground-water monitoring samples are analyzed according to detailed, written analytical procedures that are briefly described below. Minimum detectable concentrations for the various medium/analysis combinations and other analytical information are shown in Table D.1.

Total Alpha-Emitting Radionuclides are measured after the samples are evaporated and the salts and solids are dissolved in nitric acid and extracted from the acid by the diethyl ether method. Each sample is then evaporated, dried on a counting dish, and measured by the ZnS scintillation counter. The chemical yield is about 83%.

Total Beta-Emitting Radionuclides are measured after each sample has been evaporated onto a 1-in. counting dish. The residue is then counted with a gas-flow proportional counter.

Gamma-Emitting Radionuclides are measured by analyzing 500-mL samples in polyethylene bottles. An NaI or a Ge(Li) detector is used to count the samples. The standards are traceable to the National Bureau of Standards.

Tritium samples are first distilled from a neutralized aliquot to which holdback carriers have been added. After the first fraction of distillate is discarded, 20 mL are collected in a single vial. Aliquots of distillate are counted with a liquid scintillation spectrometer. Duplicate counts are made to reduce the error of the measurements.

GROUND-WATER MONITORING: CHEMICAL SAMPLES

Samples collected to monitor the quality of the ground water are analyzed according to standard methods. The most applicable methods are recommended by the American Public Health Association in these publications: *Standard Methods for the Examination of Water and Wastewater: Including Bottom Sediment and Sludges* (APHA 1985), *ASTM's (American Society for Testing and Materials) Annual Book of ASTM Standards* (Sections 11.01 and 11.02) (ASTM 1987), *Manual on Water,* STP 442A, and *Test Methods for Evaluating Solid Waste,: Physical Chemical Methods, Second Edition* (EPA 1982).

Fluoride is measured by ion chromatograph (see Inorganic Anions) or by an electrode method to attain a lower detection level (20 ppb). A 50-mL aliquot of sample is mixed with ionic strength buffer. The specific ion electrode is placed in the mixture while it is being gently stirred. The meter reading is compared to a previously developed calibration curve (20 to 25,000 ppb) to determine the sample concentration.

Temperature, pH, and Conductivity are determined in the field according to field instrument instructions.

Coliform Count is determined by multiple-tube fermentation.

Metals are measured by either the Inductively Coupled Plasma (ICP) method or the Graphite Furnace Atomic Absorption (GFAA) method. In either

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case, the sample is first acid-digested. In the ICP method, the digest is then nebulized, with the resultant aerosol being transported to the plasma torch where excitation occurs. The atomic emission is then measured by an optical spectroscopic technique. In the GFAA method, the digest is dried, ashed, and atomized in a graphite tube furnace. The constituent concentration is proportional to the absorption of hollow-cathode radiation during atomization.

Inorganic Anions (including nitrate) are determined by ion chromatography. After it is injected into the ion chromatograph, the sample is pumped through three ion exchange columns to convert the anions in the sample to their corresponding acids. The separated anions in their acid form are measured using an electrical-conductivity cell. During the second half of the year, a five-fold dilution was done on all samples for NO_3^- analyses. An increase in the detection limit from 500 to 2500 ppb resulted.

Volatile Organic Chemicals are determined by Gas Chromatography and Mass Spectrometry (GC/MS). Volatile organic chemicals are introduced to the mass spectrometer by the purge-and-trap method, in which the volatile components are converted from an aqueous phase to a vapor phase, trapped on a sorbent column, and then desorbed onto a gas chromatographic column. This column is heated to elute the components, which are then detected by the mass spectrometer.

Certain Organic Constituents are analyzed by direct aqueous injection, which requires no preparatory steps before the samples are injected into the gas chromatograph and detected by the mass spectrometer. Substances identified in samples by GC/MS techniques are verified by comparing the suspect mass spectra to the mass spectrum of a standard of the suspected substance. The computerized mass-spectrometry library search system used is capable of providing a forward comparison using the standard spectra contained in the EPA/National Institute of Health mass spectral data base.

Pesticides, Herbicides, and Polychlorinated Biphenyls are measured by gas chromatography with an appropriate detector. Extractions are performed as necessary. Positive concentrations are verified by reanalysis of the extract using a confirmation gas chomatography column or by GC/MS.

Total Organic Halogens are measured after the sample is passed through a column containing activated carbon. The column is washed to remove trapped inorganic halides, and the carbon is then analyzed to convert the adsorbed organohalides to a titratable species that can be measured by a microcoulometric detector.

Total Organic Carbon is determined by the combustion-infrared method. The sample is sparged with hydrochloric acid to remove inorganic carbon. The homogenized sample is vaporized with an oxidative catalyst, thereby converting the organic carbon to CO_2. The CO_2 is measured by means of a nondispersive infrared analyzer.

A summary of analytical methods used for chemical ground-water monitoring is shown in Table D.2.

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TABLE D.1. Radiological Monitoring Sampling Summary

Medium Sampled	Type of Analysis	Frequency of Analysis	Approximate Sample Size	Count Time	Minimum Detectable Concentration (MDC)	Analysis Aliquot Size	Sampling Location
Air	Gross alpha	Biweekly	850 m^3	50 min	0.001 pCi/m^3	850 m^3	Off Site/ On Site
	Gross beta	Biweekly	850 m^3	40 min	0.003 pCi/m^3	850 m^3	Off Site/ On Site
	HTO[a]	Monthly	10 m^3	150 min	0.3 pCi/mL	5 mL	Off Site/ On Site
	14C[b]	Bimonthly	40 m^3	150 min	1.0 pCi/m^3	10 g of carbon	Off Site/ On Site
	^{85}Kr[c]	Monthly	0.3 m^3	150 min	2.0 pCi/m^3	0.3 m^3	Off Site/ On Site
	^{89}Sr	Quarterly comp.	5,100 m^3 per station	100 min	0.01 pCi/m^3	2,000-10,000 m^3	Off Site/ On Site
	^{90}Sr	Quarterly comp.	5,100 m^3 per station	100 min	0.001 pCi/m^3	2,000-10,000 m^3	Off Site/ On Site
	^{129}I[d]	Quarterly comp.	850 m^3 per station	NA	0.00001 pCi/m^3	850 m^3	Off Site/ On Site
	^{131}I	Biweekly	850 m^3	100 min	0.01 pCi/m^3	850 m^3	Off Site/ On Site
	Gamma scan (^{137}Cs)	Monthly comp.	1,700 m^3 per station	50 min	0.01 pCi/m^3	1,700-7,700 m^3	Off Site/ On Site
	^{238}Pu	Quarterly comp.	5,100 m^3 per station	1,000 min	0.000025 pCi/m^3	2,000-10,000 m^3	Off Site/ On Site
	^{239,240}Pu	Quarterly comp.	5,100 m^3 per station	1,000 min	0.000025 pCi/m^3	2,000-10,000 m^3	Off Site/ On Site
	U (isotopic)[e]	Quarterly comp.	5,100 m^3 per station	NA	0.00005 pCi/m^3	2,000-10,000 m^3	Off Site/ On Site
Ground water	Gross alpha	Quarterly	1 L	100 min	4 pCi/L	100 mL	On Site
	Gross beta	Quarterly	1 L	30 min	16 pCi/L	100 mL	On Site
	Gamma scan	M,Q,SA,A[f]	1 L	100 min	30 pCi/L	500 mL	On Site
	^{3}H	M,Q,SA[f]	1 L	1,200 min	300 pCi/L	4 mL	On Site
	^{90}Sr	Q,SA[f]	1 L	30 min	0.6 pCi/L	500 mL	On Site
	^{129}I	Annually	4 L	NA	1 x 10^{-4} pCi/L	<1–<50 mL	On Site
	^{129}I	Annually	4 L	100 min	15 pCi/L	4,000 mL	On Site
	^{129}I (DWS)	Annually	4 L	1,000 min	1 pCi/L	1,000 mL	On Site
	Plutonium (gross)	Quarterly	1 L	1,000 min	0.10 pCi/L	1,000 mL	On Site
	^{238}Pu	Quarterly	1 L	1,000 min	0.10 pCi/L	1,000 mL	On Site

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TABLE D.1. (contd)

Medium Sampled	Type of Analysis	Frequency of Analysis	Approximate Sample Size	Count Time	Minimum Detectable Concentration (MDC)	Analysis Aliquot Size	Sampling Location
	Uranium (natural)	M,Q[1]	1 L	100 min	0.5 pCi/L	0.5 mL	On Site
	^{99}Tc	Quarterly	1 L	150 min	15 pCi/L	1,000 mL	On Site
	^{63}Ni	Quarterly	1L	150 min	10 pCi/L	1,000 mL	On Site
	^{14}C	P	200 mL	150 min	20 pCi/L	200 mL	On Site
River water	Gross alpha	Weekly	1 L	50 min	4.0 pCi/L	1 L	Off Site
	Gross beta	Weekly	4 L	20 min	4.0 pCi/L	1 L	Off Site
	Gross alpha	Monthly comp.	40 L	50 min	4.0 pCi/L	500 mL	Off Site
	Gross beta	Monthly comp.	40 L	20 min	4.0 pCi/L	500 mL	Off Site
	^{3}H (enriched)	Monthly comp.	40 L	450 min	50 pCi/L	150 mL	Off Site
	^{89}Sr	Monthly comp.	40 L	100 min	0.6 pCi/L	10 L	Off Site
	^{90}Sr	Monthly comp.	40 L	100 min	0.06 pCi/L	4-10 L	Off Site
	Gamma scan (^{137}Cs)	Monthly comp.	40 L	50 min	8.0 pCi/L	4-10 L	Off Site
	Total U	Monthly comp.	40 L	NA	0.5 pCi/L	100-1,000 mL	Off Site
Resin	^{129}I	Quarterly comp.	6,000 L	NA	0.000001 pCi/L	1,500-3,000 L	Off Site/ On Site
Resin and particulate	Gamma scan (^{137}Cs)	Biweekly	1,000 L	1,000 min	0.01 pCi/L	250-500 L	Off Site/ On Site
Resin	Pu	Quarterly comp.	6,000 L	24-72 h	0.0005 pCi/L	1,500-3,000 L	Off Site/ On Site
Particulate	Pu	Quarterly comp.	6,000 L	24-72 h	0.00005 pCi/L	1,500-3,000 L	Off Site/ On Site
Surface water	Gross alpha	Quarterly	10 L	50 min	4.0 pCi/L	500 mL	On Site
	Gross beta	Quarterly	10 L	20 min	4.0 pCi/L	500 mL	On Site
	^{3}H	Quarterly	10 L	150 min	300 pCi/L	5 mL	On Site
	^{89}Sr	Quarterly	10 L	100 min	0.6 pCi/L	4-10 L	On Site
	Gamma scan (^{137}Cs)	Quarterly	10 L	50 min	8.0 pCi/L	4-10 L	On Site
Milk	^{3}H	Monthly	10 L	150 min	300 pCi/L	5 L	Off Site
	^{89}Sr	Quarterly	10 L	100 min	5.0 pCi/L	1 L	Off Site
	^{90}Sr	Quarterly	10 L	100 min	2.0 pCi/L	1 L	Off Site

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TABLE D.1. (contd)

Medium Sampled	Type of Analysis	Frequency of Analysis	Approximate Sample Size	Count Time	Minimum Detectable Concentration (MDC)	Analysis Aliquot Size	Sampling Location
	^{131}I	Biweekly	10 L	100 min	0.5 pCi/L	4 L	Off Site
	^{131}I	Monthly	10 L	100 min	0.5 pCi/L	4 L	Off Site
	^{129}I	Semiannually	4 L	NA	0.00005 pCi/L	3-4 L	Off Site
	Gamma scan (^{137}Cs)	Biweekly	10 L	1,000 min	10 pCi/L	450 mL	Off Site
	Gamma Scan (^{137}Cs)	Monthly	10 L	1,000 min	10 pCi/L	450 mL	Off Site
Fruit	^{3}H	Annually	2 kg	150 min	300 pCi/L	5 mL (water)	Off Site
	^{90}Sr	Annually	2 kg	200 min	0.005 pCi/g	100 g	Off Site
	Gamma scan (^{137}Cs)	Annually	2 kg	1,000 min	0.015 pCi/g	250-500 g	Off Site
Crops and produce	^{90}Sr	Annually	2 kg	200 min	0.005 pCi/g	100 g	Off Site
	Gamma scan (^{137}Cs)	Annually	2 kg	1,000 min	0.015 pCi/g	250-500 g	Off Site
Beef	^{90}Sr	Annually	1 kg	100 min	0.005 pCi/g	100 g	Off Site
	Gamma scan (^{137}Cs)	Annually	1 kg	1,000 min	0.015 pCi/g	250-500 g	Off Site
Poultry	^{90}Sr	Semiannually	1 chicken (2 lb boneless muscle)	100 min	0.005 pCi/g	100 g	Off Site
	Gamma scan (^{137}Cs)	Semiannually	1 chicken (2 lb boneless muscle)	1,000 min	0.015 pCi/g	250-500 g	Off Site
Eggs	^{90}Sr	Semiannually	1 doz.	100 min	0.005 pCi/g	100 g	Off Site
	Gamma scan (^{137}Cs)	Semiannually	1 doz.	1,000 min	0.015 pCi/g	250-500 g	Off Site
Wine	^{3}H	Annually	750 mL	150 min	300 pCi/L	5 mL	Off Site
	Gamma scan (^{137}Cs)	Annually	750 mL	50 min	8.0 pCi/L	750 mL	Off Site
Fish fillet	^{90}Sr	20 per year	1 fish fillet	100 min	0.005 pCi/g	100 g	Off Site/ On Site
	Gamma scan (^{137}Cs)	20 per year	1 fish fillet	1,000 min	0.015 pCi/g	250-500 g	Off Site/ On Site
Fish carcass	^{90}Sr	20 per year	1 fish carcass	100 min	0.005 pCi/g	100 g	Off Site/ On Site

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TABLE D.1. (contd)

Medium Sampled	Type of Analysis	Frequency of Analysis	Approximate Sample Size	Count Time	Minimum Detectable Concentration (MDC)	Analysis Aliquot Size	Sampling Location
	Gamma Scan (^{137}Cs)	8 per year	1 kg (muscle)	1,000 min	0.015 pCi/g	250-500 g	On Site
	Pu	8 per year	1 kg (liver)	1,000 min	0.006 pCi/g	100 g	On Site
Rabbits	^{90}Sr	12 per year	250 g (bone)	100 min	0.005 pCi/g	100 g	On Site
	Gamma scan (^{137}Cs)	12 per year	500 g (muscle)	1,000 min	0.015 pCi/g	250-500 g	On Site
	Pu	12 per year	1 liver	1,000 min	0.0006 pCi/g	100 g	On Site
Soil	^{90}Sr	A,B[f]	1.5 kg	100 min	0.005 pCi/g	100 g	Off Site/ On Site
	Gamma scan (^{137}Cs)	A,B[f]	1.5 kg	100 min	0.02 pCi/g	500 g	Off Site/ On Site
	Total U	A,B[f]	1.5 kg	NA	0.01 pCi/g	10 g	Off Site/ On Site
	Pu	A,B[f]	1.5 kg	1,000 min	0.0006 pCi/g	100 g	Off Site/ On Site
	^{241}Am	A,B[f]	1.5 kg	1,000 min	0.05 pCi/g	10 g	Off Site/ On Site
Native vegetation	Gamma scan (^{137}Cs)	A,B[f]	2 kg	1,000 min	0.03 pCi/g	125 g	Off Site/ On Site
	^{90}Sr	A,B[f]	2 kg	200 min	0.005 pCi/g	100 g	Off Site/ On Site
	Total U	A,B[f]	2 kg	NA	0.01 pCi/g	10 g	Off Site/ On Site
	Pu	A,B[f]	2 kg	1,000 min	0.0006 pCi/g	100 g	Off Site/ On Site
Direct radiation exposure	Thermoluminescent dosimeter	Monthly	5 TLDs per dosimeter	NA	1.0 mR[g]	NA	Off Site/ On Site

(a) Tritiated water vapor.
(b) Four locations.
(c) Twelve locations.
(d) Eight locations.
(e) Four locations.
(f) M = Monthly, Q = Quarterly, SA = Semiannually, A = Annually, B = Biannually, P = Periodic.
(g) Absolute sensitivity in the manner it is used is well below one millirem.
NA Not applicable.

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TABLE D.2. Analytical Methods for Chemicals in Ground Water

Constituent	Collection and Preservation[a,b]	Methods[c]	Detection Limit, ppb[d]
Barium			6
Cadmium			2
Chromium			10
Silver			10
Sodium			200
Nickel			10
Copper	P, HNO_3 to pH<2	EPA 1982 No. 6010	10
Vanadium			5
Aluminum			150
Manganese			5
Potassium			100
Iron			30
Calcium			50
Zinc			5
Beryllium			5
Strontium			20
Antimony			100
Arsenic	P, HNO3 to pH<2	EPA 1982 No. 7060	5
Mercury	G, HNO_3 to pH<2	EPA 1982 No. 7470	0.1
Selenium	P, HNO_3 to pH<2	EPA 1982 No. 7740	5
Lead	P, HNO_3 to pH<2	EPA 1982 No. 7421	3
Nitrate			500, 2500[g]
Sulfate			500
Fluoride	P, None	70-IC[e,f]	500
Chloride			500
Phosphate			1,000
Total Organic Halogen	G, H_2SO_4 to pH<2 No headspace	EPA 1982 No. 9020	20
Total Organic Carbon	G, H_3PO_4 to pH<2	APHA 1985 No. 505	1,000
Total Carbon	G, None	APHA 1985 No. 505	1,000
Ammonium ion	G, H_2SO_4 to pH<2	APHA 1985 No. 417, A-E	50

TABLE D.2. (contd)

Constituent	Collection and Preservation[a,b]	Methods[c]	Detection Limit, ppb[d]
Cyanide	P, NaOH	EPA 1982 No. 9010	10
Fluoride (LDL)[h]	P, None	Specific Ion Electrode	20
Volatile Organic Analysis (see Table D.3 for detailed list)	G, No headspace	EPA 1982 No. 8240	
Gross Alpha	P, HNO_3 to pH<2	EPA 1975 No. 680	4 pCi/L
Gross Beta	P, HNO_3 to pH<2	EPA 1975 No. 680	8 pCi/L
Alkalinity	P, None	APHA 1985 No. 403	---
pH (Lab)	P, None	APHA 1975 No. 423	---
pH	Field measurement		0.01 pH unit[i]
Temperature	Field measurement		0.1°C[i]
Specific Conductance	Field measurement		1 µmho[i]
Hexachlorophene			10
Naphthalene			10
Phenol			10
Kerosene			10
Chlorinated Benzenes			10 ppm
1,2-dichlorobenzene			
1.3-dichlorobenzene			
1,4-dichlorobenzene	G, None	EPA 1982 No. 8270	
hexachlorobenzene			
pentachlorobenzene			
1,2,4,5-tetrachlorobenzene			
1,2,3,4-trichlorobenzene			
1,2,3-trichlorobenzene			

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TABLE D.2. (contd)

Constituent	Collection and Preservation[a,b]	Methods[c]	Detection Limit, ppb[d]
1,3,5-trichlorobenzene			
1,2,3,4-tetrachlorobenzene			
1,2,3,5-tetrachlorobenzene			

(a) P = plastic, G = glass.
(b) All samples cooled to 4°C on collection.
(c) Constituents grouped together are analyzed by the same method.
(d) Detection limit units except where indicated.
(e) In-house analytical method from UST Procedure Manual based on Test Method. The Determination of Inorganic Anions in Water by Ion Chromatography (O'Dell et al. 1984).
(f) IC = ion chromatography.
(g) Detection limit 2500 when five-fold dilution used.
(h) LDL = Low detection level.
(i) Measurement resolution.

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TABLE D.3. Volatile Organic Compounds and Detection Limits

Constituent	Detection Limit
Acetonitrile	<3 ppm
Ethylene Oxide	<3 ppm
Tetrachloromethane (carbontetrachloride)	<5 ppb
Benzene	<5 ppb
Chloroform	<5 ppb
Toluene	<5 ppb
1,1,1-Trichloroethane	<5 ppb
1,1,2-Trichloroethane	<5 ppb
1,1,2-Trichloroethene (Trichloroethylene)	<5 ppb
Perchloroethylene	<5 ppb
Xylene (O, P)	<5 ppb
Xylene (M)	<5 ppb
Acrolein	<10 ppb
Acrylonitrile	<10 ppb
Bis (Chloromethyl) Ether	<10 ppb
Bromo Acetone	<10 ppb
Chloromethylmethylether	<10 ppb
Crotonaldehyde	<10 ppb
1,2-Dibromo-3-Chloropropane	<10 ppb
1,2-Dibromoethane	<10 ppb
Dibromomethane	<10 ppb
1,4-Dichloro-2-Butene	<10 ppb
Dichlorodiflouromethane	<10 ppb
N,N-Diethylhydrazine	<10 ppb
Hydrogen Sulfide	<10 ppb
Iodo Methane	<10 ppb
Methacrylonitrile	<10 ppb
Methanethiol	<10 ppb
Chloromethane	<10 ppb
1,1-Dichloroethane	<10 ppb
1,2-Dichloroethane	<10 ppb
Methyl Bromide	<10 ppb
Carbon Disulfide	<10 ppb
Chlorobenzene	<10 ppb
2-Chloroethylvinylether	<10 ppb
Methylethyl Ketone	<10 ppb
Methyl Methacrylate	<10 ppb
Ethyl Methacrylate	<10 ppb
Pentachloroethane	<10 ppb
1,1,1,2-Tetrachloroethane	<10 ppb
Trichloromethanethiol	<10 ppb
Trichloroflouromethane	<10 ppb
Trichloropropane	<10 ppb
1,2,3-Trichloropropane	<10 ppb

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TABLE D.3. (contd)

Constituent	Detection Limit
Diethylarsine	<10 ppb
Trans-1,2-Dichloroethene	<10 ppb
1,1-Dichloroethene	<10 ppb
Methylene Chloride	<10 ppb
1,2-Dichloropropane	<10 ppb
1,3-Dichloropropenes	<10 ppb
1,1,2,2-Tetrachloroethane	<10 ppb
Bromoform	<10 ppb
Vinyl Chloride	<10 ppb
Hexone	<10 ppb
Dioxane	<500 ppb
Formaldehyde	<500 ppb
Pyridine	<500 ppb

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APPENDIX E

DATA SUMMARIES

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APPENDIX E

DATA SUMMARIES

Measuring any physical quantity (e.g., temperature, distance, time, or radioactivity) has some degree of inherent uncertainty. This uncertainty results from the combination of all possible inaccuracies in the measurement process, including such factors as the reading of the result, the calibration of the measurement device, and numerical rounding errors. In this report, individual radioactivity measurements are accompanied by a plus or minus (±) value, which is the uncertainty term known as a two-sigma counting error. Because measuring a radionuclide requires a process of counting random radioactive emissions from a sample, the two-sigma counting error gives information on what the measurement might be if the same sample were counted again under identical conditions. The two-sigma counting error implies that approximately 95% of the time, a recount of the same sample would give a value somewhere between the reported value minus the two-sigma counting error and the reported value plus the two-sigma counting error. Values in the tables that are less than the two-sigma counting error indicate that the reported result might have come from a sample with no radioactivity. Also note that each radioactive measurement must have the random background radioactivity of the measuring instrument subtracted; therefore, negative results are possible, especially when the sample has very little radioactivity.

Just as individual values are accompanied by two-sigma counting errors, reported means ($\bar{x}$) are accompanied by two standard errors (SE) of the mean. If the data fluctuate randomly, then the SE is a measure of the uncertainty in the estimated mean of the data due to this randomness. If trends or periodic (e.g., seasonal) fluctuations are present, then the SE is primarily a measure of the variability in the trends and fluctuations about the mean of the data, rather than a measure of the uncertainty of the estimated mean due to random fluctuations in the data.

The mean, $\bar{x}$, was computed as:

$$\bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i$$

where n is the number of measurements and x_i is the ith measurement, where i=1, 2, ...,n.

The standard error of the mean was computed as

$$SE = \sqrt{\frac{S^2}{n}}$$

where S^2 is the variance of the n measurements, a measure of variability. S^2 was computed as the sum of the measurement variance S_M^2 and the average counting variance (S_C^2), i.e.,

$$S^2 = S_M^2 + S_c^2$$

If $n \geq 10$, then (S_M^2) was computed as

$$S_M^2 = \frac{1}{n-1} \sum_{i=1}^{n} (x_i - \bar{x})^2$$

If $n < 10$, then $S_M^2 = f^2 R^2$, where f is a factor [from Table A.6 in Snedecor and Cochran (1980)] that depends on the value of n, and R is the range of the n measurements (largest minus smallest measurement).

The average counting variance, S_C^2, was computed as

$$S_c^2 = \frac{1}{m} \sum_{i=1}^{m} s_i^2$$

where m is the number of the n measurements for which a counting variance was reported ($m \leq n$), and s_i^2 is the counting variance for the ith measurement.

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APPENDIX F

DOSE CALCULATIONS

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APPENDIX F

DOSE CALCULATIONS

The radiation dose to the public during 1987 from Hanford operations is assessed in terms of the "dose equivalent" and "effective dose equivalent." These dose quantities are given in units of millirems (mrem) for individuals and in units of person-rems for the collective dose to the total population within an 80-km radius of the Site. These quantities provide a way to express the radiation dose, regardless of the type or source of radiation or the means by which it is delivered. The values given in this report may be compared to standards for radiation protection (Table C.5, Appendix C). This appendix describes how the doses were calculated for this report.

The transport of radionuclides from the environment to the body is simulated by empirical exposure pathway models. These pathways account for inhalation or ingestion of radionuclides present in air, water, and foods. Radionuclides taken into the body may be distributed among different organs and retained for various times. In addition, long-lived radionuclides deposited on the ground become possible sources for long-term external exposure and uptake by agricultural products.

Where possible, the dose values calculated for this report were based on measured radionuclide concentrations in environmental samples. Dietary factors and exposure parameters were applied to convert the environmental concentrations to exposure in terms of radiation dose. Ideally, such calculations would be based on a precise understanding of the amount of radionuclides taken into the body. However, radionuclide release rates from Hanford Site activities are usually too low to be measured in offsite air, drinking water, and food crops. Therefore, in most cases, the dose calculations were based on measurements made at the point of release (stacks and effluent streams). Environmental concentrations were estimated from these effluent measurements by mathematical models and computer simulations. Dietary and exposure parameters were then applied to calculate radionuclide intakes and radiation doses to man (see Figure 2.3). A set of standardized computer programs were used to perform the calculations. These programs contain internally consistent mathematical models that use site-specific dispersion and uptake parameters. These codes have recently been updated and rewritten into a new master code titled GENII[a], which employs the newer dosimetry methodology described in ICRP Reports (1979-1982). The assumptions and input data used in these calculations are described below.

TYPES OF DOSE CALCULATIONS PERFORMED

Radiation dose calculations for radionuclides released into the environment are performed to determine that the health and safety of the public not being compromised and to determine compliance with applicable standards and regulations.

Revised DOE Guidance For Dose Calculations

Beginning in 1985, the DOE required that estimates of radiation exposure to the general public be in terms of the "effective dose equivalent." The effective dose equivalent is a measure of the total risk of potential health effects from radiation exposure. The adoption and use of the effective dose equivalent was previously recommended by the ICRP (1979-1982).

Estimated radiological impacts from DOE operations have previously been reported in terms of the dose equivalent (or simply, dose), which is a measure of the energy (rads) absorbed by tissue, multiplied by a radiation quality factor, and modified by any other necessary factors. Under this system, standards for radiation protection were presented in terms of the critical organ dose limits and were expressed in rem (or mrem).

The new effective dose is the sum of individual 50-year committed organ doses multiplied by weighting factors that represent the proportion of the total health-effect risk that each organ would receive from uniform irradiation of the whole body. The organ committed dose may result from irradiation by either

(a) B. A. Napier, R. A. Peloquin, D. L. Strenge, and J. V. Ramsdell. 1988. Hanford Environmental Dosimetry Upgrade Project. GENII - The Hanford Environmental Radiation Dosimetry Software System.

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internal or external sources, and the two sources are to be summed. The new effective dose is also expressed in rem. The reader should keep in mind that the previously used cumulative dose is a measure of potential radiation risk to individual organs, whereas the new effective dose is a measure of potential radiation risk to the individual as a whole.

In addition to implementing the effective dose requirement for offsite population dose calculations, the DOE has also adopted the revised biokinetic models and metabolic parameters for radionuclides given by the ICRP (1979-1982) for estimating radiation dose.

The calculation of the new effective dose takes into account the long-term internal exposure from radionuclides taken into the body during the current year, but not the potential exposure from future intake of radionuclides remaining in the environment from the current year's release (as was done in the previous cumulative dose calculations). For these reasons, the older cumulative dose and the newer effective dose are calculated differently, and they cannot be compared directly. In this report, the effective dose equivalent is expressed in rem (or millirem), with the corresponding value in sievert (or millisievert) in parentheses.[a]

The following types of radiation doses were estimated:

1. **"Fence-Post" Whole-Body Dose Rate (mrem/h and mrem/yr).** The maximum external radiation dose rate during the year in areas accessible by the general public was determined from measurements obtained at locations of potential public access in proximity to operating facilities.

2. **"Maximally Exposed Individual" Dose (mrem).** The maximally exposed individual is a hypothetical member of the public residing near the Hanford Site who, by virtue of location and living habits, could receive the highest possible radiation dose from radioactive effluents. All potentially significant short- and long-term exposure pathways to this hypothetical individual were considered, including the following:

   - inhalation of airborne radionuclides
   - submersion in airborne radionuclides
   - ingestion of foodstuffs contaminated by radionuclides deposited on vegetation and the ground by both airborne deposition and irrigation water drawn from the Columbia River downstream of the Hanford Site
   - drinking sanitary water originating from the Columbia River at Pasco
   - exposure to ground contaminated by both airborne deposition and irrigation water
   - ingestion of fish taken from the Columbia River
   - recreation along the Columbia River, including boating, swimming, and shoreline activities.

3. **80-km Population Doses (person-rem).** Regulatory limits have not been established for population doses. Nonetheless, evaluation of the collective population dose to all residents within an 80-km radius of Hanford Site operations provides an indication of the overall environmental impact of site operations. The 80-km population dose equivalent represents the summed products of the individual doses for the number of individuals involved for all potential exposure pathways.

   The pathways depicted in Figure 2.4 for the maximally exposed individual were assumed to also be applicable to the offsite population. Consideration was given, however, to the fraction of the offsite population actually affected by each pathway. The river-related exposure pathways for the population are as follows:

   - **Drinking Water.** The cities of Richland and Pasco obtain their municipal water from the Columbia River downstream from the Hanford Site. The city of Kennewick began drawing a portion of its municipal water from the river in late 1980. During 1987, approximately 40% of Kennewick's drinking water was drawn from the Columbia River. The total affected population of these three cities was approximately 70,000.

(a) 1 rem (or 1000 mrem) = 0.01 Sv (or 10 mSv).

- **Irrigated Food.** Columbia River water is withdrawn for irrigation of small vegetable gardens and farms in the Riverview district of Pasco in Franklin County. Enough food is grown in this district to feed an estimated 2000 people.

- **River Recreation**. These activities include swimming (10 h/yr), boating (5 h/yr), and shoreline recreation (17 h/yr). An estimated 125,000 people reside adjacent to the river within 80 km of the Hanford Site and are assumed to be affected by these pathways.

- **Fish Consumption**. Population doses from the consumption of fish obtained locally from the Columbia River were calculated from an estimated total annual catch of 15,000 kg/yr (without reference to a specified human group of consumers).

DATA

The data that are needed to perform dose calculations based on measured effluent releases include information on initial transport through the atmosphere or river, transfer or accumulation in terrestrial and aquatic pathways, and public exposure. By comparison, calculations based on measured concentrations of radionuclides in food only require data describing dietary and recreational activities, exposure times, and dosimetry. These data are discussed in the following sections.

Population Distribution

Geographic distributions of population residing within an 80-km radius of the four Hanford Site operating areas are listed in Tables F.1 through F.4. These distributions are based on 1980 Bureau of Census data (Sommer, Rau, and Robinson 1981).

Atmospheric Dispersion

Radioactive material released to the atmosphere becomes diluted as the wind carries it away from the release point. The degree of dilution and the magnitude of resultant air concentrations are predicted by atmospheric dispersion models that use site-specific measurements of the occurrence frequencies for wind speed, wind direction, and atmospheric stability. The products of the dispersion model are annual average dispersion factors ($\bar{X}/Q'$, in units of Ci/m^3 per Ci/s, or s/m^3) that, when combined with annual average release rates, will predict average radionuclide air concentrations for the year. Annual average dispersion factors for the 100, 200, 300, and 400 Areas during 1987 are given in Tables F.5 through F.8. Population exposure to airborne effluents was determined using values of population-weighted atmospheric dispersion factors for each compass sector and distance.

Terrestrial and Aquatic Pathways

Following their release and initial transport through the environment, radioactive materials may enter terrestrial or aquatic pathways that lead to public exposure. These potential pathways include consumption of fish, drinking water, and locally grown food. For example, radioactive material released to the river is diluted and may be withdrawn downstream for irrigation. Radionuclides deposited on plants and soil during irrigation can be taken into plants through their roots and leaves, and may then be eaten by man or farm animals. The numerous transfer factors required for pathway and dose calculations have been described previously (Strenge and Watson 1973; Houston, Strenge, and Watson 1974; Napier, Kennedy and Soldat 1980).

Important parameters affecting the movement of radionuclides within potential exposure pathways, such as irrigation rates, growing periods, and holdup periods, are listed in Table F.9. Certain parameters are specific to either "maximally exposed" or "average" individuals. Note that for 1987 the food categories in Table F.9 and F.10 were regrouped and combined into fewer categories than in previous years. This reduced the number of calculations required without notably changing the calculated doses.

Public Exposure

Offsite radiation dose impact is related to the extent of public exposure to or intake of radionuclides associated with Hanford Site operations. Tables F.10 through F.12 give the parameters describing the diet, residency, and river recreation assumed for "maximally exposed" and "average" individuals.

DOSE CALCULATION DOCUMENTATION

The quality of the calculated doses was determined in several ways. First, comparisons were made with

doses calculated for previous annual reports, and any differences were investigated. Second, the Hanford Dose Overview Committee has defined standard, documented computer codes and input parameters to be used for radiation dose calculations for the public in the vicinity of the Hanford Site. Third, all computed doses were reviewed by the Hanford Dose Overview Committee. Summaries of dose calculation documentation for this report are given in Tables F.13 through F.17.

TABLE F.1. Distribution of Population in 80-km Radius of the 100-N Area by Population Grid Sector[a]

	Number of People					
Direction	0-16 km	16-32 km	32-48 km	48-64 km	64-80 km	Totals
N	36	953	420	1,492	7,583	10,484
NNE	5	285	561	18,531	1,350	20,732
NE	0	624	1,013	2,691	259	4,587
ENE	0	620	5,884	1,129	429	8,062
E	0	294	625	2,742	605	4,266
ESE	0	306	1,493	596	247	2,642
SE	0	54	2,113	28,922	5,001	36,090
SSE	0	0	35,127	50,292	3,354	88,773
S	0	127	4,592	2,041	176	6,936
SSW	0	258	1,676	12,603	625	15,162
SW	0	547	4,946	16,747	469	22,709
WSW	0	680	1,699	8,297	15,274	25,950
W	18	395	936	5,149	75,686	82,184
WNW	54	573	377	490	1,598	3,092
NW	74	277	425	515	683	1,974
NNW	64	277	438	1,030	4,696	6,505
Totals	251	6,270	62,325	153,267	118,035	340,148

(a) Based on 1980 census data.

TABLE F.2. Distribution of Population in 80-km Radius of the 200 Areas' Hanford Meterological Tower by Population Grid Sector[a]

	Number of People					
Direction	0-16 km	16-32 km	32-48 km	48-64 km	64-80 km	Totals
N	0	174	1,124	772	1,957	4,027
NNE	0	92	656	5,547	14,822	21,117
NE	0	262	5,930	2,963	596	9,751
ENE	0	235	773	2,366	435	3,809
E	0	340	1,329	1,659	588	3,916
ESE	0	283	1,374	230	652	2,539
SE	0	6,757	48,661	50,519	3,474	109,411
SSE	0	1,997	13,161	2,717	5,218	23,093
S	0	1,532	1,489	195	1,799	5,015
SSW	0	905	5,283	652	129	6,969
SW	0	1,190	19,786	2,182	459	23,617
WSW	5	1,840	5,063	15,088	4,573	26,569
W	32	648	949	6,874	78,635	87,138
WNW	73	444	802	833	2,833	4,985
NW	0	555	398	493	1,454	2,900
NNW	0	246	456	864	4,521	6,087
Totals	110	17,500	107,234	93,954	122,145	340,943

(a) Based on 1980 census data.

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TABLE F.3. Distribution of Population in 80-km Radius of the 300 Area by Population Grid Sector[a]

Direction	Number of People 0-16 km	16-32 km	32-48 km	48-64 km	64-80 km	Totals
N	289	241	989	5,655	5,317	12,491
NNE	307	475	841	1,950	2,269	5,842
NE	18	966	2,583	562	205	4,334
ENE	307	465	349	470	238	1,829
E	291	114	137	174	687	1,403
ESE	338	288	863	594	17,891	19,974
SE	2,549	26,150	2,922	877	1,235	33,733
SSE	7,161	30,357	1,114	1,117	1,113	40,862
S	15,561	6,651	96	17,223	5,127	44,658
SSW	11,124	4,034	99	1,209	2,038	18,504
SW	10,066	3,931	706	182	181	15,066
WSW	4,429	1,810	5,531	8,988	621	21,379
W	294	984	2,226	16,878	16,293	36,675
WNW	0	0	692	1,543	1,679	3,914
NW	0	0	74	923	785	1,782
NNW	0	0	8	875	1,212	2,095
Totals	52,734	76,466	19,230	59,220	56,891	264,541

(a) Based on 1980 census data.

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TABLE F.4. Distribution of Population in 80-km Radius of the 400 Area by Population Grid Sector[a]

Direction	Number of People 0-16 km	16-32 km	32-48 km	48-64 km	64-80 km	Totals
N	0	78	859	811	16,267	18,015
NNE	20	343	5,728	2,945	1,021	10,057
NE	114	377	760	1,033	217	2,501
ENE	211	1,041	2,644	492	451	4,839
E	229	600	183	169	183	1,364
ESE	229	442	544	292	1,060	2,567
SE	344	25,267	13,654	2,105	952	42,322
SSE	10,829	40,933	5,688	719	2,364	60,533
S	11,760	9,385	1,525	5,611	15,691	43,972
SSW	1,446	4,550	583	185	1,927	8,691
SW	179	1,538	5,234	535	239	7,725
WSW	0	1,206	7,748	14,956	481	24,391
W	0	190	3,339	6,089	17,171	26,789
WNW	0	0	932	1,221	3,176	5,329
NW	0	0	295	903	705	1,903
NNW	0	0	264	1,302	1,182	2,748
Totals	25,361	85,950	49,980	39,368	63,087	263,746

(a) Based on 1980 census data.

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TABLE F.5. Annual Average Atmospheric Dispersion ($\bar{X}/Q'$) Around the 100-N Area During 1987 for an 89-Meter Release Height[a]

Direction	$\bar{X}/Q'$ (s/m^3) 0.8 km	2.4 km	4.0 km	5.6 km	7.2 km	12 km	24 km	40 km	56 k	72 km
N	6.08×10^{-8}	5.31×10^{-8}	4.44×10^{-8}	3.54×10^{-8}	2.87×10^{-8}	1.75×10^{-8}	8.26×10^{-9}	4.64×10^{-8}	3.15×10^{-9}	2.36×10^{-9}
NNE	4.09×10^{-8}	4.08×10^{-8}	3.21×10^{-8}	2.48×10^{-8}	1.98×10^{-8}	1.18×10^{-8}	5.53×10^{-9}	3.09×10^{-9}	2.10×10^{-9}	1.57×10^{-9}
NE	7.64×10^{-8}	4.62×10^{-8}	3.63×10^{-8}	2.86×10^{-8}	2.32×10^{-8}	1.43×10^{-8}	7.02×10^{-9}	4.05×10^{-9}	2.81×10^{-9}	2.12×10^{-9}
ENE	1.08×10^{-7}	6.81×10^{-8}	5.67×10^{-8}	4.61×10^{-8}	3.81×10^{-8}	2.43×10^{-8}	1.22×10^{-8}	7.14×10^{-9}	4.98×10^{-9}	3.76×10^{-9}
E	1.52×10^{-7}	1.15×10^{-7}	9.72×10^{-8}	7.89×10^{-8}	6.51×10^{-8}	4.14×10^{-8}	2.09×10^{-8}	1.23×10^{-8}	8.57×10^{-9}	6.53×10^{-9}
ESE	1.27×10^{-7}	7.08×10^{-8}	5.98×10^{-8}	4.91×10^{-8}	4.08×10^{-8}	2.64×10^{-8}	1.35×10^{-8}	8.01×10^{-9}	5.63×10^{-9}	4.30×10^{-9}
SE	1.27×10^{-7}	6.13×10^{-8}	4.75×10^{-8}	3.79×10^{-8}	3.11×10^{-8}	1.99×10^{-8}	1.02×10^{-8}	6.05×10^{-9}	4.25×10^{-9}	3.24×10^{-9}
SSE	1.20×10^{-7}	4.90×10^{-8}	3.67×10^{-8}	2.67×10^{-8}	2.33×10^{-8}	1.45×10^{-8}	7.22×10^{-9}	4.23×10^{-9}	2.95×10^{-9}	2.25×10^{-9}
S	1.56×10^{-7}	6.57×10^{-8}	5.08×10^{-8}	4.05×10^{-8}	3.33×10^{-8}	2.11×10^{-8}	1.06×10^{-8}	6.18×10^{-9}	4.29×10^{-9}	3.25×10^{-9}
SSW	9.84×10^{-8}	3.88×10^{-8}	2.87×10^{-8}	2.22×10^{-8}	1.80×10^{-8}	1.11×10^{-8}	5.52×10^{-9}	3.22×10^{-8}	2.24×10^{-9}	1.70×10^{-9}
SW	7.20×10^{-8}	3.52×10^{-8}	2.68×10^{-8}	2.13×10^{-8}	1.76×10^{-8}	1.13×10^{-8}	5.88×10^{-9}	3.51×10^{-9}	2.48×10^{-9}	1.90×10^{-9}
WSW	5.18×10^{-8}	4.20×10^{-8}	3.70×10^{-8}	3.10×10^{-8}	2.63×10^{-8}	1.78×10^{-8}	9.31×10^{-9}	5.61×10^{-9}	3.96×10^{-9}	3.04×10^{-9}
W	1.03×10^{-7}	8.33×10^{-8}	7.26×10^{-8}	6.02×10^{-8}	5.05×10^{-8}	3.31×10^{-8}	1.71×10^{-8}	1.02×10^{-8}	7.12×10^{-9}	5.43×10^{-9}
WNW	8.62×10^{-8}	6.62×10^{-8}	5.62×10^{-8}	4.57×10^{-8}	3.78×10^{-8}	2.40×10^{-8}	1.20×10^{-9}	6.95×10^{-9}	4.81×10^{-9}	3.64×10^{-9}
NW	8.09×10^{-8}	7.35×10^{-8}	5.95×10^{-8}	4.69×10^{-8}	3.80×10^{-8}	2.34×10^{-8}	1.13×10^{-8}	6.37×10^{-9}	4.34×10^{-9}	3.25×10^{-9}
NNW	5.00×10^{-8}	5.54×10^{-8}	4.48×10^{-8}	3.49×10^{-9}	2.80×10^{-8}	1.70×10^{-8}	8.03×10^{-9}	4.52×10^{-9}	3.07×10^{-9}	2.30×10^{-9}

(a) Calculated from meteorological data collected at the 100-N Area and the Hanford Meteorology Tower.

TABLE F.6. Annual Average Atmospheric Dispersion ($\bar{X}/Q'$) Around the 200 Areas During 1987 for an 89-Meter Release Height[a]

Direction	$\bar{X}/Q'$ (s/m^3) 0.8 km	2.4 km	4.0 km	5.6 km	7.2 km	12 km	24 km	40 km	56 km	72 km
N	5.91×10^{-8}	4.25×10^{-8}	3.61×10^{-8}	2.95×10^{-8}	2.45×10^{-8}	1.58×10^{-8}	8.21×10^{-9}	4.95×10^{-9}	3.51×10^{-9}	2.70×10^{-9}
NNE	6.14×10^{-8}	3.20×10^{-8}	2.79×10^{-8}	2.33×10^{-8}	1.98×10^{-8}	1.30×10^{-8}	6.75×10^{-9}	4.02×10^{-9}	2.82×10^{-9}	2.15×10^{-9}
NE	5.94×10^{-8}	3.35×10^{-8}	3.04×10^{-8}	2.62×10^{-8}	2.25×10^{-8}	1.54×10^{-8}	8.35×10^{-9}	5.07×10^{-9}	3.59×10^{-9}	2.76×10^{-9}
ENE	3.90×10^{-8}	3.82×10^{-8}	3.64×10^{-8}	3.14×10^{-8}	2.70×10^{-8}	1.85×10^{-8}	1.01×10^{-8}	6.24×10^{-9}	4.48×10^{-9}	3.47×10^{-9}
E	6.85×10^{-8}	8.91×10^{-8}	6.42×10^{-8}	7.19×10^{-8}	6.12×10^{-8}	4.10×10^{-8}	2.16×10^{-8}	1.29×10^{-8}	9.08×10^{-9}	6.95×10^{-9}
ESE	9.27×10^{-8}	1.00×10^{-7}	8.95×10^{-8}	7.42×10^{-8}	6.21×10^{-8}	4.03×10^{-8}	2.05×10^{-8}	1.20×10^{-8}	8.38×10^{-9}	6.36×10^{-9}
SE	1.33×10^{-7}	1.10×10^{-7}	9.10×10^{-8}	7.25×10^{-8}	5.91×10^{-8}	3.65×10^{-8}	1.76×10^{-8}	9.92×10^{-9}	6.74×10^{-9}	5.03×10^{-9}
SSE	1.71×10^{-7}	9.37×10^{-8}	6.74×10^{-8}	5.06×10^{-8}	3.98×10^{-8}	2.33×10^{-8}	1.08×10^{-8}	5.99×10^{-9}	4.08×10^{-9}	3.03×10^{-9}
S	3.05×10^{-7}	1.31×10^{-7}	6.94×10^{-8}	6.53×10^{-8}	5.03×10^{-8}	2.84×10^{-8}	1.25×10^{-8}	6.73×10^{-9}	4.48×10^{-9}	3.30×10^{-9}
SSW	1.72×10^{-7}	6.61×10^{-8}	4.48×10^{-8}	3.26×10^{-8}	2.50×10^{-8}	1.40×10^{-8}	6.12×10^{-9}	3.29×10^{-9}	2.19×10^{-9}	1.61×10^{-9}
SW	1.55×10^{-7}	5.37×10^{-8}	3.60×10^{-8}	2.61×10^{-8}	1.99×10^{-8}	1.10×10^{-8}	4.75×10^{-9}	2.54×10^{-9}	1.68×10^{-9}	1.24×10^{-9}
WSW	1.27×10^{-7}	4.53×10^{-8}	3.02×10^{-8}	2.19×10^{-8}	1.68×10^{-8}	9.37×10^{-9}	4.11×10^{-9}	2.23×10^{-9}	1.50×10^{-9}	1.11×10^{-9}
W	1.38×10^{-7}	6.56×10^{-8}	4.89×10^{-8}	3.72×10^{-8}	2.93×10^{-8}	1.71×10^{-8}	7.71×10^{-9}	4.23×10^{-9}	2.84×10^{-9}	2.10×10^{-9}
WNW	7.94×10^{-8}	5.03×10^{-8}	3.95×10^{-8}	3.05×10^{-8}	2.43×10^{-8}	1.44×10^{-8}	6.66×10^{-9}	3.69×10^{-9}	2.49×10^{-9}	1.85×10^{-9}
NW	6.89×10^{-8}	4.48×10^{-8}	3.64×10^{-8}	2.89×10^{-8}	2.34×10^{-8}	1.44×10^{-8}	6.96×10^{-9}	4.01×10^{-9}	2.77×10^{-9}	2.10×10^{-9}
NNW	5.71×10^{-8}	3.33×10^{-8}	2.72×10^{-8}	2.20×10^{-8}	1.82×10^{-8}	1.16×10^{-8}	5.89×10^{-9}	3.45×10^{-9}	2.41×10^{-9}	1.83×10^{-9}

(a) Calculated from meteorological data collected at the Hanford Meteorology Tower.

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TABLE F.7. Annual Average Atmospheric Dispersion ($\bar{X}/Q'$) Around the 300 Area During 1987 for a 10-Meter Release Height[a]

Direction	$\bar{X}/Q'$ (s/m^3) 0.8 km	2.4 km	4.0 km	5.6 km	7.2 km	12 km	24 km	40 km	56 km	72 km
N	6.04×10^{-6}	1.28×10^{-6}	6.11×10^{-7}	3.78×10^{-7}	2.65×10^{-7}	1.31×10^{-7}	5.08×10^{-8}	2.56×10^{-8}	1.64×10^{-8}	1.18×10^{-8}
NNE	3.35×10^{-6}	6.79×10^{-7}	3.21×10^{-7}	1.98×10^{-7}	1.38×10^{-7}	6.75×10^{-8}	2.60×10^{-8}	1.31×10^{-8}	8.33×10^{-9}	5.97×10^{-9}
NE	2.93×10^{-6}	6.07×10^{-7}	2.89×10^{-7}	1.78×10^{-7}	1.25×10^{-7}	6.13×10^{-8}	2.38×10^{-8}	1.20×10^{-8}	7.67×10^{-9}	5.51×10^{-9}
ENE	2.43×10^{-6}	4.84×10^{-7}	2.28×10^{-7}	1.40×10^{-7}	9.82×10^{-8}	4.79×10^{-8}	1.85×10^{-8}	9.26×10^{-9}	5.91×10^{-9}	4.23×10^{-9}
E	3.05×10^{-6}	6.32×10^{-7}	3.00×10^{-7}	1.86×10^{-7}	1.30×10^{-7}	6.37×10^{-8}	2.47×10^{-8}	1.24×10^{-8}	7.95×10^{-9}	5.71×10^{-9}
ESE	2.52×10^{-6}	5.34×10^{-7}	2.55×10^{-7}	1.58×10^{-7}	1.11×10^{-7}	5.44×10^{-8}	2.11×10^{-8}	1.07×10^{-8}	6.83×10^{-9}	4.90×10^{-9}
SE	3.71×10^{-6}	7.88×10^{-7}	3.78×10^{-7}	2.33×10^{-7}	1.63×10^{-7}	8.02×10^{-8}	3.11×10^{-8}	1.57×10^{-8}	1.00×10^{-8}	7.21×10^{-8}
SSE	5.00×10^{-6}	1.03×10^{-6}	4.91×10^{-7}	3.03×10^{-7}	2.12×10^{-7}	1.03×10^{-7}	3.99×10^{-8}	2.00×10^{-8}	1.28×10^{-8}	9.17×10^{-9}
S	5.34×10^{-6}	1.09×10^{-6}	5.17×10^{-7}	3.19×10^{-7}	2.23×10^{-7}	1.09×10^{-7}	4.18×10^{-8}	2.10×10^{-8}	1.34×10^{-8}	9.59×10^{-9}
SSW	1.56×10^{-6}	2.97×10^{-7}	1.38×10^{-7}	8.46×10^{-8}	5.88×10^{-8}	2.64×10^{-8}	1.08×10^{-8}	5.39×10^{-9}	3.42×10^{-9}	2.45×10^{-9}
SW	8.95×10^{-7}	1.66×10^{-7}	7.70×10^{-8}	4.70×10^{-8}	3.26×10^{-8}	1.57×10^{-8}	5.98×10^{-9}	2.98×10^{-9}	1.89×10^{-9}	1.36×10^{-8}
WSW	9.57×10^{-7}	1.66×10^{-7}	7.58×10^{-8}	4.58×10^{-8}	3.16×10^{-8}	1.51×10^{-8}	5.65×10^{-9}	2.79×10^{-9}	1.77×10^{-9}	1.26×10^{-9}
W	1.80×10^{-6}	3.33×10^{-7}	1.55×10^{-7}	9.47×10^{-8}	6.58×10^{-8}	3.18×10^{-8}	1.22×10^{-8}	6.07×10^{-9}	3.87×10^{-9}	2.77×10^{-8}
WNW	3.21×10^{-6}	6.56×10^{-7}	3.11×10^{-7}	1.92×10^{-7}	1.34×10^{-7}	6.55×10^{-8}	2.53×10^{-8}	1.27×10^{-8}	8.12×10^{-8}	5.82×10^{-9}
NW	4.89×10^{-6}	1.04×10^{-6}	4.96×10^{-7}	3.07×10^{-7}	2.15×10^{-7}	1.06×10^{-7}	4.13×10^{-8}	2.09×10^{-8}	1.34×10^{-8}	9.62×10^{-9}
NNW	4.42×10^{-6}	9.25×10^{-7}	4.40×10^{-7}	2.72×10^{-7}	1.91×10^{-7}	9.35×10^{-8}	3.63×10^{-8}	1.83×10^{-8}	1.17×10^{-8}	8.38×10^{-8}

(a) Calculated from meteorological data collected at the 300 Area and the Hanford Meteorology Tower.

TABLE F.8. Annual Average Atmospheric Dispersion ($\bar{X}/Q'$) Around the 400 Area During 1987 for a 10-Meter Release Height[a]

Direction	$\bar{X}/Q'$ (s/m^3) 0.8 km	2.4 km	4.0 km	5.6 km	7.2 km	12 km	24 km	40 km	56 km	72 km
N	5.47×10^{-6}	1.15×10^{-6}	5.46×10^{-7}	3.38×10^{-7}	2.37×10^{-7}	1.17×10^{-7}	4.53×10^{-8}	2.29×10^{-8}	1.46×10^{-8}	1.05×10^{-8}
NNE	3.64×10^{-6}	7.25×10^{-7}	3.42×10^{-7}	2.10×10^{-7}	1.47×10^{-7}	7.18×10^{-8}	2.77×10^{-8}	1.39×10^{-8}	8.86×10^{-9}	6.35×10^{-9}
NE	2.80×10^{-6}	5.78×10^{-7}	2.75×10^{-7}	1.70×10^{-7}	1.19×10^{-7}	5.83×10^{-8}	2.26×10^{-8}	1.14×10^{-8}	7.27×10^{-9}	5.22×10^{-9}
ENE	1.97×10^{-6}	3.91×10^{-7}	1.84×10^{-7}	1.13×10^{-7}	7.86×10^{-8}	3.81×10^{-8}	1.46×10^{-8}	7.26×10^{-9}	4.61×10^{-8}	3.30×10^{-9}
E	2.94×10^{-6}	6.05×10^{-7}	2.87×10^{-7}	1.77×10^{-7}	1.24×10^{-7}	6.05×10^{-8}	2.33×10^{-8}	1.17×10^{-8}	7.47×10^{-9}	5.35×10^{-9}
ESE	3.20×10^{-6}	6.47×10^{-7}	3.06×10^{-7}	1.88×10^{-7}	1.32×10^{-7}	8.42×10^{-8}	2.47×10^{-8}	1.24×10^{-8}	7.90×10^{-9}	5.66×10^{-9}
SE	3.98×10^{-6}	8.27×10^{-7}	3.93×10^{-7}	2.42×10^{-7}	1.70×10^{-7}	8.30×10^{-8}	3.21×10^{-8}	1.61×10^{-8}	1.03×10^{-8}	7.37×10^{-9}
SSE	2.73×10^{-6}	5.89×10^{-7}	2.82×10^{-7}	1.75×10^{-7}	1.23×10^{-7}	8.06×10^{-8}	2.36×10^{-8}	1.20×10^{-8}	7.68×10^{-9}	5.52×10^{-9}
S	3.56×10^{-6}	7.27×10^{-7}	3.45×10^{-7}	2.13×10^{-7}	1.49×10^{-7}	7.31×10^{-8}	2.83×10^{-8}	1.43×10^{-8}	9.15×10^{-9}	6.57×10^{-9}
SSW	2.54×10^{-6}	5.18×10^{-7}	2.46×10^{-7}	1.51×10^{-7}	1.08×10^{-7}	5.13×10^{-8}	2.00×10^{-8}	1.01×10^{-8}	6.44×10^{-9}	4.62×10^{-9}
SW	1.68×10^{-6}	3.22×10^{-7}	1.50×10^{-7}	9.18×10^{-8}	6.36×10^{-8}	3.08×10^{-8}	1.18×10^{-8}	5.78×10^{-9}	3.65×10^{-9}	2.61×10^{-9}
WSW	1.56×10^{-6}	3.04×10^{-7}	1.42×10^{-7}	8.73×10^{-8}	6.08×10^{-8}	2.95×10^{-8}	1.13×10^{-8}	5.64×10^{-9}	3.59×10^{-9}	2.57×10^{-9}
W	1.97×10^{-6}	3.72×10^{-7}	1.73×10^{-7}	1.06×10^{-7}	7.35×10^{-8}	3.54×10^{-8}	1.35×10^{-8}	8.71×10^{-9}	4.26×10^{-9}	3.05×10^{-9}
WNW	1.33×10^{-6}	2.44×10^{-7}	1.13×10^{-7}	6.63×10^{-8}	4.72×10^{-8}	2.26×10^{-8}	8.48×10^{-9}	4.18×10^{-9}	2.64×10^{-9}	1.88×10^{-9}
NW	2.57×10^{-6}	5.17×10^{-7}	2.44×10^{-7}	1.50×10^{-7}	1.05×10^{-7}	5.10×10^{-8}	1.96×10^{-8}	9.83×10^{-9}	6.27×10^{-9}	4.49×10^{-9}
NNW	3.58×10^{-6}	7.34×10^{-7}	3.49×10^{-7}	2.15×10^{-7}	1.51×10^{-7}	7.38×10^{-8}	2.66×10^{-8}	1.44×10^{-8}	9.20×10^{-9}	6.60×10^{-9}

(a) Calculated from meteorological data collected at the 400 Area and the Hanford Meteorology Tower.

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TABLE F.9. Food Pathway Parameters Used in 1987 Dose Calculations

	Holdup, days (except as noted)[a]		Growing Period, days	Yield, kg/m²	Irrigation Rate, L/m²/month
	Maximally Exposed Individual	Average Individual			
Leafy vegetables	1	14	90	1.5	150
Other vegetables	5	14	90	4	170
Fruit	5	14	90	2	150
Cereal	180	180	90	0.8	0
Eggs	1	18	90	0.8	0
Milk	1	4			
Hay			45	2	200
Pasture			30	1.5	200
Red Meat	15	34			
Hay			45	2	200
Grain			90	0.8	0
Poultry	1	34	90	0.8	0
Fish	24 h	24 h	---	---	---
Drinking water	24 h	24 h	---	---	---

(a) Holdup is the time between harvest and consumption.

TABLE F.10. Dietary Parameters Used in 1987 Dose Calculations

	Consumption, kg/yr	
	Maximally Exposed Individual	Average Individual
Leafy vegetables	30	15
Other vegetables	220	140
Fruit	330	64
Grain	80	72
Eggs	30	20
Milk[a]	270	230
Red Meat	80	70
Poultry	18	8.5
Fish	40	---[b]
Drinking water[a,c]	730	440

(a) Units L/yr.
(b) Average individual consumption not identified; radiation doses were calculated based on estimated total annual catch of 15,000 kg.
(c) 330 L/yr for infant.

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TABLE F.11. Residency Parameters Used in the 1987 Dose Calculations

Parameter	Exposure, h/yr: Maximally Exposed Individual	Exposure, h/yr: Average Individual
Ground contamination	4,383	2,920
Air submersion	8,766	8,766
Inhalation[a]	8,766	8,766

(a) Inhalation rates: Adult 270 cm^3/s, infant 44 cm^3/s.

TABLE F.12. Recreational Parameters Used in the 1987 Dose Calculations

Parameter	Exposure, h/yr[a]: Maximally Exposed Individual	Exposure, h/yr[a]: Average Individual
Shoreline	500	17
Boating	100	5
Swimming	100	10

(a) Assumed river water travel times from 100-N to the point of aquatic recreation were 8 h for the maximally exposed individual and 13 h for the average individual. Correspondingly lesser times were used for other locations.

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TABLE F.13. Documentation of 100-N Area Airborne Release Dose Calculation for 1987

Facility name:	100-N Area
Releases:	See Table G.1
Meteorological conditions:	1987 annual average, calculated from data collected at the 100-N Area and the Hanford Meteorology Station from January 1987 through December 1987, using the computer code HANCHI; (see Table F.5)
$\bar{X}$ /Q':	Maximally exposed individual, 3.5 x 10^{-9} s/m^3 at 53 km SSE; 80-km population, 1.5 x 10^{-3} person-s/m^3.
Release height:	89-m effective stack height
Population distribution:	340,000 (see Table F.1)
Computer code:	GENII, Version 1.194, 3-8-88
Doses calculated: annual	Chronic, 1-year exposure, 50-year committed internal dose, and effective (whole-body) dose equivalent to individual and population
Pathways considered:	External exposure to plume and ground deposits Inhalation Ingestion of locally produced foods
Files Addressed:	Radionuclide Library, Rev. 12-2-87 Food Transfer Library, Rev. 2-24-88 External Dose Factor Library, Rev. 2-8-88 Internal Dose Factor Library, Rev. 2-28-88

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TABLE F.14. Documentation of 100-N Area Liquid Release Dose Calculation for 1987

Facility name:	100-N Area
Releases:	See Table G.5
Mean river flow:	101,000 cfs
Shore-width factor:	0.2
Population distribution:	70,000 for drinking water pathway 125,000 for aquatic recreation 2,000 for consumption of irrigated foodstuffs 15,000 kg/yr total harvest of Columbia River fish
Computer code:	GENII, Version 1.194, 3-8-88
Doses calculated:	External exposure to irrigated soil, to river water and to shoreline sediments Ingestion of aquatic foods, irrigated farm products, and drinking water
Files addressed:	Radionuclide Library, Rev. 12-2-87 Food Transfer Library, Rev. 2-24-88 External Dose Factor Library, Rev. 2-8-88 Internal Dose Factor Library, Rev. 2-28-88 Bioaccumulation Factor Library, Rev. 4-4-86

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TABLE F.15. Documentation of 200 Areas Airborne Release Dose Calculation for 1987

Facility name:	200 Areas
Releases:	See Table G.1
Meteorological conditions:	1987 annual average, calculated from data collected at the Hanford Meteorology Station from January 1987 through December 1987, using the computer code HANCHI; (see Table F.6)
$\bar{X}/Q'$:	Maximally exposed individual, 9.2 x 10^{-9} s/m^3 at 43 km SE; 80-km population, 1.8 x 10^{-3} person-s/m^3
Release height:	89-m effective stack height
Population distribution:	341,000 (see Table F.2)
Computer code:	GENII, Version 1.194, 3-8-88
Doses calculated:	Chronic, 1-year exposure, 50-year committed internal dose, and annual effective (whole-body) dose equivalent to individual and population
Pathways considered:	External exposure to plume and ground deposits Inhalation Ingestion of locally produced foods
Files Addressed:	Radionuclide Library, Rev. 12-2-87 Food Transfer Library, Rev. 2-24-88 External Dose Factor Library, Rev. 2-8-88 Internal Dose Factor Library, Rev. 2-28-88

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TABLE F.16. Documentation of 300 Area Airborne Release Dose Calculation for 1987

Facility name:	300 Area
Releases:	See Table G.1
Meteorological conditions:	1987 annual average, calculated from data collected at the 300 Area and the Hanford Meteorology Station from January 1987 through December 1987, using the computer code HANCHI; (see Table F.7)
$\bar{X}/Q'$:	Maximally exposed individual, 7.5×10^{-8} m^3/s at 13 km SSE; 80-km population, 7.0×10^{-3} person-s/m^3.
Release height:	10 m
Population distribution:	265,000 (see Table F.3)
Computer code:	GENII, Version 1.194, 3-8-88.
Doses calculated:	Chronic, 1-year exposure, 50-year committed internal dose, and annual effective (whole-body) dose equivalent to individual and population
Pathways considered:	External exposure to plume and ground deposits Inhalation Ingestion of locally produced foods
Files Addressed:	Radionuclide Library, Rev. 12-2-87 Food Transfer Library, Rev. 2-24-88 External Dose Factor Library, Rev. 2-8-88 Internal Dose Factor Library, Rev. 2-28-88

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TABLE F.17. Documentation of 400 Area Airborne Release Dose Calculation for 1987

Facility name:	400 Area
Releases:	See Table G.1
Meteorological conditions:	1987 annual average, calculated from data collected at the 400 Area and the Hanford Meteorology Station from January 1987 through December 1987, using the computer code HANCHI, (see Table F.8)
$\bar{X}/Q'$:	Maximally exposed individual, 2.1×10^{-8} s/m^3 at 22 km SSE; 80-km population, 4.2×10^{-3} person-s/m^3.
Release height:	10 m
Population distribution:	264,000 (see Table F.4)
Computer code:	GENII, Version 1.194, 3-8-88
Doses calculated:	Chronic, 1-year exposure, 50-year committed internal dose, and annual effective (whole-body) dose equivalent to individual and population
Pathways considered:	External exposure to plume and ground deposits Inhalation Ingestion of locally produced foods
Files Addressed:	Radionuclide Library, Rev. 12-2-87 Food Transfer Library, Rev. 2-24-88 External Dose Factor Library, Rev. 2-8-88 Internal Dose Factor Library, Rev. 2-28-88

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APPENDIX G

EFFLUENTS, WASTE DISPOSAL, AND UNUSUAL OCCURRENCES

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APPENDIX G

EFFLUENTS, WASTE DISPOSAL, AND UNUSUAL OCCURRENCES

The operating contractors at Hanford have the responsibility to control, monitor, sample, and report effluents released into the environment from their facilities. This section briefly summarizes the planned and unplanned releases of effluents that occurred at Hanford during 1987 as reported by the contractors.

EFFLUENTS AND WASTE DISPOSAL

Radioactive and nonradioactive materials were released to the environment during operations at Hanford in 1987. These releases consisted of airborne effluents (gases or particles), liquid effluents, and solid wastes. Both anticipated and unanticipated releases occurred. The formal reporting of effluent release data was the responsibility of the operating contractors. Radioactive discharges to the environment were reported to DOE. Nonradioactive discharges to the Columbia River were reported to EPA through monthly NPDES Discharge Monitoring Reports.

Airborne Releases

Radioactive and nonradioactive effluents discharged to the atmosphere during 1987 are summarized in Tables G.1 and G.2. These tables are subdivided according to the major operating areas and include all releases reported by the contractors. Radioactive materials discharged to the atmosphere consisted mainly of fission and activation products, uranium, and some transuranics normally associated with Hanford operations. Nonradioactive airborne releases consisted primarily of emissions from fossil-fueled steam plants, organic liquids evaporated from scientific laboratories, and nitrogen oxides released from the fuel-fabrication plant, the UO_3 Plant, and the PUREX Plant.

Liquid Releases

Liquid wastes generated at Hanford were managed in several ways. They were stored, converted to solids, discharged to the ground through cribs, ditches, ponds, or septic systems, or discharged directly into the Columbia River. Radioactive and nonradioactive effluents (except sanitary wastes) discharged to ground disposal facilities during 1987 are summarized in Tables G.3 and G.4.

Radioactive liquids discharged into the Columbia River from operating facilities during 1987 are listed in Table G.5. The reported discharges are from liquid effluent systems in the 100 Areas and include seepage into the river from the 1301-N/1325-N Liquid Waste Disposal Facilities. The ^{3}H and ^{129}I that may have entered the Columbia River through springs from the unconfined aquifer are not included in the releases listed in Table G.5. Nonradioactive liquids released to the Columbia River were monitored according to the individual requirements of each NPDES-permitted discharge point.

Solid-Waste Burial

Solid radioactive wastes were buried in trenches or special retrievable storage facilities within the 200 Areas. Radioactive materials in solid wastes included fission and activation products, uranium, and transuranics. Solid wastes containing ^{238}U or transuranic radionuclides were packaged and buried separately from other wastes for planned retrieval at a future date. Table G.6 lists the quantities of radionuclides buried during 1987.

Nonradioactive solid wastes were buried in sanitary landfills near the 200 Areas. The quantities of nonradioactive solid wastes buried during 1987 are also included in Table G.6.

ENVIRONMENTALLY RELATED UNUSUAL OCCURRENCES

Unusual occurrences were reported to DOE during 1987 by onsite contractors. Several of these occurrences involved the inadvertent release of radioactive or nonradioactive pollutants to the environment. Generally, the pollutants were dispersed naturally, stabilized in existing waste disposal sites, or controlled and cleaned up with no permanent environmental impact noted. In some cases, particularly where the contaminants may have reached the

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ground water, the environmental impact is under continuing observation and evaluation. Summaries, including event descriptions and corrective actions, are available for review in the DOE-RL's Public Reading Room at the Federal Building, Richland, Washington. The occurrences with the most potential environmental impacts are summarized below.

Diesel Oil Leak in Underground Piping (UOR No. UNI-87-01)

An unknown quantity of diesel fuel leaked from an underground line connecting the 166-N oil storage area to the 184-N powerhouse building. The leak was discovered on January 16, 1987, during routine monitoring of storage tank levels. The defective line was isolated and locked out, then excavated and cut in half for hydrostatic tests. A 1/4-in. break in the pipe was found, and a 12-in. section of pipe was replaced. Valves will be installed to sectionalize the supply line and aid in scheduled, periodic hydrostatic testing. Oil from the leak was detected in ground water collected from a nearby well on January 29, 1987. Continued monitoring has shown that the Clean Water Act has not been violated, because no oil had been discharged to the Columbia River.

Release of Oil to the Columbia River (UOR No. UNI-87-02)

On February 6, 1987, approximately 5 gal of turbine oil was discharged to the Columbia River near the 182-N tank farm raw water return. A pinhole leak in a lube oil line in the No. 2 drive turbine allowed oil to enter the secondary steam system. Steam condensate from this system returns to the 100-N yard steam condensate system, which drains to the river. The leak in the lube line was repaired. A second spill occurred on February 18, 1987, when a sump in the 109-N basement overflowed when the secondary steam condensate system was drained. Draining was suspended until a procedure was approved to prevent reoccurrences.

Overturned Fuel Truck (UOR No. RHO-87-07)

On April 16, 1987, 395 gal of fuel (diesel and gasoline) and antifreeze spilled onto the ground when the driver of a fuel delivery truck lost control of his vehicle on the 100-F access road near its junction with Route 2 North. After the truck was removed, the area was hosed down and soil samples were taken for analysis. Test results indicated no toxicity or fire hazard problems. On May 1, 1987, the top 1 in. of soil was removed and transported to the Central Landfill. Appropriate notifications were sent to DOE, EPA, and the WDOE.

Nitrite Release from the PUREX Chemical Sewer (UOR No. WHC-87-09)

On April 25, 1987, 1000 gal of an aqueous solution containing 1275 lb of sodium nitrate escaped to the environment via the PUREX chemical sewer. A drain valve on tank TK-105 was found to be partially open, allowing one-half of the tank's contents to flow into a floor drain. This spill violated both WDOE and CERCLA release limits for this extremely hazardous waste. In the future, this valve will be tagged and locked when not in use and only operated in accordance with approved written procedures.

Herbicide Spill at the 2711E Garage Parking Lot (UOR No. RHO-87-10)

On May 16, 1987, approximately 6 gal of an aqueous solution of herbicide 2-4-D/Banvil leaked to the ground from a sprayer truck parked at the 200-East Area garage. An investigation revealed that valves controlling the contents of the sprayer had been inadvertently opened or had vibrated open between the time the sprayer was moved from the job site to the garage. The WDOE was notified because the spill exceeded the 2.2-lb hazardous waste listing for reportable discharges.

Release of an Acidic Chrome Solution to the Ground via a Sanitary Drain (WHC-UO-87-004-2703E-01)

Approximately 38 gal of an acidic test solution containing $Cr(NO_3^-)_3$ leaked from a process vessel, through a failed, brass pressure gauge fitting, to the 2703-E Building drain system and finally to the ground. The leak was discovered at the beginning of the day shift on July 28, 1987. Action was taken to confine the spill as much as possible. The solution was neutralized and removed via an absorbent material. The trivalent chromium was handled as an extremely hazardous waste as defined by the Washington State Administrative Code [WAC 173-303 (WDOE 1986)]. To prevent further occurrences, drains in drain trenches will be modified by adding capped standpipes to control accidental trench drainage.

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Liquid and Atmospheric Releases of Ammonium Hydroxide (NH_4OH) and Ammonia (NH_3) from the 242-A Evaporator and from PUREX (WHC-UO-87-020-PUREX-01)

On August 30, 1987, discharges of NH_4OH to the 216-A-36B crib at PUREX and the 216-A-37-1 crib at the tank farms exceeded WDOE and CERCLA limits. Additionally, NH_3 discharges from facility stacks in both locations were also in violation. Processes generating NH_3 at both locations were curtailed and a hold was placed on discharging additional NH_4OH to the cribs.

Acid Leak and Lack of Containment (WHC-UO-87-023-100N-07)

An estimated 15 to 30 gal of concentrated sulfuric acid was released to the ground during an acid transfer procedure at 100-N on November 9, 1987. A 200-gal leak from a ruptured 20-year-old pipe was believed to be contained in a secondary concrete containment trench. However, during cleanup, it was determined that a french drain within the trench had mistakenly not been removed as part of recent upgrade work on the trench, allowing some of the acid to reach the soil. Because the spill exceeded the WDOE Dangerous Waste limit, DOE-RL was notified and they, in turn, notified WDOE.

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TABLE G.1. Radionuclides in Gaseous Effluents Discharged to the Atmosphere in 1987

Radionuclide[b]	Half-Life	Release, Ci[a]			
		100 Areas	200 Areas	300 Area	400 Area
^{3}H	12.3 yr	0.45	70.0		[c]
^{14}C	5730 yr		1.0		
^{24}Na	15.0 h	0.003			
^{41}Ar	1.8 h	4,500			36.0
^{51}Cr	27.7 d				
^{54}Mn	312 d	0.0007			
^{56}Mn	2.6 h				
^{59}Fe	44.6 d	0.001			
^{58}Co	70.8 d				
^{60}Co	5.3 yr	0.0065		2×10^{-5}[d]	
^{76}As	26.3 h	0.014			
^{85m}Kr	4.5 h	13			
^{85}Kr	10.7 yr		70,000		0.30
^{87}Kr	76.3 min	24			
^{88}Kr	2.8 h	21			
^{89}Sr	50.5 d	2.4×10^{-5}			
^{90}Sr	28.8 yr	8.9×10^{-6}	0.0002	0.0003[e]	2×10^{-5}
^{91}Sr	9.5 h	0.0048			
^{95}Zr	64.0 d	ND	$<2 \times 10^{-5}$		
^{95}Nb	36 d	0.00048	$<1 \times 10^{-5}$		
^{99}Mo	66.0 h	0.0059			
^{99}Tc	2.1×10^{5} yr				
^{103}Ru	39.4 d	0.00046	<0.0002		
^{106}Ru	367 d		0.02		
^{113}Sn	115 d		<0.0002		
^{125}Sb	2.7 yr		<0.001		
^{129}I	1.6×10^{7} yr		0.5		
^{131}I	8.0 d	0.028	<0.0002	0.0002	1.5×10^{-5}
^{132}I	2.3 h	0.079			
^{133}I	20.9 h	0.13			
^{135}I	6.6 h	0.12			
^{133}Xe	5.25 d				
^{135}Xe	9.1 h	37			
^{134}Cs	2.1 yr		$<1 \times 10^{-5}$		
^{137}Cs	30.0 yr	0.001	4×10^{-5}		
^{138}Cs	32.2 min	27			
^{140}Ba	12.8 d	0.0036			
^{140}La	40.3 h	0.0021			
^{141}Ce	32.5 d				
^{144}Ce	284 d	0.0019			
^{147}Pm	2.62 yr		0.001		
^{208}Tl	3.1 min		0.04		
^{212}Pb	10.6 h		0.2		
^{212}Bi	60.6 min		0.1		
^{212}Po	3×10^{-7}		0.08		
^{216}Po	0.15 s		2		
^{220}Rn	55.6 s		2		

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TABLE G.1. (contd)

Radionuclide[b]	Half-Life	Release, Ci[a] 100 Areas	200 Areas	300 Area	400 Area
^{234}U	2.4×10^{5} yr		2×10^{-6}	2.5×10^{-6}[f]	
^{235}U	7.0×10^{8} yr		7×10^{-6}	1.1×10^{-7}[f]	
^{236}U	2.3×10^{7} yr				
^{238}U	4.5×10^{9} yr		2×10^{-6}	2.4×10^{-6}[f]	
^{238}Pu	87.7 yr	2.0×10^{-7}	3×10^{-5}		5×10^{-6}
$^{239,240}Pu$	2.4×10^{4} yr	1.3×10^{-6}	0.0004	2×10^{-5}	
^{241}Pu	14.4 yr		0.003		
^{241}Am	433 yr		$<1 \times 10^{-4}$		

(a) Except as noted in this table, all effluent releases are as reported by operating contractors via the DOE's Effluent Information System.
(b) The activity values are for the listed radionuclides only. For those radionuclides whose radioactive daughters are not listed, the daughter activity is added during the dose calculations.
(c) Blank entry indicates no value reported by the operating contractor.
(d) Includes 2.8×10^{-7} Ci reported as mixed activation products, assumed to be ^{60}Co for dose calculations.
(e) Includes 2.2×10^{-5} Ci reported as mixed fission products, assumed to be ^{90}Sr for dose calculations.
(f) Includes fractional contribution from 5.0×10^{-6} Ci originally reported as natural uranium.

TABLE G.2. Nonradioactive Constituents in Gaseous Effluents Discharged to the Atmosphere in 1987

Constituent	Release, kg[a] 100 Areas	200 Areas	300 Area	1100 Area
Particulates	19,000	3,520	13,000	620
Nitrogen oxides	60,000	740,000	140,000	3,300
Sulfur oxides	270,000	12,000	430,000	21
Carbon monoxide	5,800	92,000	18,000	120
Hydrocarbons	1,200	46,000	9,200	8.2
Carbon tetrachloride	---	8,300	---	---

(a) Values are those reported by operating contractors.

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TABLE G.3. Radionuclides in Liquid Effluents Discharged to Ground Disposal Facilities in 1987

Radionuclide	Half-Life	Release, Ci[a]		
		100 Areas	200 Areas	300 Area
^{3}H	12.3 yr	98	2,000	[b]
^{32}P	14.3 d	0.88		
^{51}Cr	27.7 d	13		
^{54}Mn	312 d	59		
^{59}Fe	44.6 d	15		
^{58}Co	70.8 d	2.5		
^{60}Co	5.3 yr	200		
^{65}Zn	244 d	3.9		
^{89}Sr	50.5 d	8.0		
^{90}Sr	28.8 yr	15	<0.5	
^{95}Zr	64.0 d	4.6		
^{99}Tc	2.1×10^{5} yr			0.02
^{99}Mo	66.0 h	55		
^{103}Ru	39.4 d	2.2	<0.003	
^{106}Ru	367 d	15	0.50	
^{113}Sn	115 d		0.015	
^{124}Sb	60.2 d			
^{125}Sb	2.7 yr			
^{129}I	1.6×10^{7} yr		<0.009	
^{131}I	8.0 d	27		
^{133}Xe	5.25 d	41		
^{134}Cs	2.1 yr	2.0		
^{137}Cs	30.2 yr	46	<1.2	
^{140}Ba	12.8 d	12		
^{141}Ce	32.5 d	1.6		
^{144}Ce	284 d	10		
^{147}Pm	2.62 yr		0.063	
Unidentified beta				0.02
Short-lived radionuclides[c]		1,900		
^{234}U	2.4×10^{5} yr		0.0021[d]	0.008
^{235}U	7.0×10^{8} yr		7×10^{-5}[d]	0.0004
^{236}U	2.3×10^{7} yr		0.0002[d]	
^{238}U	4.5×10^{9} yr		0.0014[d]	0.006
^{238}Pu	87.7 yr	0.053	<0.01	
$^{239,240}Pu$	2.4×10^{4}	0.35	<0.04	
^{239}Np	2.4 d	30		
^{241}Pu	14.4 yr		0.85	
^{241}Am	433 yr		<2.7	

(a) Values are those reported by operating contractors.
(b) Blank entry indicates no value reported by the operating contractor.
(c) Short-lived radionuclides have half-lives of less than 48 h.
(d) Fractional contributions estimated from value of 0.0037 Ci of gross uranium reported by contractor.

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TABLE G.4. Nonradioactive Constituents in Liquids Discharged to Ground Disposal Facilities in 1987

Constituent	Release, kg[a]		
	100 Areas	200 Areas	300 Area
Total organic carbon		12,000	6,800
Nitrates		9,700	3,400
Copper			47
Fluoride			360
Chromium			12
Aluminum sulfate	240,000		
Polyacrylamide	430		
Sodium hydroxide	230,000		
Sulphuric acid	500,000		
Sodium sulphate	400,000		

(a) Values are those reported by operating contractors.

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TABLE G.5. Radionuclides in Liquid Effluents Discharged to the Columbia River in 1987

Radionuclide	Half-Life	Release, Ci[a]
^{3}H	12.3 yr	98
^{24}Na	15.0 h	ND
^{32}P	14.3 d	0.0015
^{51}Cr	27.7 d	ND
^{54}Mn	312 d	0.0025
^{59}Fe	44.6 d	ND
^{58}Co	70.8 d	ND
^{60}Co	5.3 yr	0.33
^{89}Sr	50.5 d	0.83
^{90}Sr	28.8 yr	2.5
^{95}Zr	64.0 d	ND
^{99}Mo	66.0 h	ND
^{103}Ru	39.4 d	0.0082
^{106}Ru	367 d	0.038
^{124}Sb	60 d	ND
^{125}Sb	2.7 yr	0.042
^{131}I	8.0 d	0.0043
^{133}I	20.9 h	ND
^{133}Xe	5.25 d	ND
^{137}Cs	30.2 yr	0.08
^{140}Ba	12.8 d	ND
^{141}Ce	32.5 d	ND
^{144}Ce	284 d	ND
^{238}Pu	87.7 yr	4.4×10^{-6}
$^{239,240}Pu$	2.4×10^{4} yr	0.0005

(a) Values are those reported by contractors.
ND Not detected.

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TABLE G.6. Composition of Solid Wastes Buried on the Site During 1987

Constituent	Quantities[a]
Radioactive	
Uranium	5.1×10^6 g
Plutonium	3.6 g
Americium	1.0 g
Thorium	1.6×10^6 g
Strontium	1.4×10^4 Ci
Ruthenium	0.61 Ci
Cesium	1.5×10^4 Ci
Other fission and activation products	1.3×10^5 Ci
Nonradioactive	
Nonhazardous trash, refuse	4.4×10^4 m^3
Asbestos	6.7×10^2 m^3
Septic sludge	120 m^3

(a) Values are those reported by the operating contractors.

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American Public Health Association (APHA). 1985. **Standard Methods for the Examination of Water and Wastewater: Including Bottom Sediments and Sludges.** 16th ed. APHA, Washington, D.C.

American Society for Testing and Materials. (ASTM). 1987. **Annual Book of ASTM Standards.** Section 11, Water and Environment Technology. Vol. 11.01 - Water (I), Vol. 11.-2 - Water (II), ASTM, Philadelphia.

Association of Official Analytical Chemists (AOAC). 1975. **Statistical Manual of the AOAC**. AOAC, Arlington, Virginia.

Houston, J. R., D. Strenge, and E. C. Watson. 1974. **DACRIN: A Computer Program for Calculating Organ Dose from Acute or Chronic Radionuclide Inhalation**. BNWL-B-389, Pacific Northwest Laboratory, Richland, Washington.

International Commission on Radiological Protection (ICRP). 1979-1982. **Limits for Intakes of Radionuclides by Workers**. ICRP Publication 30, Annals of the ICRP, Vol. 2, No. 3/4, through Vol. 8, No. 4, Pergamon Press, Elmsford, New York.

Napier, B. A., W. E. Kennedy, Jr., and J. K. Soldat. 1980. **PABLM-A Computer Program to Calculate Accumulated Radiation Doses from Radionuclides in the Environment**. PNL-3209, Pacific Northwest Laboratory, Richland, Washington.

O'Dell, J. W., J. D. Pfaff, M. E. Gales, and G. D. McKee. 1984. **Test Method. The Determination of Inorganic Anions in Water by Ion Chromatography - Method 300.0**. EPA-600/4-84-017, U.S. Environmental Protection Agency, Cincinnati, Ohio.

Sommer, D. J., R. G. Rau, and D. C. Robinson. 1981. **Population Estimates for the Area Within a 50-mile Radius of Four Reference Points on the Hanford Site**. PNL-4010, Pacific Northwest Laboratory, Richland, Washington.

Strenge, D. L., and E. C. Watson. 1973. **KRONIC: A Computer Program for Calculating Annual Average External Doses from Chronic Atmospheric Releases of Radionuclides.** BNWL-B-264, Pacific Northwest Laboratory, Richland, Washington.

U.S. Department of Energy (USDOE). 1981. "Environmental Protection, Safety, and Health Protection Program for DOE Operations." **DOE Order 5480.1A**, Washington, D.C.

U.S. Environmental Protection Agency (EPA). 1975. **Handbook of Radiochemical Analytical Methods**, EPA-680/4-75-001, National Environmental Research Center, Office of Research and Development, EPA, Las Vegas, Nevada.

U.S. Environmental Protection Agency (EPA). 1976. **National Interim Primary Drinking Water Regulations.** EPA-570/9-76-003, Office of Water Supply, Washington, D.C.

U.S. Environmental Protection Agency (EPA). 1982. **Test Methods for Evaluating Solid Waste: Physical/Chemical Methods.** 2nd ed. SW-846, Washington, D.C.

U.S. Environmental Protection Agency (EPA). 1983. **National Emission Standard for Hazardous Air Pollutants; Standards for Radionuclides.** 40 CFR 61, U.S. Government Printing Office, Washington D.C.

Washington State Department of Ecology (WDOE). 1982. **Water Quality Standards for Waters of the State of Washington**. Washington Administrative Code, Chapter 173-201, Olympia, Washington.

Washington State Department of Ecology (WDOE). 1986. **Dangerous Waste Regulations**. Washington Administrative Code, Chapter 173-303, Olympia, Washington.

Washington State Department of Social and Health Services (WDSHS). August 1983 (Revised). **Public Water Supplies.** Washington Administrative Code, Chapter 248-54, Olympia, Washington.

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