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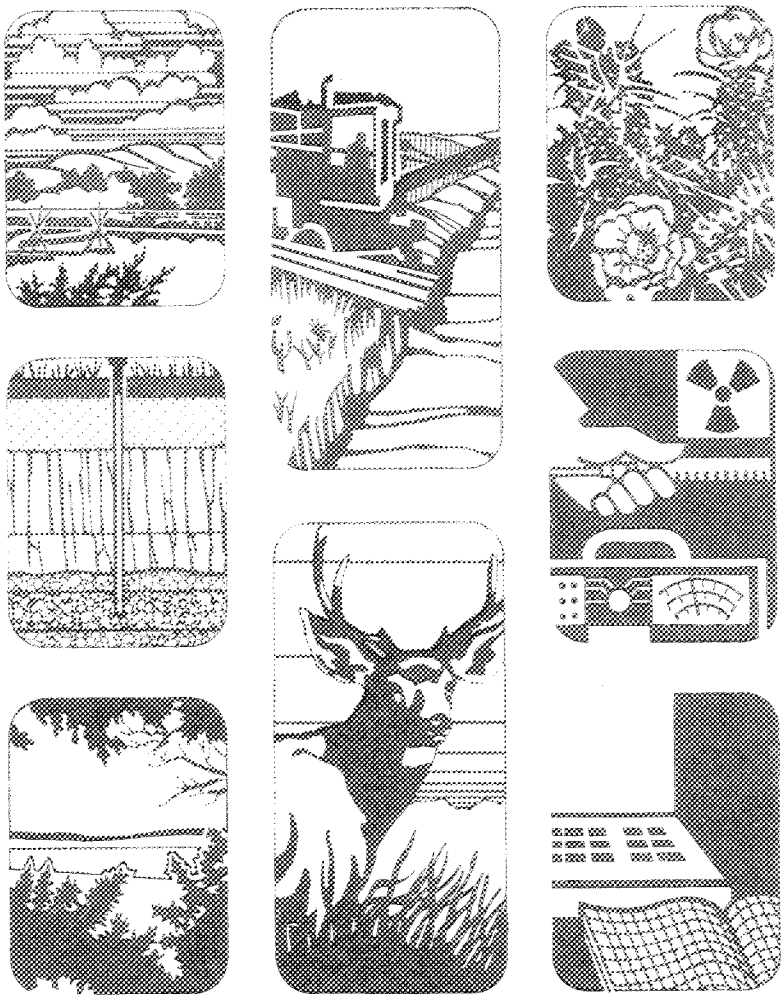

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Hanford Site Environmental Report for Calendar Year 1988

R. E. Jaquish, Editor
R. W. Bryce, Editor

May 1989

Prepared for
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PREFACE

Various nuclear and non-nuclear 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. The U.S. Department of Energy (DOE) conducts 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, the environmental monitoring program has been conducted by Pacific Northwest Laboratory (PNL), which is operated for DOE by Battelle Memorial Institute. The operations and engineering contractor, Westinghouse Hanford Company, performs effluent monitoring for its facilities. Pacific Northwest Laboratory performs effluent monitoring of its research activities.

From 1946 to 1957, environmental monitoring results were 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 following 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 in 1984)

- *Ground-Water Monitoring at the Hanford Site for Calendar Year* (monitoring results for the onsite subsurface environs; discontinued in 1984).

Beginning in 1985, these three reports were combined into one document that summarized all the data collected each calendar year. Changes in the title and format of the 1988 report reflect new guidance contained in DOE Order 5400.1. The 1988 report contains information on additional environmental programs including wildlife resources, meteorology and climatology, cultural resources, and the Hanford Environmental Dose Reconstruction Project. This year's report also contains additional information on the environmental status of the Hanford Site (e.g., the status of compliance with environmental permits and regulations).

This report represents a single, comprehensive source of offsite and onsite environmental data collected during 1988. It contains data on Hanford effluents, the surface environment, and ground water. Also included is an assessment of the 1988 radiological doses to the hypothetical maximally exposed individual and the local population. Appendix C contains data with statistical estimates of variation. Information in Appendix C is intended for readers with a scientific interest or for those who wish to evaluate the results in more detail. Those interested in reviewing the raw data can do so at the Department of Energy-Richland Operations' Public Reading Room at the Federal Building, Richland, Washington.

Radionuclide data are expressed as 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 curie is 37 billion nuclear transformations per second. 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 extremely small numbers that are best expressed as picocuries or attocuries.

Metric units are primarily used in 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 P.1. A more complete account of radionuclides addressed by environmental monitoring can be found in Appendix G, Tables G.1, G.3, and G.5. Gross alpha and gross beta results are from screening analyses that measure all alpha- or beta-emitting radionuclides in the sample, without specifying the radionuclide present.

TABLE P.1. Radionuclide Nomenclature

Radionuclide	Symbol
Antimony-125	^{125}Sb
Carbon-14	^{14}C
Cesium-137	^{137}Cs
Cobalt-60	^{60}Co
Europium-154	^{154}Eu
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

Chemicals and the corresponding symbols used in this report are listed in Table P.2. Because chemical concentrations are often very low, they are expressed as micrograms per liter (μg/L) or, occasionally, milligrams per liter (mg/L).

A glossary and list of acronyms and abbreviations are presented in Appendix A. Acronyms are spelled out the first time they are used in each chapter, except commonly used acronyms, such as DOE and EPA. Applicable standards and environmental permits are described in Appendix B. Environmental monitoring data for 1988 are listed in Appendix C. Sample analysis procedures are described in Appendix D. Methods used for data analysis are summarized in Appendix E. Methods used for dose calculation in 1988 are discussed in Appendix F. Appendix G contains the 1988 Hanford effluent data.

TABLE P.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_3^-
Phosphate	PO_4^{3-}
Potassium	K
Selenium	Se
Silver	Ag
Sodium	Na
Strontium	Sr
Sulfate	SO_4^{2-}
Vanadium	V
Zinc	Zn

SUMMARY

Environmental activities at Hanford in 1988 included monitoring and compliance programs, and related programs such as cultural resources, wildlife, and meteorology. Monitoring activities conducted at Hanford during 1988 indicated radionuclide concentrations well below applicable DOE and EPA standards. Radioactive materials released from Hanford operations were generally indistinguishable from background concentrations in the offsite environment. 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 Hanford operations and natural background levels. Several chemicals regulated by the EPA and the State of Washington exceeded EPA drinking water standards (DWS). The major sections of this report are summarized in the following paragraphs.

COMPLIANCE STATUS

Several federal, state, and local agencies are responsible for enforcing environmental regulations at the Hanford Site. Principal among these agencies are the EPA, the State of Washington Department of Ecology (WDOE), and the Benton, Franklin, and Walla Walla Counties Air Pollution Control Authority.

A number of compliance activities during 1988 were related to the Resource Conservation and Recovery Act (RCRA) and Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). Part A permit applications were submitted to WDOE for all facilities that treated, stored for more than 90 days, or disposed of hazardous or radioactive mixed waste. A Tri-Party Agreement, initiated among DOE, EPA, and WDOE, will govern the conduct of the permitting and cleanup activities at Hanford.

Other compliance activities involved monitoring and managing waste to meet requirements of applicable environmental laws including the Clean Air Act, Clean Water Act, Safe Drinking Water Act, and Toxic Substances Control Act (see "Compliance Summary," Section 2.0).

OPERATIONAL AND ENVIRONMENTAL HIGHLIGHTS

The Plutonium Uranium Extraction Plant (PUREX) continued operations in 1988 and processed 590 tons of irradiated reactor fuel. The Fast Flux Test Facility (FFTF) achieved a 98.9% efficiency factor while operating most of the year. The N Reactor did not operate in 1988.

Environmental highlights included nomination of the Hanford Site for placement on the National Priorities List (NPL) of CERCLA sites. In 1988, Congress enacted Public Law 100-605 authorizing a study of the Hanford Reach of the Columbia River. The law includes a provision to consider the potential addition of all or part of the study area to the National Wild and Scenic Rivers System (see "Operational Highlights at Hanford in 1988," Section 2.2).

ENVIRONMENTAL OCCURRENCES

Onsite and offsite environmental occurrences (spills, leaks, etc.) of radioactive and nonradioactive chemical wastes were reported to DOE by the onsite contractors and to other federal and state agencies as required by law. Fourteen occurrences with the greatest potential for impacting the environment are summarized in this report (see "1988 Environmental Occurrences," Section 2.3).

ENVIRONMENTAL PROGRAMS

Environmental monitoring of the Hanford Site and annual reporting of results are conducted in accordance with guidance from DOE

orders. There were no draft or final environmental impact statements issued in 1988 (see "Environmental Program Information," Section 3.0).

ENVIRONMENTAL MONITORING RESULTS

Air–In 1988, the average Hanford Site perimeter concentrations of ^{3}H, ^{90}Sr, ^{137}Cs, and uranium were numerically greater than levels measured at distant monitoring stations. These differences were not significantly different statistically (at the 5% significance level). Krypton-85 and ^{129}I concentrations were numerically greater at the perimeter stations than at the distant stations, and the differences were statistically significant. However, even the maximum single perimeter sample for any radionuclide was only 0.3% of the applicable DOE Derived Concentration Guide (DCG)(Appendix B, Table B.6). The total dose from air emissions is compared to Clean Air Act and DOE dose standards in "Potential Radiation Doses from 1988 Hanford Operations," Section 4.8. Annual average NO_2 concentrations at all sampling locations remained well below federal and Washington State ambient air standards (see "Air Monitoring," Section 4.1).

Surface Water–During 1988, low levels of some radionuclides continued to be detected in samples of Columbia River water collected at Priest Rapids Dam, the 300 Area, and 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, ^{235}U, ^{238}U, and $^{239,240}Pu$. Concentrations of ^{234}U, ^{235}U, ^{238}U, and $^{239,240}Pu$ were similar in water collected from both locations. Tritium, ^{90}Sr, and ^{129}I concentrations were statistically higher in water collected at the Richland Pumphouse than in water from Priest Rapids Dam. All radionuclides observed in Columbia River water during 1988 exist in worldwide fallout, as well as in effluents from Hanford facilities. Tritium and uranium also occur naturally in the environment. Concentrations of radionuclides identified in the river water during 1988 were below limits established for drinking water by the EPA and Washington State.

Nonradiological water quality parameters measured during 1988 were similar to those reported during previous years and generally within Washington State Water Quality Standards.

Three onsite ponds were routinely sampled for radiological constituents during 1988. Concentrations of radionuclides in water collected from these ponds were similar to those observed during past years. Water samples were collected from five wells located across the Columbia River from the Hanford Site that are used for drinking and irrigation. The annual average concentration in the wells were within applicable standards (see "Surface-Water Monitoring," Section 4.2).

Food and Farm Products–Low levels of radionuclides attributable to worldwide fallout were found in several foodstuff and farm product samples during 1988. 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. Special samples of selected fruits and vegetables were collected in 1988 and analyzed for ^{129}I. The concentrations were all below the detectable level of the analytical method (see "Food and Farm Product Monitoring," Section 4.3).

Wildlife–Samples of deer, fish, gamebirds, waterfowl, and rabbits were collected from areas 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 1988 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 1988, was below applicable DOE standards (see "Wildlife Monitoring," Section 4.4).

Soil and Vegetation–During 1988, measurable concentrations of radionuclides were detected in onsite and offsite samples of surface soils and rangeland vegetation. However, evaluations of the samples provided no indication of significant increases in radionuclide concentrations in offsite samples that could be attributed to Hanford operations (see "Soil and Vegetation Monitoring," Section 4.5).

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 operation 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. During the year, a special study was conducted to compare the results obtained from PNL environmental dosimeters with other organizations. The Washington Public Power Supply System, the Oregon State Health Department, and the Washington State Department of Social and Health Services all participated with PNL in the study. The results showed some differences, but overall there was a general agreement among the four organizations (see "Penetrating-Radiation Monitoring," Section 4.6).

Effluent Monitoring–The amounts of radioactive and non-radioactive liquids, gases, and solids released or disposed to the environment from Hanford operations are measured and documented. The levels are assessed for compliance with applicable federal, state, and local regulations and permits (see "Effluent Monitoring," Section 4.7). A list of the quantities of radioactive and nonradioactive effluents released to the environment from Hanford operations in 1988 is provided in Appendix G.

Potential Radiation Doses from 1988 Hanford Operations–Measured external radiation exposure and calculated radiation doses to the public from 1988 Hanford operations were well below applicable regulatory limits. The effective dose equivalent to the hypothetical maximally exposed individual from 1988 operations was calculated to be 0.08 mrem, compared to 0.05 mrem reported in 1987. The population effective dose equivalent from 1988 operations was calculated to be 5 person-rem compared to 4 person-rem reported for 1987. These doses are much lower than doses received from common sources of radiation, such as natural background radiation. They are also much lower than the 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 the maximally exposed individual (see "Potential Radiological Doses from 1988 Hanford Operations," Section 4.8).

GROUND WATER

Radiological and chemical constituents in ground water were monitored during 1988 throughout the Hanford Site. Monitoring activities were conducted to 1) determine the distribution of mobile radionuclides and nitrates, 2) relate the distribution of these constituents to Site operations, and 3) identify chemicals present in ground water as a result of Site operations. To comply with RCRA, additional monitoring was conducted to assess the impact that specific facilities have had on ground-water quality.

Analytical results for samples were compared to EPA Drinking Water Standards (DWS) and DOE's Derived Concentration Guides (DCG). Ground water beneath the Hanford Site is used for drinking at four locations. In addition,

water supply wells for the city of Richland are located adjacent to the southern boundary of the Hanford Site.

Radiological monitoring results indicate that gross alpha, gross beta, ^{3}H, ^{60}Co, ^{90}Sr, ^{99}Tc, ^{106}Ru, ^{129}I, and ^{137}Cs concentrations near operating areas were at levels above DWS. Concentrations of ^{234}U and ^{238}U in the 200-West Area were above the DCG. Concentrations of ^{3}H 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 operating areas. Sampling of new and existing monitoring wells near Richland water supply wells showed that concentrations of regulated ground-water constituents in this area are below DWS, and in general below detection levels (see "Ground-Water Protection and Monitoring Program," Section 5.0).

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 (QA/QC) techniques were used during the sample collection, laboratory analysis, data management, and dose calculation activities. The quality of the data was verified by a continuing program of analytical laboratory quality control (QC), interlaboratory cross-checks, replicate sampling and analysis, and sample splitting with other laboratories. The QA/QC evaluations documented that the monitoring data were valid (see "Quality Assurance," Section 6.0).

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Numerous PNL personnel were responsible for a productive environmental monitoring program during 1988. Important contributions were made by those people who collected samples, maintained equipment, provided laboratory analysis, 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. G. Hefty for report coordination. Thanks also to R. E. Lundgren and D. A. Perez for technical editing. Valuable text processing support was provided by J. L. Clark, D. J. Kennedy, and L. M. Valdez.

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1.0 INTRODUCTION

K. R. Price, R. W. Bryce, and B. N. Bjornstad

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 (Figure 1.1) 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.

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, the 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 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 is the nearest dam upstream of the Site, and McNary is the nearest dam downstream. (The Hanford Reach of the Columbia River extends from Priest Rapids Dam to the head of Lake Wallula near Richland, which is created by McNary Dam, and is the last stretch of the Columbia River above Bonneville Dam that remains unimpounded by a dam.) The width of the river varies from approximately 300 m to 1000 m.

Flows in the Hanford Reach fluctuate significantly because of the relatively small storage capacity and the operational practices of upstream dams. Flow rate of the Columbia River through the Site is regulated primarily by Priest Rapids Dam, minimum regulated flow rate of 1000 cubic meters per second (m³/s). Typical daily flows range from 1000 m³/s to 7000 m³/s, with peak spring runoff flows of up to 12,600 m³/s. Typical annual average flows at Priest Rapids Dam are 2800 m³/s to 3400 m³/s. 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. Mean monthly temperatures for the river range from approximately 3°C to about 20°C over a year. Solar radiation, water storage management practices at upstream dams, and water flow rate dictate, to a large extent, the thermal characteristics of the Columbia River along the Hanford Reach.

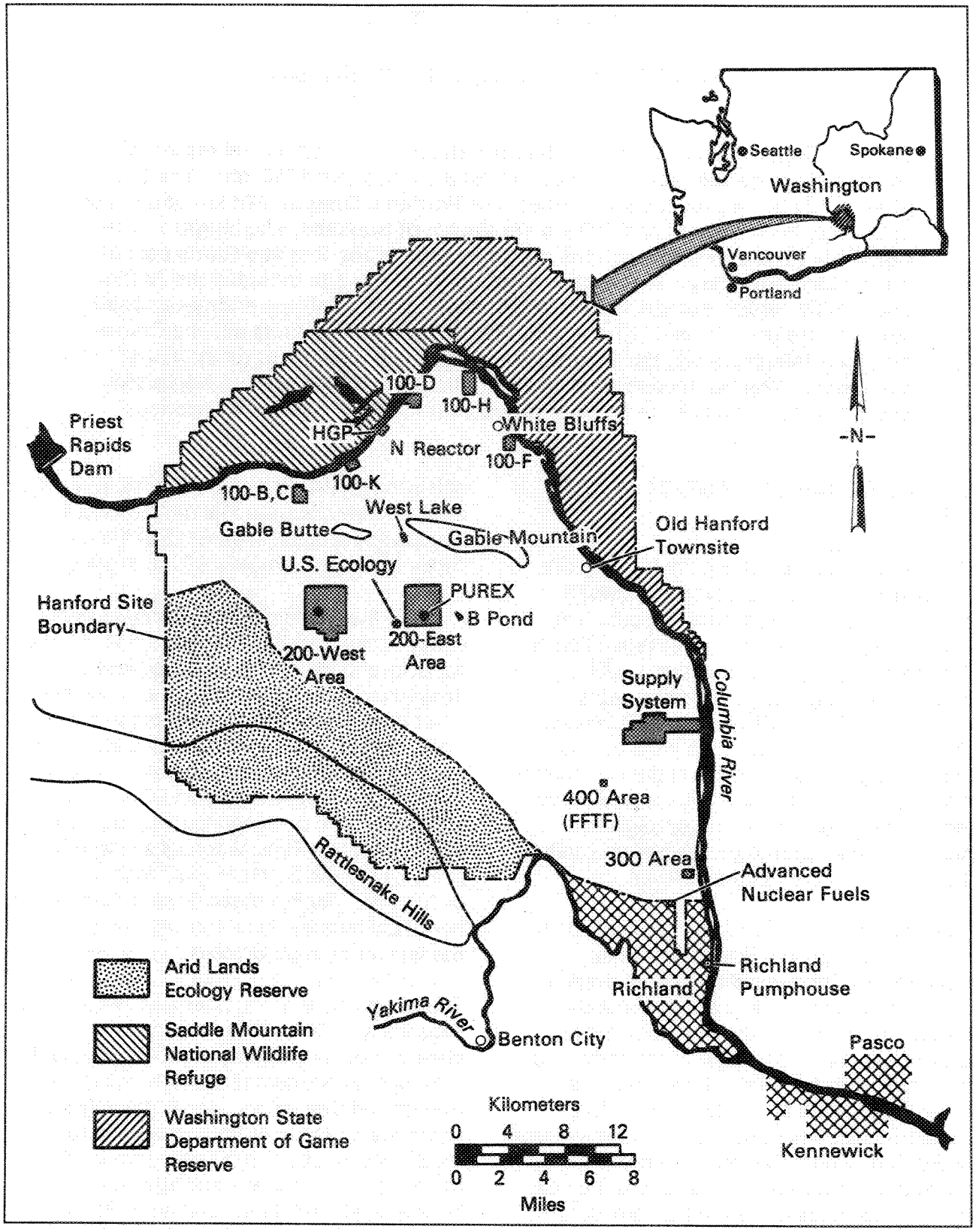

FIGURE 1.1. DOE's Hanford Site

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, wind surfing, and swimming. 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. Other surface water on the Site consists of West Lake (a small, natural pond), Rattlesnake Springs, Dry Creek, 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 (see Section 3.4). 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 15 km/h in summer to 10 km/h in winter (see Section 3.4). The prevailing regional winds are from the northwest, with occasional cold-air drainage into valleys and strong crosswinds. The region is a typical desert basin where frequent strong temperature inversions occur at night and break during the day, resulting in unstable and turbulent wind conditions.

Land surrounding 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 (ALE) Reserve 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 historically have been discharged to the ground through cribs, ditches, and ponds. These discharges have greatly influenced ground-water flow and contaminant movement in the unconfined aquifer beneath the Site. Approximately 2.42 billion L of liquid effluent in the 200 Areas were disposed to the ground during 1988, including process cooling water and water containing low-level radioactive and hazardous wastes. Approximately 0.8 billion L 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-1940s 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; surface ponds and ditches were primarily used for disposal of uncontaminated cooling water (Graham et al. 1981). A crib is an underground structure designed to receive liquid waste and allow it to percolate into the ground directly or through a connected tile field. Sanitary wastes were discharged to the ground via tile fields. Most liquid disposal occurred in the Separations Areas, which include the 200-East and 200-West Areas (Figure 1.1). 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 the 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.

Geology

The Hanford Site lies within the Pasco Basin, one of many topographic and structural basins within the Columbia Plateau. Principal geologic units beneath the Hanford Site include, in ascending order, the Columbia River Basalt Group, the Ringold Formation, and a series of deposits informally referred to as the Hanford formation. These units are covered locally by a few meters or less of recent alluvial or windblown deposits. Older geologic units have been deformed into a series of roughly east-west trending folds. The stratigraphic and structural relationships between these units are displayed in Figure 1.2.

Emplacement of Columbia River basalt flows, which ended in the Pasco Basin approximately 8.5 million years ago, was followed by a period of river and lake sedimentation. These deposits, which belong to the Ringold Formation, contain a wide range of sediment types, with beds ranging from weakly cemented coarse sandy gravel to compact silt and clay. The Hanford formation was deposited later as a result of giant floods associated with the sudden draining of glacier-dammed lakes, located northeast of the Columbia Plateau. Cataclysmic floods occurred several or more times over the last million years. Within the Pasco Basin, the Hanford formation consists of mostly coarse gravel and sand, and overlies the eroded surface of the Ringold Formation, but in places the Hanford formation directly overlies basalt. In the vicinity of the 200-West Area, the Ringold and Hanford formations are separated by a well-developed buried soil (Plio-Pleistocene unit) and fine-grained wind deposits (early "Palouse" soil).

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 the Columbia River (Gephart et al. 1979). This relatively shallow aquifer has been affected by waste-water 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 basalt ridges that surround the basin and by the Yakima and Columbia rivers. The basalt ridges have a low permeability and act as a barrier to lateral flow of ground water (Gephart

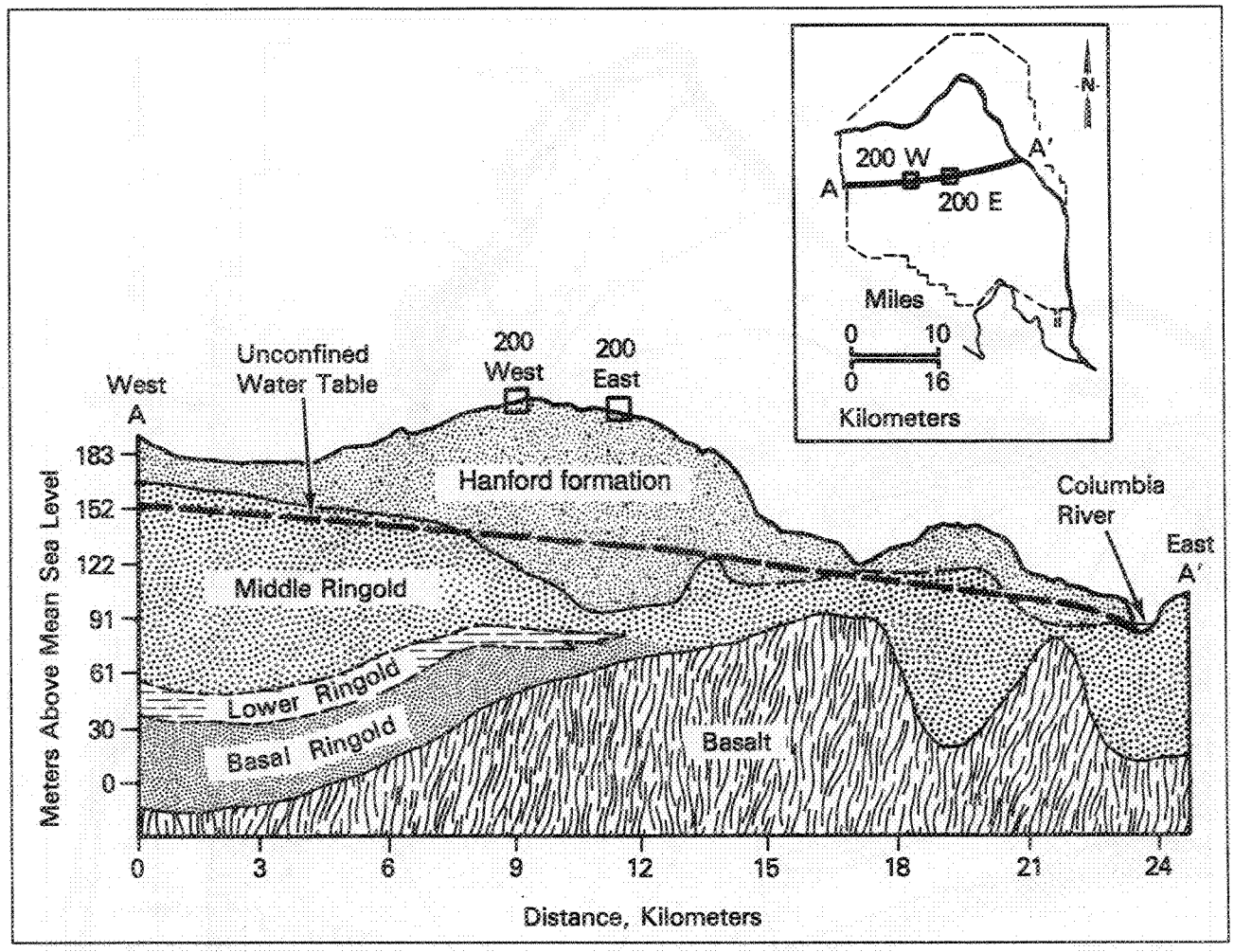

FIGURE 1.2. Geologic Cross Section of the Site (modified from Tallman et al. 1979)

et al. 1979) where they rise above the water table. 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 ridges. 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 1988 is shown in Figure 1.3.

Recharge to the unconfined aquifer originates from several sources (Graham et al. 1981). Natural recharge occurs from precipitation at higher elevations and runoff from intermittent 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 vegetated areas of the Hanford Site because of a high rate of evapotranspiration from native soil and vegetation. However, studies described by Gee (1987) suggest that precipitation may contribute recharge to the ground water in areas where soils are coarse textured and bare of vegetation.

Large-scale artificial recharge occurs from offsite agricultural irrigation and liquid-waste disposal in the operating areas. Recharge from

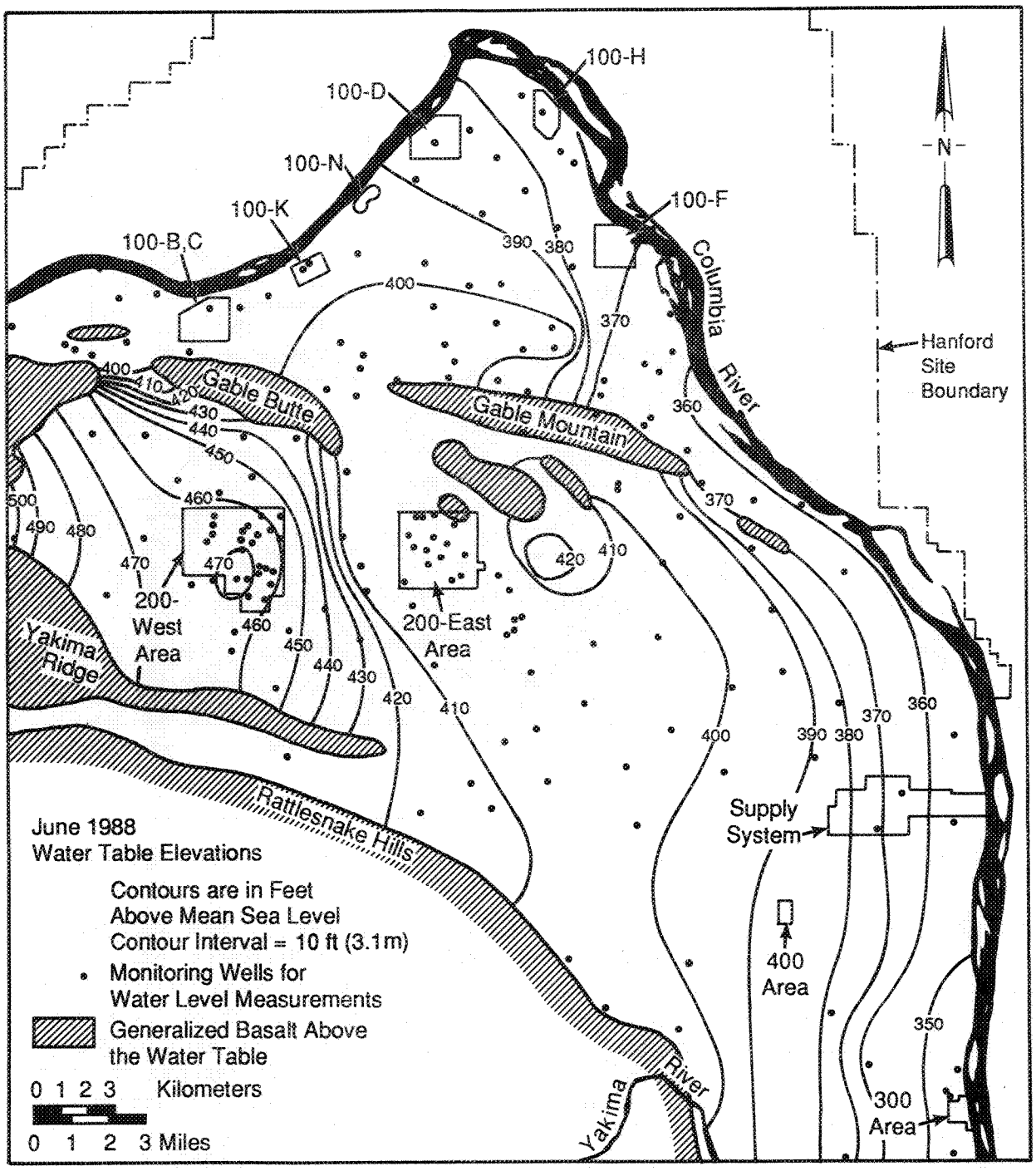

FIGURE 1.3. Water Table Elevations for June 1988 (Evans, Bryce, and Sherwood 1989)

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 200 Areas. Recharge to the ground water from facilities in the 200 Areas (including B Pond and the various cribs and trenches in the 200 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 200 Areas. 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 200 Areas, ground-water mounding also occurs in the 100 and 300 Areas. Ground-water mounding in these areas is not as significant as in the 200 Areas 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 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 attenuate or delay the movement of some 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 more soluble constituents move downgradient in the same direction as and at a rate nearly equal to the flow of ground water. When the liquid effluents reach the ground water, their concentrations are reduced by dilution. As these constituents move with the ground water, radionuclide and hazardous chemical concentrations are further 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 1.1)]. The 100 Areas include facilities for the N Reactor and 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 fabrication 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.[a]

Privately owned facilities located within the Hanford Site boundaries include the Washington Public Power Supply System (Supply System) Hanford Generating Project, adjacent to N Reactor, the Supply System power reactor (WPPSS-2) and office buildings, and a low-level radioactive-waste burial site operated by U.S. Ecology on the 200 Area Plateau. The Advanced Nuclear Fuel Corp. fuel fabrication facility is immediately adjacent to the southern boundary of the Hanford Site.

Principal DOE contractors at Hanford in 1988 were:

Westinghouse Hanford Company — 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; conducting effluent monitoring; decommissioning old facilities; and providing Site support services, such as

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(a) Both N Reactor and fuel fabrication facilities in 300 Area were inactive in 1988.

security, fire protection, central stores, and electrical power distribution.

Battelle Memorial Institute (BMI) — responsible for operating PNL for DOE, including research and development in the physical, chemical, life, and environmental sciences; producing advanced methods of nuclear waste management; and conducting environmental monitoring at the Site.

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

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

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

2.0 COMPLIANCE SUMMARY

2.1 COMPLIANCE STATUS

R. A. Paasch, Westinghouse Hanford Company

Several federal, state, and local agencies are responsible for enforcing environmental regulations at the Hanford Site. Principal among these agencies are the EPA, the State of Washington Department of Ecology (WDOE), and the Benton, Franklin, and Walla Walla Counties Air Pollution Control Authority. These agencies issue permits, review compliance reports, participate in joint monitoring programs, inspect facilities and operations, and direct compliance with applicable regulations.

The EPA develops, promulgates, and enforces environmental protection and technology-based standards and regulations as directed by statutes passed by the U.S. Congress. In some instances, the EPA delegates regulatory authority to WDOE for state programs which meet or exceed the EPA's program requirements. Where regulatory authority is not delegated, EPA Region 10 (which includes the State of Washington and the Hanford Site) is responsible for reviewing and evaluating compliance with the EPA regulations as they pertain to the Hanford Site.

TRI-PARTY AGREEMENT

The EPA and WDOE are overseeing the cleanup and permitting activities at the Hanford Site. An agreement between EPA, WDOE, and DOE, called the Tri-Party Agreement, will govern the conduct of these activities. The agreement addresses those actions necessary to: 1) achieve full Resource Conservation and Recovery Act of 1976 (RCRA), as amended, compliance for the treatment, storage, and disposal of hazardous wastes and obtain a final RCRA permit for the Hanford Site, and 2) cleanup of inactive waste sites as RCRA corrective actions or remedial actions under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), as amended.

The Tri-Party Agreement is a consent order and compliance agreement that establishes jurisdictions, authorities, and other legal responsibilities between the parties. An Action Plan defines how the parties will work together, describes the processes and procedures to be followed, defines the units to be addressed, and provides the enforceable milestones and work schedule for conduct of work.

COMMUNITY RELATIONS PROGRAM

Cleanup activities regulated by CERCLA and RCRA 3004(u), and permitting and closure activities regulated by RCRA and the State Hazardous Waste Act will occur simultaneously at Hanford. The DOE, EPA, and WDOE will conduct community relations activities to inform and involve the public about the hazardous waste management activities at Hanford. It will be necessary to use a variety of communication techniques to reach the large number of people interested in the site. A draft plan for community relations was prepared in 1988.

RCRA PERMITS

These permits (which specify requirements for operation, closure, and postclosure monitoring) are granted by the EPA and WDOE. Permit applications are submitted by DOE to the regulatory agencies in two parts. Part A identifies the facility, provides its design parameters, and identifies the hazardous waste to be handled. Part B provides detailed facility descriptions, describes future operations, and identifies how the facility will be closed. For the facilities that will not continue to operate and will be clean closed, only Part A applications and closure plans will be submitted. For facilities that will not continue to operate but will be closed with waste remaining in place, Part A permit applications, closure plans, and post closure plans will be submitted. Submission of a Part A application is required for any facility that continued to manage hazardous wastes after the wastes became subject to RCRA or state dangerous waste regulations. An operating permit is issued after the EPA and WDOE have reviewed the submitted applications and supporting data, negotiated permit requirements, and continued public comment on the draft permit. Closure plan approval follows a similar process.

At the Hanford Site, Part A permit applications have been submitted to WDOE for all known facilities that treated, stored for more than 90 days, or disposed of hazardous or mixed waste. Existing facilities that have handled hazardous waste or mixed waste and are intended to continue operations as treatment, storage, or disposal facilities will continue to operate under interim status pending issuance of an operating permit. Part B permit applications and closure plans are in various stages of preparation. A number of applications have been submitted to WDOE and are currently under review.

HANFORD ENVIRONMENTAL COMPLIANCE PROJECT

In February 1987, DOE prepared a congressional budget request to establish line-item funding for those capital improvements deemed necessary to achieve compliance with applicable environmental requirements at the Hanford Site. The Hanford Environmental Compliance Project, a line item, will provide $180 million in capital funding in FY 1989 through 1995 for new facility construction and upgrades to existing facilities. These capital projects primarily support the effort to achieve RCRA compliance and the congressional commitment to discontinue disposal of contaminated liquids to the soil column at the Hanford Site. These include liquid effluent treatment and disposal, ground-water monitoring, hazardous waste storage, analytical support upgrades, and environmental control upgrades of existing facilities. The 1989 subprojects within the Hanford Environmental Compliance Project have been validated for a funding level of $12 million.

ENVIRONMENTAL RESTORATION

Within the boundaries of the Hanford Site, about 1100 individual Waste Management Units (WMUs) have been identified as requiring action under RCRA, CERCLA, or a combination of both. In order to manage these 1100 WMUs, the Hanford Site has been divided into four aggregate areas and 78 operable units within the aggregate areas. The WMUs have either been assigned to an operable unit for specific Environmental Restoration remedial actions or associated with the operable unit for other types of action such as decontamination and decommissioning. The Environmental Restoration activities at the Hanford Site include: 1) the Environmental Restoration Remedial Actions Program, and 2) Environmental Restoration Decontamination and Decommissioing Program, more commonly referred to as the Hanford Surplus Facilities Program.

Under the Tri-Party Agreement, 19 operable units have been designated as CERCLA past practice units, 15 operable units as RCRA Section 3004(u) past practice units, and 44 units have yet to be designated. The Tri-Party Agreement will stipulate the schedule for

conducting investigative and corrective measures for both categories of operable units.

Six of the 15 operable units involve both RCRA past practice WMUs and the 149 single-shell tank WMUs ,and are located in the 200 Areas (Chemical Processing Areas). During FY 1989-1995, interim stabilization and isolation of 147 of the 149 single-shell tanks will be accomplished. This includes the removal of pumpable liquids from 49 of the 51 single-shell tanks not yet stabilized and the installation of interim isolation seals on all portals of the 147 single-shell tanks to prevent liquids from leaking in or out of the portals. Also included is the development of waste retrieval technologies for the several types of single-shell tank wastes with emphasis on optimizing waste removal while minimizing personnel exposure.

Included in the Hanford Surplus Facilities Program are the surveillance, maintenance, decontamination, and decommissioning of over 100 radioactively contaminated structures, including surplus production reactors, chemical process buildings, and ancillary structures. Scheduled surveillance and maintenance ensures that radioactive contamination is controlled in accordance with DOE orders regarding environmental protection, safety, and health protection.

Current decontamination and decommissioning activities include the 183-H Solar Basins in the 100-H Area, the 201-C Strontium Semiworks Plant in the 200-E Area, and 100 Areas ancillary facilities. Also, the Surplus Production Reactor Decommissioning-Environmental Impact Statement (SPRD-EIS) for decommissioning eight shutdown reactors in the 100 Areas is scheduled for issuance in CY 1989.

UNDERGROUND STORAGE TANKS

The Hanford Site has many underground storage tanks, including some that are no longer in use. To comply with CY 1988 promulgated federal regulations in 40 CFR 280, Technical Standards and Corrective Action Requirements for Owners and Operators of Underground Storage Tanks, approximately 20 tanks will be removed under the Environmental Restoration program by December 22, 1989. The remainder (approximately 45) must be tightness tested and upgraded for corrosion protection and spill/overfill prevention. Tanks and piping must meet all new tank standards described in the law by 1998. Not all storage tanks are affected by the current regulations. Excluded or deferred are radioactive waste tanks, emergency generator tanks, and fuel tanks used exclusively for heating. Included are gasoline and diesel storage tanks used to fuel vehicles or for other purposes not specifically excluded by the regulations.

CLEAN AIR ACT

Airborne radionuclide emissions from DOE facilities are regulated by EPA under the Clean Air Act, as promulgated by Section 40, Code of Federal Regulations (40 CFR) Part 61, National Emission Standards for Hazardous Air Pollutants, in Subpart H, National Emission Standard for Radionuclide Emissions from DOE facilities. This standard limits emissions of radionuclides to air to those amounts that cause a dose equivalent of 25 mrem/yr to the whole body or 75 mrem/yr to the critical organ of any member of the public.

Radioactive airborne emissions from the Hanford Site are not covered by a permit but are monitored. These monitoring records are summarized on an annual basis and submitted to EPA. No radioactive emissions were released in CY 1988 that exceeded the EPA Clean Air Act, DOE dose limits, or Westinghouse Hanford Company administrative controls.

CLEAN WATER ACT

Liquid effluents discharged from Hanford to surface waters are regulated under the National Pollutant Discharge Elimination

System (NPDES) provisions of the Clean Water Act. The current permit (WA0003743) was issued in 1981 and is being renegotiated with EPA. The permit covers eight separate discharges from the Hanford Site. The monitoring requirements and limits for the permit are listed in Appendix B. Hanford is in compliance with the permit.

SAFE DRINKING WATER ACT

Sanitary water quality surveillance on the Hanford Site is conducted as a joint effort by the Hanford Environmental Health Foundation (HEHF) and PNL. This surveillance monitors the quality of the drinking water on the Hanford Site and evaluates compliance with applicable regulations. There are 16 individual drinking water systems on the Site. Eleven of the systems use Columbia River water as a raw water source, four systems use ground water, and one system a combination of the two.

The water supplies are monitored for the contaminants indicated in the National Interim Primary Drinking Water Regulations and the Rules and Regulations of the State Board of Health Regarding Public Water Systems. In 1988, all water supplies were in compliance with the requirements of the applicable regulations.

TOXIC SUBSTANCES CONTROL ACT (TSCA)

The primary compliance requirements of the TSCA on the Hanford Site are for management of polychlorinated biphenyls (PCBs) and asbestos. The PCB-containing transformers, hydraulic fluids, specialized lubricants, heat transfer agents, and machine tool cutting oils were used on the Hanford Site. Specific actions for PCBs are 1) to continue with removal of PCBs from electrical, hydraulic, and other equipment, and 2) to identify and implement a disposal method for PCB-contaminated radioactive waste oil. Asbestos has been used on the Hanford Site in pipe insulation and building products. Asbestos abatement activities are in progress on the site, which are in accordance with the Occupational Safety and Health Administration and Washington Industrial Safety and Health Act requirements. Procedures, inspections, and records for PCB and asbestos programs at Hanford are in compliance with TSCA requirements.

SARA REPORTING

The Superfund Amendments and Reauthorization Act of 1986 (SARA) Title III introduced new hazardous material inventory reporting requirements under three sections. These reporting requirements have been complied with as follows:

- Section 311 - By October 17, 1987, a list was submitted to the State Emergency Response Commission, the local emergency planning committee, and the local fire department of all reportable hazardous materials present on Site in excess of 4536 kg and all reportable extremely hazardous materials present on Site in quantities for which a Material Safety Data Sheet is required by the Occupational Safety and Health Administration.

- Section 312 - By March 17, 1988, Hazardous Chemical Inventory Forms were submitted to the State Emergency Response Commission, the local emergency planning committee, and the local fire department for all reportable hazardous materials present on Site in excess of 4536 kg and for all reportable extremely hazardous materials. This reporting must be done annually. (In March 1989 reporting the threshold decreases from 4536 to 227 kg, and in March 1990 reporting the threshold decreases to 0 kg).

- Section 313 - By July 1, 1988, Toxic Chemical Release Forms were submitted to WDOE and EPA for reportable chemicals and chemical categories (i.e., copper and copper compounds) used on Site in excess of 4536 kg per year. These forms must be submitted annually after 1988.

WASTE RECEIVING AND PROCESSING FACILITY

The Waste Receiving and Processing (WRAP) Facility for inspecting, assaying, and treating radioactive solid waste producing a transuranic waste component for shipment to the Waste Isolation Pilot Plant (WIPP) and a low-level waste component for onsite disposal is in the conceptual design stage. The construction of WRAP will occur in two phases.

Phase 1 will provide the capability to receive, assay, and package wastes. Once operational in September 1996, phase 1 will allow for the removal of wastes from the current transuranic waste storage pads for preparation prior to shipment to WIPP in New Mexico. Such action will allow for closure of the storage pads under RCRA.

Phase 2, which will be operational in September 1999, will provide the treatment systems necessary for both transuranic and mixed wastes prior to their final disposal. Low-level mixed wastes are currently being stored at Hanford awaiting RCRA-qualified treatment and disposal facilities.

HANFORD WASTE VITRIFICATION PLANT

The RCRA does not allow for the long-term storage of hazardous wastes which are restricted from land disposal. The Hanford Waste Vitrification Plant (HWVP) will be constructed in order to treat much of the waste currently stored in double-shell underground storage tanks. The HWVP may also be required to eventually treat the wastes that are retrieved from the single-shell tanks. The HWVP is presently in the conceptual design stage and construction is scheduled to commence in July 1991. The high-level waste fraction resulting from the pretreatment of the stored wastes would be immobilized into borosilicate glass and stored at the HWVP facility until a geologic repository is ready to receive this waste. The low-level waste fractions would be solidified as a cement-based grout and disposed of near surface in preconstructed, lined concrete vaults.

2.2 OPERATIONAL HIGHLIGHTS AT HANFORD IN 1988

R. E. Jaquish

The following are highlights of operational activities at Hanford during 1988:

• The N Reactor did not operate during 1988. The reactor is now in a "cold standby" condition that preserves the capability of restart. Operations at the 300 Area reactor fuel fabrication facilities were also placed in "cold standby."

• In the 200 Areas, the Plutonium Uranium Extraction (PUREX) Plant operated throughout the year reprocessing about 590 metric tons of irradiated reactor fuel. The Remote Mechanical-C Line at the Plutonium Finishing Plant operated for a total of 4 months, but the Plutonium Recovery Facility did not operate. The 242-A Evaporator processed high-level waste for about 8 months, and the Transportable Grout Facility began initial operation in August and operated about 1 month.

• The Fast Flux Test Facility (FFTF) achieved a 98.9% efficiency factor while operating during 1988. The test reactor also operated at a capacity factor of 78.5% and an availability factor of 81.2%. Several research and laboratory facilities operated to support FFTF and other Hanford facilities.

• The Basalt Waste Isolation Project (BWIP) underwent the first phase of closure and reclamation during 1988. Reclamation was begun at the Near Surface Test Facility on Gable Mountain by removing all test equipment, filling the mine shafts and boxcuts with spoils originally removed during mining, importing soil to rocky areas, and restoring original contours. The large drill rig at the Exploratory Shaft Site was sold, and all material was removed from the site. The gravel stabilizer was removed and the site was recontoured to match natural contours. Native grasses and shrubs were planted to restore original cover. Gravel was removed from a total of 34 borehole sites totaling some 56 acres (22.7 ha), of which some 41 acres (16.6 ha) have been planted with native species.

• On November 4, 1988, Congress enacted Public Law 100-605 authorizing a study of the Hanford Reach of the Columbia River. The law directs the Department of Interior, in consultation with the Secretary of Energy, to conduct a study of the Hanford Reach and its immediate environment (i.e., fish and wildlife, geologic, scenic, recreational, natural, historical, and cultural values) and examine alternatives for their preservation. It also includes a provision to consider the potential addition of all or part of the study area to the National Wild and Scenic Rivers System. For 8 years after the enactment of this law, interim protection of the area is provided through a provision that all existing projects that affect the study area shall be operated and maintained to minimize any direct and adverse effects on the values for which the river is under study.

• In 1988, negotiations between EPA, the Washington Department of Ecology (WDOE), and DOE were conducted to establish a Tri-Party Agreement. The scope of the agreement is to 1) achieve full *Resource Conservation and Recovery Act of 1976* (RCRA) compliance and the final RCRA permit for the Hanford Site, including closure of inactive RCRA treatment, storage, and disposal facilities and 2) cleanup of inactive waste sites as RCRA corrective actions or remedial actions under the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA). The agreement will: 1) clearly define all commitments with the regulatory agencies and ensure they are properly prioritized, 2) provide a basis for obtaining needed resources, and 3) reflect a concerted effort to achieve full regulatory

compliance and cleanup of the Hanford Site. Completion of the Tri-Party Agreement is expected in 1989.

• More than 30 surplus facilities at the Hanford Site have been demolished/stabilized. These include support facilities, stacks, and effluent systems. In 1988, the 117-C Filter Building was demolished, and concrete slabs at 100-B, 100-D, and 100-F Areas were removed. Work continued on decommissioning of the Strontium Semiworks and the 183-H Solar Evaporation Basins. Decommissioning of the Strontium Semiworks, which began in 1984, is scheduled to be completed in 1989 when an engineered earthen barrier is placed over the decommissioned site. Cleanup and closure of the 183-H Solar Evaporation Basins began in 1986. Westinghouse Hanford Company prepared a closure plan and submitted it to the WDOE in 1988.

• The National Priorities List (NPL) is an ordered ranking of CERCLA sites. Sites are evaluated using the hazardous ranking system and placed on the NPL in order of decreasing potential hazard. The hazardous ranking system score establishes the priority in which the sites will be funded by the EPA and remediated. The initial effort toward proposing Hanford inactive sites to the NPL started in 1986 with a DOE report on assessment of inactive waste sites at Hanford. The NPL package for Hanford that was proposed to the EPA comprised four aggregate areas in which 337 CERCLA sites have been identified. On June 21, 1988, EPA Region 10 issued an information bulletin announcing a 60-day public comment period for the proposal packages to add the Hanford Site waste sites to the NPL. After considering all comments, EPA will add the Hanford waste sites to the NPL if the sites meet established criteria for the NPL listing. Inclusion on the NPL will mandate funding and initiation of cleanup of the four sites.

• Work at Hanford during 1988 also included National Environmental Research Park (NERP) and Arid Lands Ecology (ALE) studies and continued operation of various national research and laboratory facilities.

2.3 1988 ENVIRONMENTAL OCCURRENCES

R. W. Hanf

Onsite and offsite environmental occurrences (spills, leaks, etc.) of radioactive effluent materials during 1988 were reported to DOE by onsite contractors. Environmental occurrences of nonradioactive chemical wastes were reported to other federal and state agencies as required by law. The specific agencies notified depended on the type, amount, and location of the individual occurrences. Generally, effluents were dispersed naturally, stabilized in existing waste disposal sites, or controlled and cleaned up. In some cases, particularly where the contaminants may have reached the ground water, the environmental impact is under continuing observation and evaluation. Occurrence reports, including event descriptions and corrective actions, are available for review in the DOE Richland Operations Office (DOE-RL) Public Reading Room at the Federal Building, Richland, Washington. The 1988 occurrences with the greatest potential environmental impacts are summarized below.

High Lead Content in 300-Area Weekly Process Sewer Composite Sample (WHC-UO-88-26-300-1)

About 150 ppb of lead were found in a 300-Area process sewer composite sample for the period ending May 24, 1988. A total lead release to the process trench of 4.5 kg was calculated based on the total weekly process sewer flow for the week. This amount violated the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Reportable Quantity Limit of 0.5 kg per 24-hour period. The DOE-RL, EPA, and Washington State Department of Ecology (WDOE) were notified. Investigations by 300-Area building managers failed to identify the origin of this lead contamination, and no mechanism was identified that could have resulted in contamination of analyzed samples.

Decrease in Liquid Level in Waste Tank Exceeds Criteria (WHC-UO-88-028-TF-03)

A single-walled waste storage tank located in the 200-West Area was declared an assumed leaker when the interstitial liquid level exceeded the 0.09-m decrease criteria. Planned action included stabilizing the tank by transferring all pumpable liquid to a new double-walled tank. NOTE: Information was obtained from a preliminary occurrence report; the post-investigative final report had not been issued at the time this document was prepared.

Unauthorized Release of Water to the Columbia River (WHC-UO-88-021-SWU-02)

On May 17, 1988, approximately 567,750 L of water overflowed from the 182-B reservoir to the Columbia River via a sewer line from the decommissioned 105-B Reactor facility and the nonpermitted 1904-B outfall. This intentional, but unauthorized, overflow was the result of an attempt by a power operator to skim off a small oil slick that was floating on the reservoir surface. This was the first known overflow of this reservoir and was a violation of the EPA's Clean Water Act (utilization of a nonpermitted release point to a navigable water source). A water sample collected from the 1904-B outfall showed concentrations of ^{60}Co and Cs, but levels for both were below current release limits.

Possible Leak in Waste Tank (WHC-UO-88-034-TF-05)

Surface-level measurements in a 200-East Area single-walled waste tank indicated that residual liquid material may have leaked or evaporated from the tank. As a precautionary measure, surface-level monitoring was increased, and plans were made to transfer all

remaining pumpable liquid to another storage unit. NOTE: Information was obtained from a preliminary occurrence report; the post-investigative final report had not been issued at the time this document was prepared.

The Release of More Than 45 kg of Ammonia During a 24-Hour Period (WHC-UO-88-027-PUREX-05)

Ammonia produced during a fuel decladding operation was improperly exhausted when the lid to a dissolver unit was not properly closed. This resulted in a release to the atmosphere [both inside and outside the Plutonium Uranium Extractor (PUREX) Plant] of approximately 450 to 635 kg of ammonia. This exceeded the CERCLA limit of 45 kg per 24-hour period. When personnel realized that the leak was due to an improperly secured lid, the dissolver unit was shut down and stabilized. The declad solution was removed, and the dissolver was refilled with water. No radionuclide limits were exceeded. Any radiation exposure to employees inside the plant was considered insignificant because of very low radionuclide concentrations and short exposure times.

A Surface-Level Decrease Is Measured in a Single-Walled Tank (WHO-UO-88-043-TF-07)

A single-walled waste storage tank was suspected of leaking when measurements indicated an abnormal decrease in surface levels. The contents of the tank were removed to another storage unit. NOTE: Information was obtained from a preliminary occurrence report; the post-investigative final report had not been issued at the time this document was prepared.

2,4-D Amine Spill to Asphalt, 19 L (WHC-UO-88-019-RAM-01)

This incident occurred because a fork-lift operator failed to use due caution when off-loading palletized 19-L cans of material. A can on one pallet was inadvertently punctured when the operator tried to set another pallet next to it. A pool of 2,4-D Amine was found under a pallet after a strong odor was detected. The area was immediately cordoned off, and an absorbent material was dispersed to control the spread of the spill. Cleanup was completed in about 10 days.

Excess Ammonia Gas Release (WHC-UO-88-035-PUREX-07)

An ammonia leak in excess of the federal reporting limit of 45 kg per day occurred at the PUREX Plant during a test of the ammonia scrubber system. Planned action included resetting monitoring alarms to warn personnel when ammonia emissions were approaching regulatory limits and issuing new training information to plant personnel to clarify existing ammonia limits and controls. NOTE: Information was obtained from a preliminary occurrence report; the post-investigative final report had not been issued at the time this document was prepared.

A Spill of 25 L of Everite Formula-ST (Waste Alkaline Liquid) to a 300-Area Asphalt Parking Lot

Approximately 25 L of a 4.3% sodium nitrite solution were released to an asphalt roadway in the 300 Area when the bottom of a polyethylene carboy broke as it was being loaded into a pickup truck. Absorbent material was used to cleanup as much of the spill as possible from the pickup and the asphalt. It was estimated that all but approximately 1.9 L was recovered. Apparently, this carboy had been stored outside, and the plastic may have been brittle due to exposure to the sun. The amount spilled was a reportable quantity, and DOE-RL and WDOE were notified. Polyethylene carboys holding liquid wastes are no longer stored in outside areas.

Tanker Truck Overflows, 38 L (WHC-UO-88-032-B PLANT-01)

About 38 L (48 kg) of aluminum nitrate nonahydrate, a nonradioactive acidic liquid, were

spilled onto a blacktopped area when workers overfilled a 17,790-L tanker truck at the 211 Tank Farm. The contamination was confined to a small area, stabilized and immediately cleaned up. However, because the volume of the spill exceeded environmental guidelines, state and federal authorities were notified.

337 Liters of Gasoline Spilled to the Ground (WHC-UO-88-004-R,D&EO-1)

When dispensing gasoline from a tank truck to underground storage tanks at the 100-N fueling station, an employee failed to notice that the automatic shutoff on the tanker truck's fuel nozzle failed to operate, allowing 337 L of gasoline to overflow onto the surrounding area. An additional small spill occurred when the employee filled a second underground tank using another nozzle and it, too, failed to shut off. These spills were reportable because they exceeded the EPA 100-kg reportable quantity set for dangerous wastes (the gasoline was designated an ignitable dangerous waste). To prevent recurrence, the defective nozzles were replaced. In addition, the fuel truck dispensing procedures were revised so that the service station tanks can only be filled to 90% of their capacity, and a thorough review of fueling operations and procedures was conducted.

Suspected Leak in Hanford Waste Tank (WHC-UO-88-029-TF-04)

A single-walled underground waste storage tank in the 200-East Area was suspected of leaking when surface-level measurements indicated a drop of 3.18 cm over an extended time. This equates to the loss of about 10,219 L of material, more then can be accounted for by evaporation. Several dry wells located around the tank were monitored for increased activity, but no evidence of activity was detected. Most of the contents of this tank recently had been pumped to a new double-walled storage unit, and the tank had been sealed to prevent intrusion by liquids. As a precaution, the remainder of the liquid in the tank also will be pumped out. State and federal authorities were notified of this problem. NOTE: Information was obtained from a preliminary occurrence report; the post-investigative final report had not been issued at the time this document was prepared.

A Release of Nitrogen Dioxide (NO_2) Gas to the Atmosphere (WHC-UO-88-003-PUREX-01)

A solution containing sodium nitrite ($NaNO_2$) and sodium hydroxide was mixed inadvertently mixed in a tank containing residual amounts of 12-M nitric acid. Reaction of the these three materials generated a large amount of gas that escaped from the tank via the vessel vent system and room exhaust system. When the reaction was noticed, the tank agitator was immediately turned off, the tank contents were diluted with water, and the water to the tank's cooling coil was turned on. Calculations based on sample results taken before and after the incident indicate that between 45 and 91 kg of NO_2 gas were generated during a half-hour period. This amount was reportable because it exceeded the CERCLA reportable discharge limit of 4.5 kg.

Insecticide Spill (WHO-UO-88-011-ET-01)

At the 222-U Building in the 200-West Area, two 1.0-L bottles of "Vapona" insecticide were broken and spilled onto a 0.6-m area of asphalt. When discovered, the spill was stabilized with an absorbent material, and possible exposure side-effects were discussed with building personnel. Planned action included the removal of the contaminated asphalt. NOTE: Information was obtained from a preliminary occurrence report; the post-investigative final report had not been issued at the time this document was prepared.

3.0 ENVIRONMENTAL PROGRAM INFORMATION

3.1 ENVIRONMENTAL MONITORING AT HANFORD

R. E. Jaquish and R. W. Bryce

Environmental monitoring of the Hanford Site and annual reporting of results are conducted in accordance with guidance from DOE Orders 5480.1B, 5484.1, and 5400.1 (DOE 1986, 1981b, 1988c). It is DOE policy to conduct its operations in an environmentally safe manner and to comply with the letter and spirit of applicable environmental statutes, regulations, and standards. DOE orders require that each site conduct monitoring through measurement and calculation of the effects of site operations on the environment and public health. This section describes the Hanford environmental monitoring programs.

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 are to:

- assess environmental impacts from Hanford Site operations to the offsite public during 1988 and identify noteworthy changes in the radiological and chemical status of the environment

- verify that in-plant controls for the containment of radioactive and nonradioactive materials within controlled areas (i.e., on the Site) are adequate

- monitor to determine potential build-up of long-lived radionuclides in uncontrolled areas (i.e., off the Site)

- provide information on our assessment of the environmental impacts to regulatory agencies and the public. The impacts are assessed by environmental monitoring and dose calculations.

CRITERIA

The criteria for environmental monitoring are derived from requirements set forth in applicable federal, state, and local regulations, DOE orders, 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 the concepts 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 3.1 illustrates these potential routes

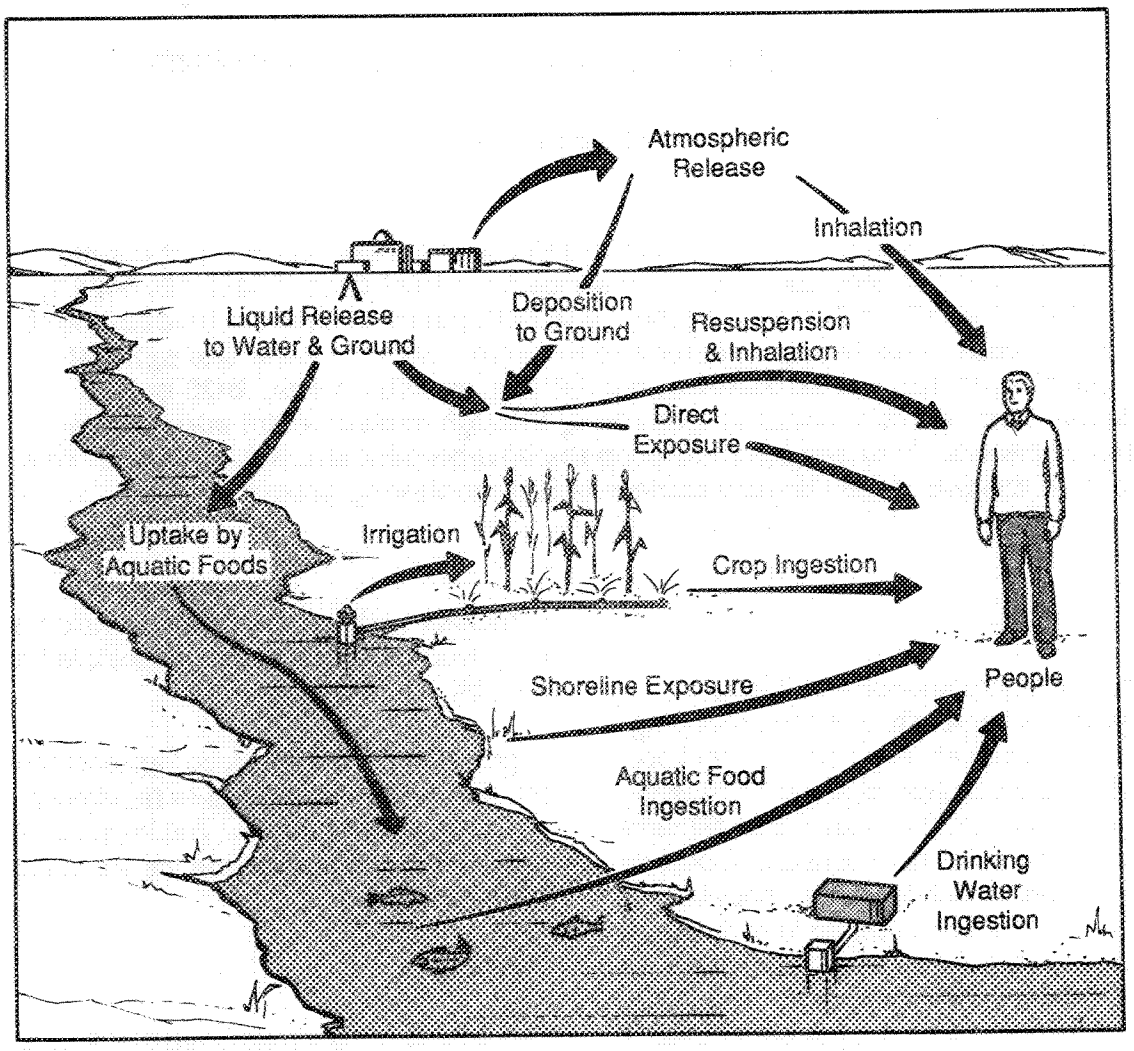

FIGURE 3.1. Primary Radiation Exposure Pathways

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 each pathway and its resultant radiation dose. To ensure that radiological analyses of samples are 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 and known biological effects of radiation exposure are used to determine what is important to monitor. Environmental

monitoring consists of collecting and analyzing samples and performing measurments of penetrating radiation. Selected ground-water and surface-water samples are also analyzed for hazardous chemical constituents. Monitoring at Hanford is designed to meet the objectives of determining the environmental and public health impacts of Hanford operations, and is not intended to provide a detailed radiological and chemical characterization of the Site or the surrounding area. The monitoring design takes into account that the releases from Hanford are low and are constantly monitored. Calculations based on effluent data show the expected concentrations off the Hanford Site to be low and for most radionuclides to be below the level that can be detected by monitoring. Past monitoring data show that the concentrations of radionuclides in environmental samples are detectable onsite near operating facilities and decrease with distance. At the perimeter of the Site and beyond, concentrations decrease to the level where only a few radionuclides are detectable (see "Environmental Monitoring Information," Section 4.0).

Environmental monitoring investigates environmental pathways that may contribute to radiation exposure of the public. Pathways are derived from previous studies and observations of radionuclide movement through the environment and through food chains. Environmental and food-chain 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 potentially critical pathway for rapid transport of radioactive materials off the Site. Ground water is sampled from wells located near operating areas and along potential transport pathways. In addition to air and water monitoring, samples of soil, native vegetation, and wildlife are collected and radiation measured to determine the effectiveness of effluent controls and any build-up 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 includes a series of sampling stations and ground-water monitoring wells positioned around the Site perimeter. Data from these stations document the levels of radioactivity at the Site boundary. Both hazardous chemical and radiological concentrations are measured in ground-water samples. 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. Water quality monitoring is performed by the U.S. Geological Survey (USGS) at the Priest Rapids Dam and at Richland.

The third monitoring zone consists of nearby and distant community locations within an 80-km radius of the Site. Monitoring at communities provides an assurance to the public that Hanford effluents are monitored and radionuclide concentrations are 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 doses received by the public are calculated from environmental monitoring data when Hanford-related radionuclide concentrations are measurable. However, data from the offsite environs and communities near the Site usually do not indicate a measurable effect from Hanford operations. When concentrations are too low to be detected by monitoring, 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 estimate the resulting radiation dose. In addition, the dose from the air pathway must also be calculated with AIRDOS-EPA and RADRISK models specified in DOE orders.

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. Numerous samples were collected and analyzed according to a predefined plan. Measured concentrations of radioactive materials were compared to applicable standards, concentration guides, natural levels of radiation, and results of other monitoring organizations. The program was designed to examine significant exposure pathways, including direct radiation exposure from operating facilities. Radiological impacts, based on environmental monitoring or effluent monitoring and modeling, are expressed in terms of radiation dose.

Table 3.1 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.

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, Hanford Environmental Health Foundation (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 program. Details on sampling, analysis, measurement, dose assessments, and QA are discussed in the sections that follow.

TABLE 3.1. Routine Environmental Sample Types and Measurement Locations

	Sample Locations				
	Total Number	Onsite	Perimeter	Nearby Communities	Distant Communities
Air	50	21	14	9	6
Ground Water	624	624			
Columbia River	4	1	2	1	
Irrigation Water	1		1		
Drinking Water	12	8	4		
Ponds	3	3			
Foodstuffs	7		4	1	2
Wildlife	12	11	1		
Soil & Vegetation	38	15	14	3	6
Dose Rate	90	30	45	9	6
Waste Site Surveys	73	73			
Railroad/Roadway Survey	16	16			
Shoreline Survey	14		14		

3.2 ENVIRONMENTAL STANDARDS AND PERMITS

R. E. Jaquish

RADIATION PROTECTION STANDARDS

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 radiation exposures to members of the public in uncontrolled areas. The revision is based on recommendations of the International Commission of 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 B.5, Appendix B). 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 (DOE 1988a, 1988b). 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.

The National Interim Primary Drinking Water Regulations of the Safe Drinking Water Act and the State of Washington regulations have limits for radionuclides and chemicals in drinking water. For man-made radionuclides, the dose limit from drinking water is 4 mrem/year to the whole body or any internal organ. The details of the radionuclide and chemical limits are described in Tables B.2 and B.3, Appendix B.

ENVIRONMENTAL PERMITS

A National Pollutant Discharge Elimination System (NPDES) permit is required for discharges to surface waters of the United States. The original Hanford NPDES permit was issued by the Environmental Protection Agency (EPA) in 1977. The current permit (WA0003743) was issued in 1981, and is being renegotiated with EPA at this time.

There are eight separate discharges included in the Hanford NPDES permit. Those discharges (outfalls) are:

003 — 181KE inlet screen backwash (100-K Area)

004 — 1908K outfall (100-K Area)

005 — tank farm storage water overflow (100-N Area)

006 — 182N Building drain (100-N Area)

007 — 181N inlet screen backwash (100-N Area)

009 — raw water return line (100-N Area)

013 — PNL fish farm (300 Area)

N-Springs — A nonpoint source along the river bank emanating from the deactivated 1301N and operating 1325N cribs (100-N Area).

The Hanford NPDES permit includes requirements for sample collection frequency and analyses to be performed on each sample. Each sample requirement has an associated NPDES permit limit, and each outfall has different sample requirements. Sample requirements include temperature, flow, pH, free available chlorine, total suspended solids, oil, grease, iron, ammonia, and chromium. Sampling activities for each outfall are summarized and reported to EPA on a monthly basis.

A Prevention of Significant Deterioration (PSD) permit is required for the discharge of airborne contaminants in excess of levels specified in 40 CFR 52, Prevention of Significant Deterioration of Air Quality. The only PSD permit (PSD-X80-14) in effect for the Hanford Site was issued by EPA in 1980. This permit covers nonradioactive emissions from PUREX and the UO_3 Plant limiting the oxide of nitrogen (NO_x) from the facilities. Any modifications to this permit must be approved by the Benton, Franklin, and Walla Walla Counties Air Pollution Control Authority and the WDOE.

The PUREX Plant and UO_3 Plant stacks are monitored for NO_x and gas flow rates. Monitored rates must fall within permit parameters. Any excess emission reports are submitted to EPA on a quarterly basis. One PSD violation (UO No. 88-31) occurred in CY 1988.

Regulatory compliance with the Resource Conservation and Recovery Act of 1976 (RCRA) for hazardous waste treatment, storage for more than 90 days, or disposal facilities is implemented through acquisition of permits. These permits, which specify requirements for operation, closure, and post closure care, are granted by EPA and WDOE. Permit applications are submitted by DOE to the regulatory agencies in two parts: 1) Part A identifies the facility, provides its design capacity, and identifies the hazardous waste to be handled and 2) Part B provides detailed facility descriptions and identifies future operations and how the facility will be closed. Submission of a Part A application allows for continued operation of facilities under interim status. A permit for continued operation is granted after an EPA and the WDOE review of submitted applications, the collection of additional information to support the applications, negotiations regarding permit requirements, public review, and a formal final decision on the applications.

At the Hanford Site, one Part A application with 58 treatment, storage, and disposal groups has been submitted to the WDOE for all known facilities that treated, stored for more than 90 days, or disposed of hazardous or radioactive mixed waste except radioactive mixed waste before November, 1987. Those facilities handling hazardous waste that will continue future operations as treatment, storage, and disposal facilities will operate under interim status and will be permitted only for closure of the past practice units as outlined in the Tri-Party Agreement Action Plan. Part B permit applications or closure plans have been submitted for 29 facilities.

The Hanford Site also has two permits for wildlife and fish sampling. These are 1) Scientific Study or Collection Permit No. 131 issued to PNL by Washington State Department of Wildlife for the collection of wildlife, including fish for environmental monitoring purposes and 2) Federal Fish and Wildlife Permit No. 671877 issued to PNL by the U.S. Fish and Wildlife Service.

3.3 ENVIRONMENTAL IMPACT STATEMENTS AND ENVIRONMENTAL ASSESSMENTS

R. E. Jaquish

No draft or final environmental impact statements (EIS) covering Hanford activities were completed in 1988. The Record of Decision (ROD) for the Hanford Defense, Transuranic, and Tank Waste EIS (1987a) was issued in April 1988.

3.4 RELATED ENVIRONMENTAL ACTIVITIES

J. C. Chatters, D. J. Holtink, and W. H. Rickard

WILDLIFE RESOURCES

The Hanford Site consists of mostly undeveloped semiarid land with a few scattered clusters of industrial buildings connected by a surface network of roadways, railroads, and electrical transmission lines. The intervening land supports sagebrush/grass vegetation that provides food and cover for native species of wildlife whose populations have generally been diminished elsewhere in southeastern Washington largely because cultivated crops have replaced stands of native sagebrush/grass vegetation.

The objective of the Wildlife Resources Project is to monitor rare, threatened, or endangered species; to monitor species of wildlife and fish that are valued as commercial, recreational, or aesthetic resources; and to monitor those species that can be used as biological indicators of toxic and hazardous materials in the environment.

The Columbia River as Fish and Wildlife Habitat

The Hanford Reach of the Columbia River is the last unimpounded segment of the Columbia River in Washington State, and its shoreline remains mostly undeveloped. It provides habitat for wildlife populations as well as fish. The Hanford Reach is also being considered for status as one of the nation's wild and scenic rivers (HR 3614). It provides the most important area in the main stem Columbia River for fall-spawning Chinook salmon (*Oncorhynchus tschawytscha*). The number of redds has been counted by aerial flight surveys each autumn since the 1940s by DOE and its predecessor agencies. In recent years, the number of salmon redds (shallow basins in river gravels scraped by adult salmon) established in the Hanford Reach has dramatically increased (Figure 3.2). The

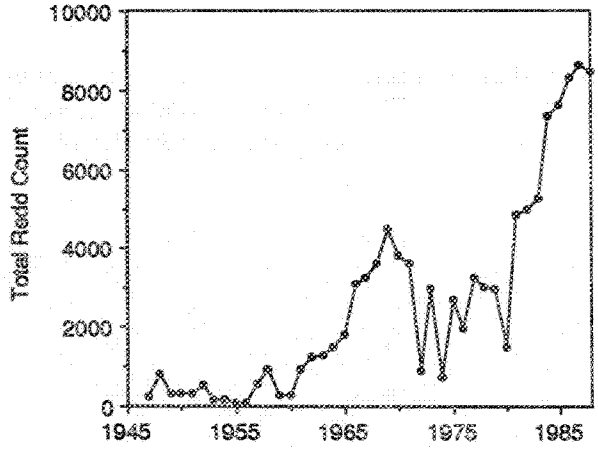

FIGURE 3.2. Counts of Chinook Salmon Spawning Redds in the Hanford Reach of the Columbia River, 1947 Through 1988

increase is attributable to the coordinated efforts of various federal and state agencies, Indian tribes, and others dedicated to maintaining Columbia River salmon runs.

The bald eagle (*Haliaeetus leucocephalus*) is listed as a threatened species in the State of Washington by the U.S. Fish and Wildlife Service and the Washington State Department of Wildlife. Bald eagles have historically spent winter months along the Hanford Reach and have been counted by aerial flight surveys since 1961. In recent years, the population of wintering eagles has increased (Figure 3.3). This can be attributed to an increased food source provided by increased numbers of spawned-out salmon carcasses. Other factors that encourage the use of the Hanford Reach by bald eagles are the presence of a few tall trees near the river that provide daytime perches and nighttime roosts, and the isolation from threatening human disturbances provided the perch sites by the limited-access regulations enforced by Hanford Site security.

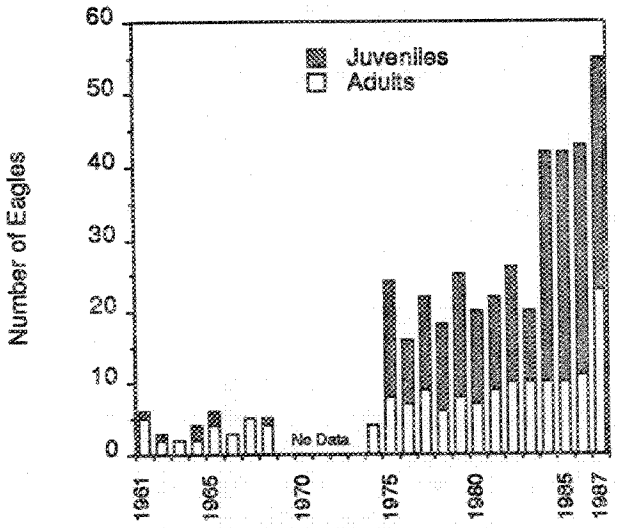

FIGURE 3.3. Maximum Numbers of Bald Eagles Seen Along the Hanford Reach of the Columbia River During Aerial Flights in Fall and Winter Months, 1961 Through 1987

The Great Basin Canada goose (*Branta canadensis moffitti*) is valued as a recreational resource and also as an aesthetic resource. Canada geese have historically nested on the sparsely vegetated islands in the Hanford Reach of the Columbia River. Goose nests established on these islands have been counted each year since 1953 by searching each island on foot during the spring nesting season (Figure 3.4). Over this period, the nesting population has varied from year to year, but there has been a shift in island use by nesting geese. In the 1950s and 1960s, the islands upstream from Ringold had more nests; however, in the 1970s and 1980s, the islands downstream have received most of the nests. The shift is attributed to persistent coyote (*Canis latrans*) intrusion to the upstream islands.

Sagebrush/Grass Vegetation on the Hanford Site as Wildlife Habitat

Elk (*Cervus elaphus*) were not inhabitants of the Hanford Site when it was established in the early 1940s. Elk first appeared in 1972, probably from Cascade Mountain herds, and by 1977 they had established a small breeding population on the Arid Lands Ecology (ALE) Reserve, a protected portion of the Hanford Site used for ecological research. In the absence of predators and competition for the grasses and other forage plants by grazing livestock, the herd rapidly increased. Elk from the ALE Reserve easily crossed fences built to exclude livestock, and they damaged many newly planted orchard trees on private property adjacent to the reserve. To reduce damage to orchards, an autumn hunting season was established by the Washington State Department of Wildlife on the private lands bordering the reserve. Hunting reduced the size of the herd to approximately 90 animals in the fall of 1988. The size of the elk herd now is probably within the capacity of the ALE Reserve to sustain the herd without incurring permanent damage to the forage resource.

The Hanford Site provides nesting sites, trees, cliffs, powerlines, and sagebrush/grass habitat for red-tailed (*Buteo jamaicensis*), Swainson's (*Buteo swainsonii*), and ferruginous hawks (*Buteo regalis*) (Figures 3.5, 3.6, and 3.7). Hawk populations have been diminished elsewhere in eastern Washington due to the loss

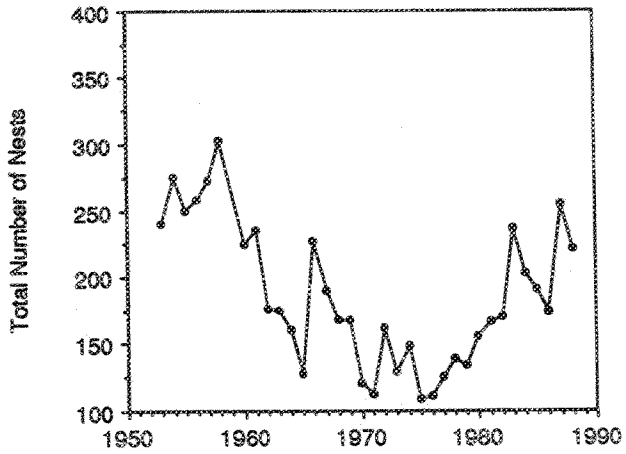

FIGURE 3.4. Number of Canada Goose Nests Established on Islands in the Hanford Reach of the Columbia River, 1953 Through 1988

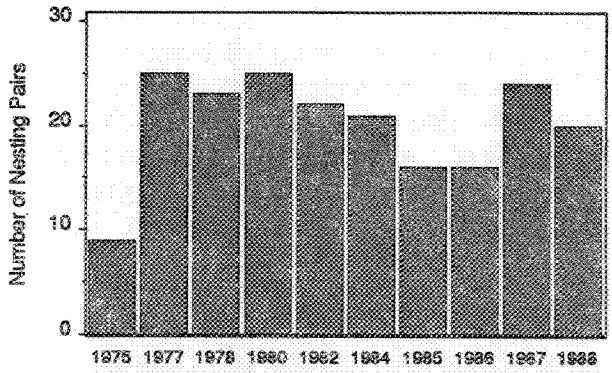

FIGURE 3.5. Nesting Pairs of Red-Tailed Hawks

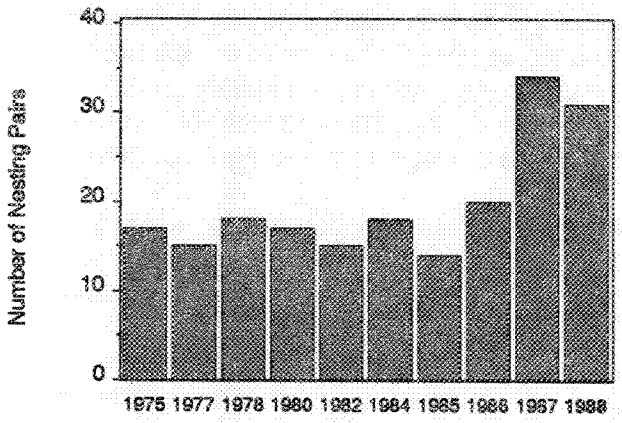

FIGURE 3.6. Nesting Pairs of Swainson's Hawks

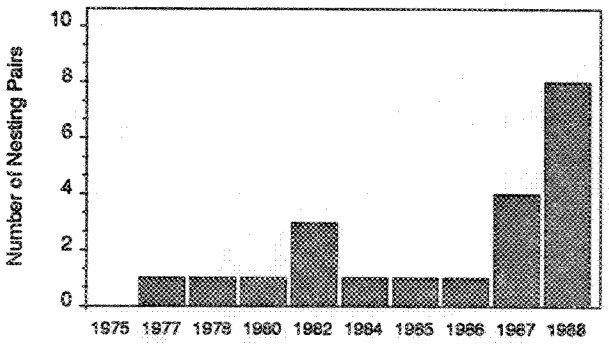

FIGURE 3.7. Nesting Pairs of Ferruginous Hawks

of suitable nest sites and habitat suitable during the brood-rearing season when parent birds forage to feed their young.

In recent years, the number of nesting ferruginous hawks, a species with a very low population in Washington State and listed as endangered by the Washington State Department of Wildlife, has increased (Figure 3.7). The increase is attributed to the hawks' acceptance of recently constructed electrical transmission line towers as nesting sites.

CULTURAL RESOURCES

The purpose of the cultural resources monitoring is to maintain compliance with the National Historic Preservation Act, the Archaeological Resources Protection Act (ARPA), and the American Indian Religious Freedom Act. A cultural resource is any phenomenon having demonstrable association with prehistory, historical events or individuals, or extant cultural systems. This includes archaeological sites, districts, and objects; standing historic structures; locations of important historical events; and places, objects, and living or nonliving things that are important to the practice and continuity of traditional cultures. Monitoring activities include 1) reviews of all proposed land-disturbing projects to assess potential impacts to cultural resources (Section 106 Reviews) and 2) periodic inspections of known archaeological and historical sites to determine their condition and the effects of land management policies on the sites (Section 110 Monitoring).

Section 106 Reviews were initiated for 150 projects in 1988, of which 133 were completed during the calendar year. Twenty-three of the cases affected undisturbed ground, and archaeological surveys were conducted. Another nine cases required monitoring by an archaeologist observer during earth disturbance. The remainder consisted of either facilities maintenance or new construction in industrialized areas and did not entail new disturbances to the landscape. The majority of reviews were of projects in the 200 Areas (69%) and 100 Areas (19%). Sixteen prehistoric archaeological sites and five historic archaeological sites were discovered. Planned locations of six projects intersected

archaeological and/or historic sites. Impacts to these sites were avoided by relocating the projects or through easement agreements. On four occasions it was necessary to consult with Indian tribes over potential impacts of projects on sites or landscapes important to their culture or religion. In each case it was possible to incorporate Indian concerns into plans for protecting or avoiding culturally significant properties.

Section 110 Monitoring is a new project that began in the last quarter of 1988. Its purpose is to determine the current condition of known archaeological and historic sites so that the impact on them from future Site management policies can be assessed from periodic future re-inspections. An important aspect of Section 110 Monitoring is to identify sites that are being looted by artifact collectors so that law enforcement personnel can increase site surveillance and apprehend violators of ARPA. Additional cultural resource sites are being discovered in the process of monitoring; some recorded sites can no longer be located and will be removed from site lists. During the first year of Section 110 Monitoring, 42 sites have been chosen for inspection by a stratified random sampling design. Stratification for sampling was based on site functional type (e.g., house pit camp, fishing camp, etc.) as described in the site record forms of the Office of Archaeology and Historic Preservation in Olympia, Washington. Thirteen sites have been inspected thus far, resulting in the removal of six from site records as spurious. An additional nine sites have been discovered. Two of the inspected sites had been looted during the calendar year, stimulating an effort to increase surveillance by the Hanford Patrol.

METEOROLOGY AND CLIMATOLOGY

The objective of the Meteorological and Climatological Services Project is to maintain a staff of professional meteorologists who will operate the Hanford Meteorology Station (HMS) and be responsive to the meteorological and climatological needs of DOE Richland Operations Office (DOE-RL) and its Hanford Site contractors in the areas of emergency response, synoptic weather forecasts (i.e., production, general and severe weather), and climatological data requirements. With respect to the annual environmental report, the Meteorological and Climatological Services Project provides the meteorological data (i.e., wind speed, wind direction, and atmospheric stability) for calculating the atmospheric dispersion used in dose calculations.

General Climatology of the Hanford Area

Hanford's climate is dry and mild; the Site receives approximately 16 cm of precipitation annually and about 40% occurs during November, December, and January. Only 10% of the total annual precipitation falls in July, August, and September. Approximately 45% of all winter season precipitation 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 15 km/h in summer to 10 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 semiarid climate where frequent strong temperature inversions occur at night and break during the day, resulting in unstable and turbulent wind conditions.

1988 Climatology

The year 1988 was one of the warmest on record at the HMS. Eight months were warmer than normal. Only 2 months had average temperatures that were 0.3°C or more below normal. The average annual temperature for 1988 of 12.7°C was 0.9° above normal (11.8°C) and was the seventh warmest since record-keeping began for the Hanford region in 1912. The years 1934 and 1958, which averaged 13.4°C, were the warmest years; while 1985, which averaged only 9.8°C, was the coldest.

Precipitation for 1988 totaled 10.5 cm, 66% of normal (15.8 cm); it was the driest year since 1976 when only 7.6 cm of precipitation were recorded (the driest year on record). Calendar year snowfall totaled 23.6 cm; normal is 34.8 cm. Snowfall for the 1987-88 winter season totaled 29.5 cm. The greatest winter snowfall occurred during 1915-16 with 110.7 cm; the least, with only 0.8 cm, occurred during 1957-58.

The last 2 months of the winter of 1987-88 (January and February) were warmer and drier than normal, and set the stage for the remainder of the year. Temperatures for the 2 months averaged 1.4° above normal, and precipitation totaled only 1.2 cm, 31% of normal (3.9 cm). Snowfall received during January and February 1988 totaled 14.2 cm, slightly below the 18.3 cm that is normal for these 2 months. The 1987-88 winter season (December 1987, January and February 1988) averaged 1.6°C, 0.6° warmer than normal (0.9°C). The warmest winter on record (1933-34) averaged 5.1°C, and the coldest (1948-49) averaged -4.3°C. The coldest temperature during the winter was -12.8°C, recorded on December 19, 1987, and February 2, 1988. The final snow for the winter fell on January 20.

The spring months (March, April, and May) were warmer and wetter than normal. Spring was the only season during 1988 with above-normal precipitation. The average temperature of 12.3°C was 0.8° above normal (11.5°C); it was the fourth consecutive spring with above-normal temperatures. Precipitation totaled 4.6 cm, 139% of normal (3.3 cm). The greatest 24-hour precipitation (1.2 cm) and the highest wind gust (101 km/h) of 1988 occurred during a thunderstorm on April 29. This wind gust was the highest recorded at the HMS since March 13, 1983, when a 105-km/h gust was recorded. The highest wind gust ever recorded at the HMS was 129 km/h on January 11, 1972.

Summer 1988 (June, July, and August) was slightly warmer and much drier than normal. The temperature averaged 23.3°C, 0.2° above normal (23.1°C); like spring, it was the fourth consecutive summer with an above-normal seasonal temperature. The hottest summer daily maximum temperature was 40.6°C on July 26. Summertime precipitation totaled only 0.6 cm, 27% of normal (2.3 cm). July 14 through September 17 (66 days) was the second longest period on record without precipitation, and August was the first month in 33 years with zero precipitation. The longest period of zero precipitation was 69 days, from May 23 through July 30, 1919.

The autumn months (September, October, and November) were very warm and drier than normal. The average seasonal temperature of 13.6°C was 2.0° above normal (11.6°C); this was the second warmest autumn on record. The warmest was 13.7°C in 1963. The maximum daily temperature of 38.9°C on September 4 was a new record daily maximum, and the hottest temperature ever recorded so late in the year. Also, the 3 days in September with maximum temperatures above 37.8°C set a record for 37.8°C+ days during September. October 1988 was the warmest October on record, averaging 15.3°C (3.6° above normal, 11.7°C) and replacing October 1952, which averaged 15.0°C in the top spot. The minimum temperature of 15.6°C on both October 2 and October 15 tied the record for the warmest minimum temperature ever recorded during October. A 15.6°C reading was also recorded on October 1, 1917; October 25, 1945; and October 27, 1937. Autumn precipitation totaled 3.1 cm, 79% of normal (3.9 cm).

December 1988 was slightly colder and drier than normal. Although not a particularly noteworthy month climatologically speaking, it was the eighth consecutive December with a below-normal average monthly temperature. The last above-normal December occurred in 1980. Precipitation was less than half of normal, with snowfall 2.8 cm below normal for the month. December was the ninth month during 1988 with below-normal precipitation, completing a year that was the driest since

1976. Table 3.2 presents some additional statistics for 1988.

Table C.1, Appendix C, provides additional monthly climatological data from the HMS for 1988. Table C.2, Appendix C, provides a temperature summary of monthly and annual temperatures from the Hanford Telemetry Network for 1988, and Figure 3.8 shows wind roses for Hanford Telemetry Network stations for 1988.

TABLE 3.2. Meteorology Statistics for 1988

Category	1988	Normal
Days with maximum temperatures ≥32.2°C	61	52
Days with maximum temperatures ≥37.8°C	13	13
Days with minimum temperatures ≤0°C	102	112
Days with minimum temperatures ≤-17.8°C	0	3
Days with fog (visibility <9.6 km)	18	24
Days with peak wind gusts ≥64 km/h	30	26
Days with thunderstorms	4	10

HANFORD ENVIRONMENTAL DOSE RECONSTRUCTION PROJECT

The objective of the Hanford Environmental Dose Reconstruction Project is to develop estimates of the radiation doses that populations could have received from Hanford operations, with descriptions of the uncertainties inherent in such estimates.

The study was prompted by concern about potential health effects to the public from more than 40 years of operations at Hanford. In 1986, the Hanford Health Effects Review Panel—convened by the Centers for Disease Control at the request of the Washington State Nuclear Waste Board and the Indian Health Service—recommended that potential doses from radioactive releases at Hanford be reconstructed. Representatives from four northwest universities selected members of an independent Technical Steering Panel to oversee the dose reconstruction effort, which is conducted by the PNL and funded by DOE.

The period of study begins in September 1944 when the first reactor began operating. Potential radiation doses prior to 1957, when historical dose estimates were first reported in annual environmental monitoring reports, are being estimated. Doses reported after 1957 are being reviewed and, if necessary, modified using current dose assessment technology.

The study area boundaries, which are determined primarily be environmental concentrations of radionuclides emitted by past Hanford operations, are defined and limited by prevailing wind direction, weather patterns, topography, and the Columbia River and its estuary.

Within the study area, radiation doses are being estimated for the general population, special subpopulations, typical individuals, and specific individuals. The subpopulations (i.e., Hanford construction workers, Army personnel, Indian tribes, and migrant workers) have characteristics that could affect the dose estimates. Construction workers and Army personnel stationed at Hanford were close to the sources of emissions. Indian tribes differed in their dietary habits and other cultural factors that could have influenced dose. Migrant workers moved frequently and worked directly with the land.

Many radionuclides released from Hanford operations have not significantly affected populations because of low levels of emissions, losses during transport, short half-lives, mode of exposure, or low biological uptake. Key radionuclides are being selected for the study on the basis of their potential to result in doses to populations.

Preliminary dose estimates will be available in December 1989; complete results will be reported in 1992.

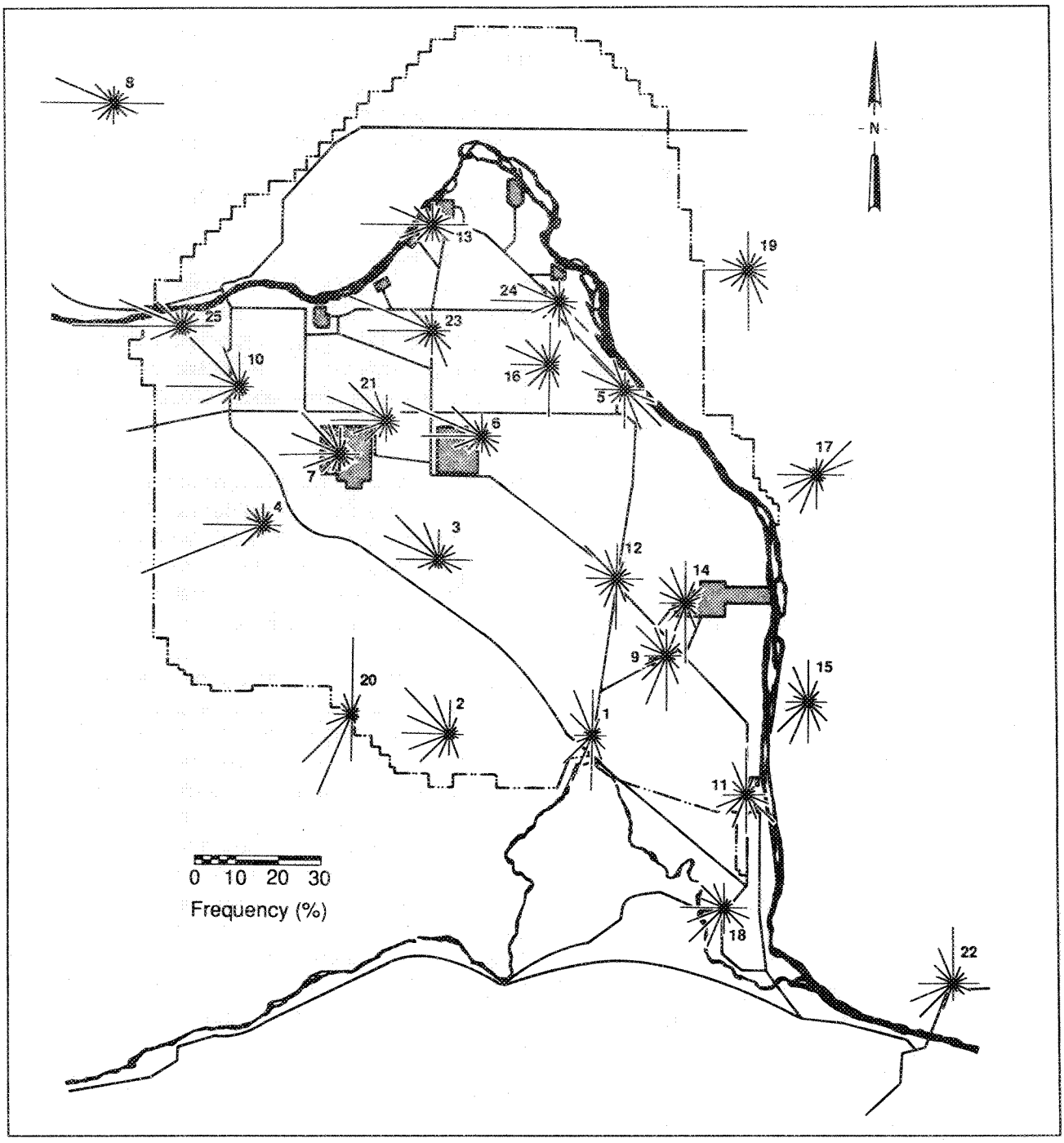

FIGURE 3.8. Hanford Telemetry Network Wind Roses for 1988[a]

(a) Wind rose arrows indicate direction from which wind blows. Length of arrow is proportional to frequency of occurrence from a particular direction.

4.0 ENVIRONMENTAL MONITORING INFORMATION

4.1 AIR MONITORING

R. K. Woodruff

Transport by wind of atmospheric releases of radioactive and nonradioactive materials from Hanford to the surrounding region represents a direct pathway for human exposure. 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 important locations. Nitrogen dioxide was sampled at seven locations onsite.[a]

Several 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 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 Plutonium Uranium Extraction (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 (0-100 km) community locations within the region and concentrations measured close to the Site.

In 1988, the annual average Hanford Site perimeter concentrations of airborne ^{3}H, ^{90}Sr, ^{137}Cs, and uranium were numerically greater than levels measured at distant monitoring stations, but the differences were not statistically significant (at the 5% significance level). Krypton-85 and ^{129}I concentrations were numerically greater at the perimeter stations than at the distant stations, and the differences were statistically significant (beyond the 5% significance level). However, even the maximum single perimeter sample for any radionuclide was only 0.3% of the applicable DOE Derived Concentration Guide (DCG) (Appendix B, Table B.6). The total dose from air emissions is compared to Clean Air Act and DOE dose standards in Section 4.8, "Potential Radiation Doses from 1988 Hanford Operations." Annual average NO_2 concentrations at all sampling locations remained well below federal and Washington State ambient air standards.

(a) Nitrogen dioxide sampling and analysis were performed by the Hanford Environmental Health Foundation (HEHF).

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 4.1 and Table C.3, Appendix C). 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 essentially 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 4.1. Airborne dust was sampled for 2 weeks by continuously drawing

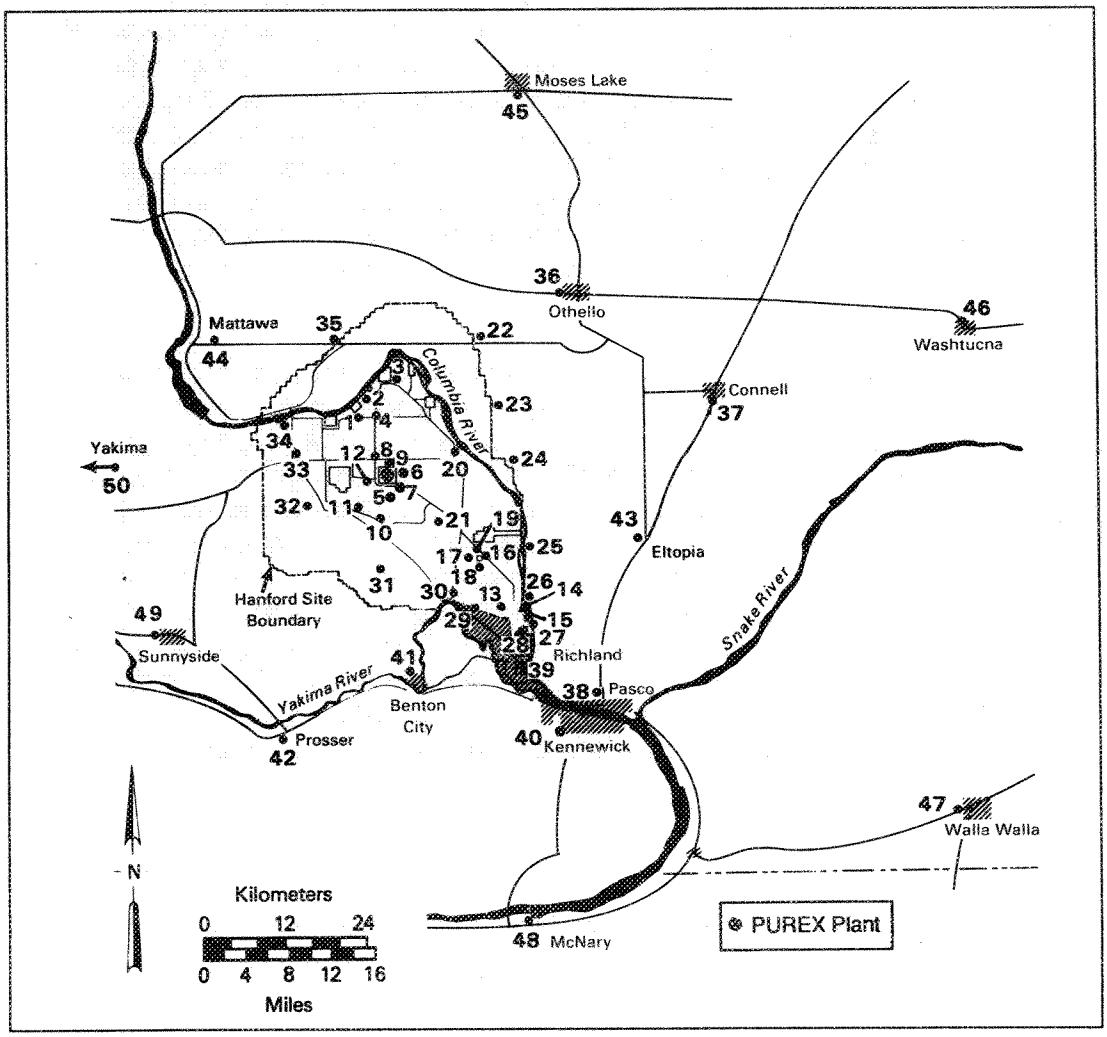

FIGURE 4.1. Air Sampling Locations (see Table C.3, Appendix C, for location key)

TABLE 4.1. Distribution of Air Sample Types by Location

Locations	Gross Beta	Gross Alpha	Particulates: ^{89}Sr, ^{90}Sr ^{238}Pu, $^{239,240}Pu$[a]	Particulates: Uranium[a]	Gases: ^{131}I[b]	Gases: ^{129}I	Gases: ^{3}H	Gases: ^{14}C	Gases: ^{85}Kr	Gases: NO_2
	Numbers of Locations Sampled									
Onsite	21	17	7/21	5/14	7/21	1	6	2	2	7
Perimeter	14	10	6/14	2/4	5/14	2	8	None	4	None
Nearby Communities	9	2	5/9	None	1/9	None	1	None	3	None
Distant Communities	6	2	4/6	2/2	2/6	1	2	2	2	None

(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 Appendix C, Table C.3 and shown in Figure 4.1.

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

air at a flow rate of 2.6 m^3/h through a 5-cm-diameter high-efficiency, fiber glass filter. The filters were collected every 2 weeks, field surveyed for gross radioactivity, held for 7 days, and then analyzed for gross beta radioactivity in a laboratory. 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. Gross radioactivity measurements provide 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 1988 are listed in Table C.3, Appendix C). Each of the monthly geographical composites was analyzed for 53 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 (5.2 m^3/h at a few locations) through a 6.3-cm-dia by 2.5-cm-deep cartridge containing activated charcoal. 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 was 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.

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. 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 and analyzed for ^{85}Kr.

Seven locations were sampled for NO_2 by the Hanford Environmental Health Foundation (HEHF) to assess nitrogen oxide concentrations. Nitrogen oxides are primarily released by the PUREX Plant. The sample locations are depicted on the map in Figure 4.2 and identified in Table C.4, Appendix C. 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-hour integrated samples. Total suspended particulate results reported in previous years were discontinued in 1988 when

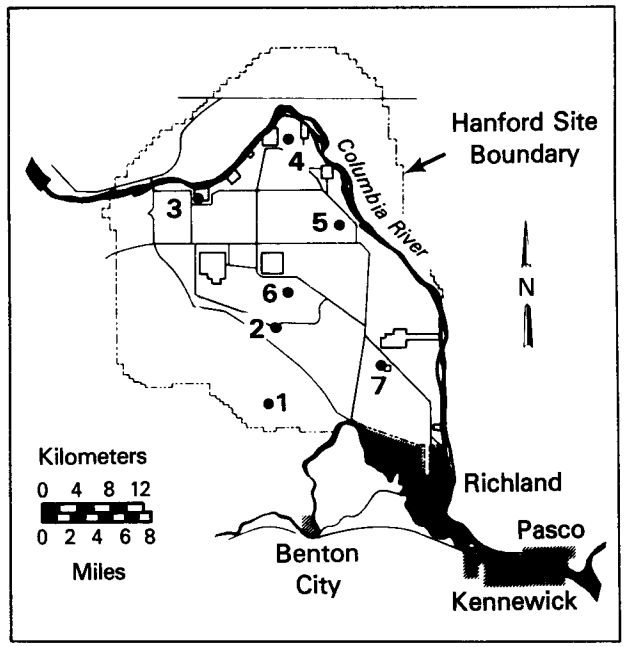

FIGURE 4.2. 1988 Nitrogen Dioxide Sampling Locations

the Basalt Waste Isolation Project, for which those measurements were required, was stopped.

RESULTS

Onsite, major operating areas, perimeter, and nearby and distant community maximum, minimum, and average annual concentrations for gross beta, gross alpha, and specific detectable radionuclides are summarized in Table C.5, Appendix C. Fifty-three radionuclides were analyzed in the monthly composite gamma energy analyses (see page D.1, Appendix D), but none of Hanford origin were consistently detectable.

Gross beta levels for 1988, as shown in Figure 4.3, peaked during winter, repeating a pattern of natural annual radioactivity fluctuations. As shown in Table C.5, Appendix C, 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

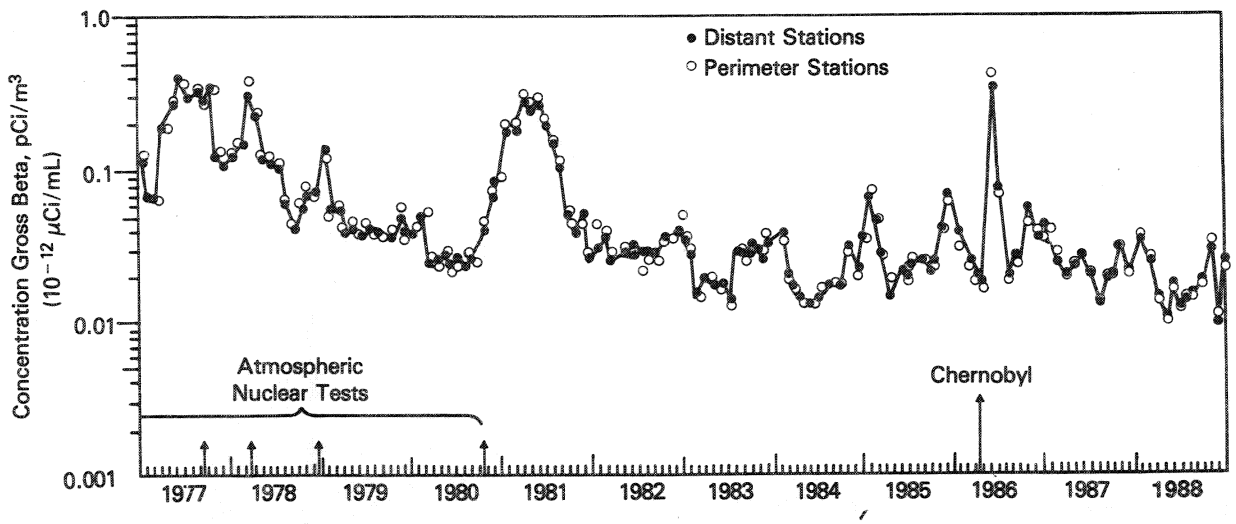

FIGURE 4.3. Monthly Average Gross Beta Radioactivity in Airborne Particulate Samples, 1978 Through 1988

an important source, concentrations would have shown a significant decrease with distance from the Hanford Site.

Measurements of ^{85}Kr continued to be an indicator of PUREX Plant plume behavior. With the resumption of PUREX Plant operations in late 1983, ambient air concentrations of ^{85}Kr at most sampling locations increased above the preoperational levels of about 19 pCi/m³ (Sula and Price 1983). Due to nuclear operations world wide, the global background has been increasing annually and is estimated to be about 27 pCi/m³ in 1988 (EPA 1988d). This is consistent with the current local background of 30 pCi/m³ reported for the distant communities in Table C.5. Concentrations on Site and at the Site perimeter have fluctuated annually primarily in response to changing operating levels (Figure 4.4). Compared to previous years, concentrations in 1988 were low on the Site and at the perimeter because of reduced PUREX Plant operations. The perimeter annual average ^{85}Kr concentration (70 pCi/m³) was 0.1% of the proposed DCG of 60,000 pCi/m³. Figure 4.5 shows the annual average ^{85}Kr concentrations for 1988 at each sampling location. Measurements along the perimeter indicate a more easterly flow of the plume in

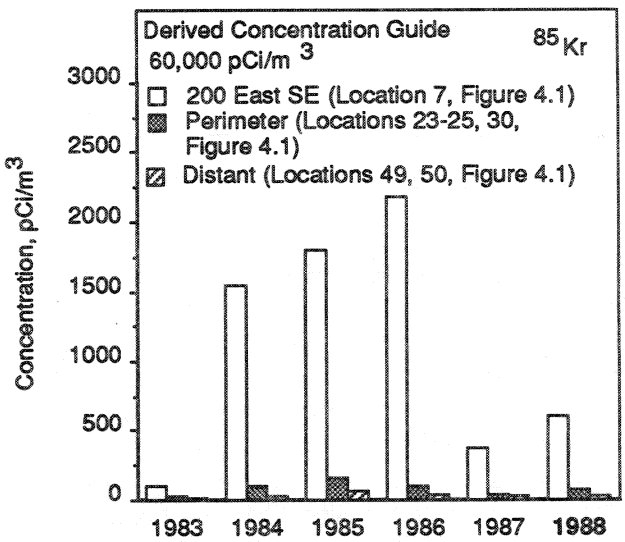

FIGURE 4.4. Annual Average Krypton-85 (^{85}Kr) Air Concentrations at Selected Locations, 1983 Through 1988

1988 than previously indicated. More typically the stack plume turns toward Richland before it crosses the eastern Site perimeter. This more southerly pattern is demonstrated in the historical record (Healy et al. 1958) and the measured climatological wind flow patterns on the Site.

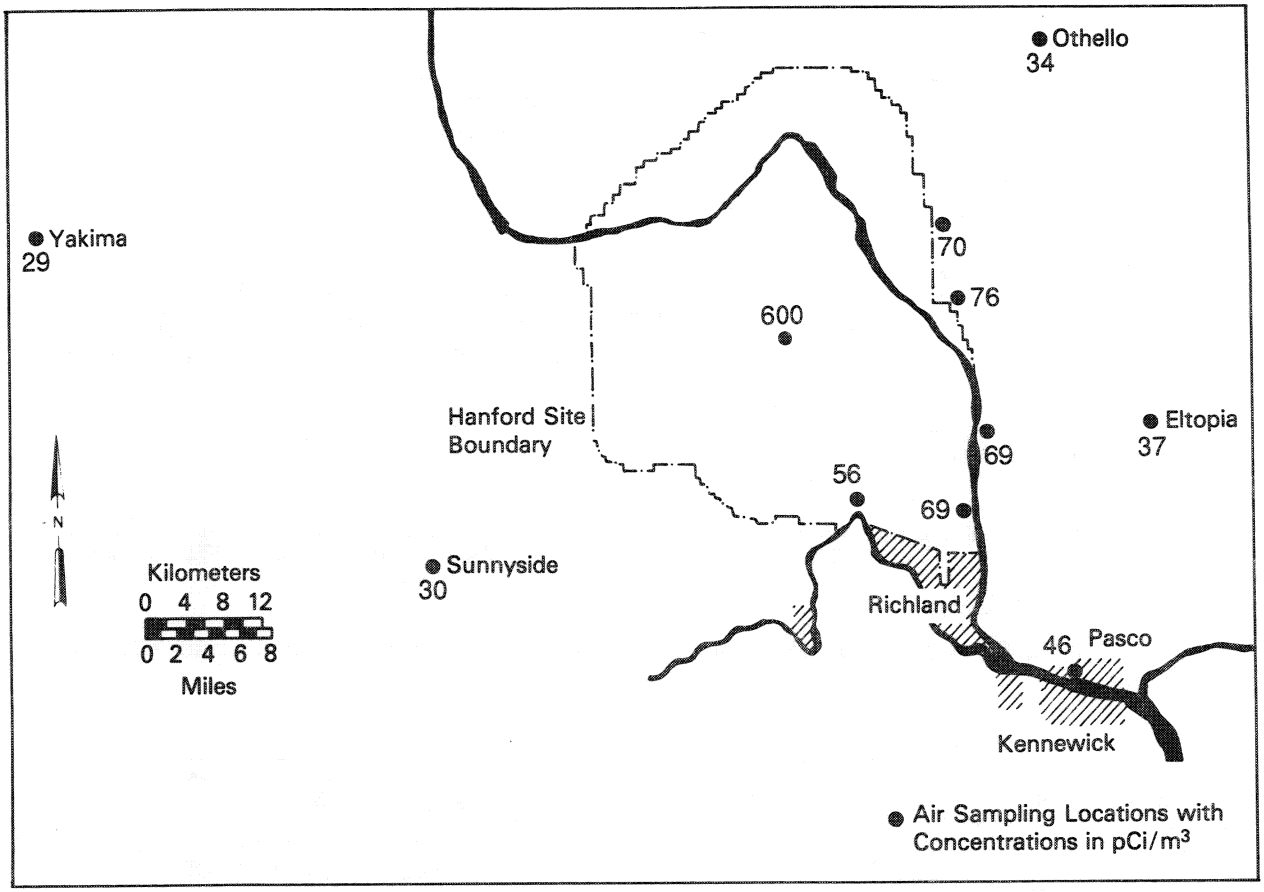

FIGURE 4.5. Annual Average Krypton-85 (^{85}Kr) Concentrations (pCi/m^3) in Air for 1988

Strontium-90 data for 1988 (Table C.5, Appendix C, and Figure 4.6) were similar on the Site, at the perimeter, and in nearby and distant communities. Figure 4.6 shows the variation from 1983 to 1988 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 1988 were similar to 1987 at these locations and generally throughout the region. Also shown are the measurements for 1983 through 1985 at 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, Larsen, and Sanderson 1985, 1988). The EML discontinued ^{90}Sr analyses at the end of 1985. Most of the increase noted in Figure 4.6 for the 200-East Area composite

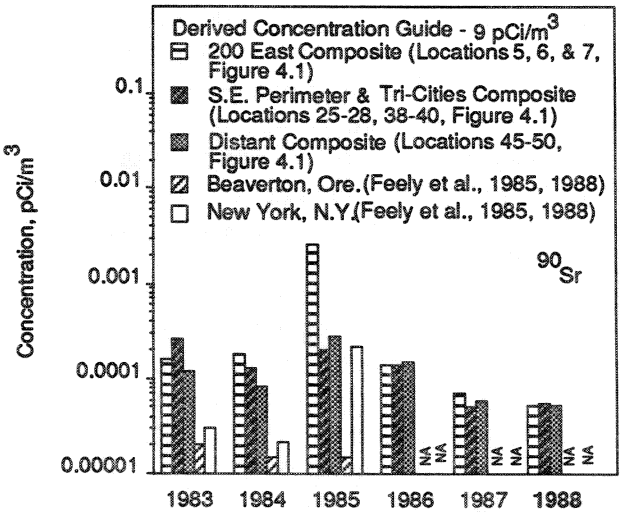

FIGURE 4.6. Annual Average Strontium-90 (^{90}Sr) Air Concentrations in the Hanford Environs Compared to Other U.S. Locations, 1983 Through 1988 (NA: New York and Beaverton data not available after 1985)

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 January (Price 1986). The annual average Site perimeter concentration in 1988 (0.00006 pCi/m³) was only 0.0007% of the applicable DCG (9 pCi/m³).

Quarterly air sampling for ^{129}I began in July 1984. Iodine-129 was sampled on Site immediately downwind of the PUREX Plant (200 ESE location), at two downwind perimeter locations, and at a distant background location (Yakima) in 1988. (Because of the low levels of ^{129}I, concentrations are reported in aCi/m³ rather than pCi/m³. One aCi/m³ = 0.000001 pCi/m³.) Concentrations at the perimeter were consistently larger than those observed at Yakima (Figure 4.7). The average onsite and distant measurements were essentially unchanged from 1987 to 1988. The annual average ^{129}I concentration at the perimeter (9.0 aCi/m³) was only 0.00001% of the DCG of 70,000,000 aCi/m³ (70 pCi/m³).

Average ^{3}H concentrations measured at the Site perimeter and at distant locations were similar (Table C.5, Appendix C). Figure 4.8

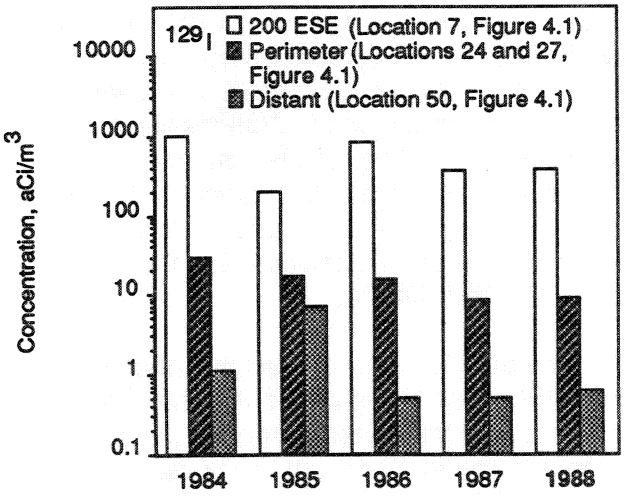

FIGURE 4.7. Annual Average Iodine-129 (^{129}I) Concentrations (aCi/m³) in Air in the Hanford Environs for 1988 (Derived Concentration Guide 70,000,000 aCi/m³)

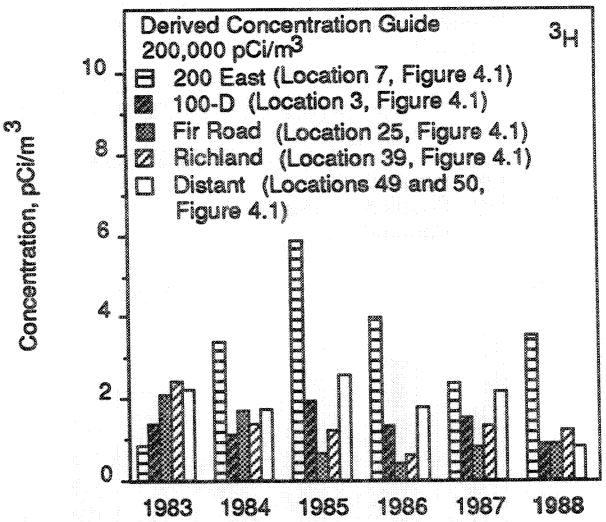

FIGURE 4.8. Annual Average Tritium (^{3}H) Concentrations (pCi/m³) in Air, 1983 Through 1988

traces the annual trend of ^{3}H concentration for two onsite and two downwind perimeter locations, and the average for two distant community locations. The effect of the restart of the PUREX Plant in late 1983 on air ^{3}H concentrations is clear at the 200-East SE sampling location. There appears to be no effect in either the perimeter or distant locations. The annual average perimeter concentration of ^{3}H in air (1.2 pCi/m³) was only 0.001% of the proposed DCG of 200,000 pCi/m³.

Air concentrations of $^{239,240}Pu$ in 1988 were low and similar to those measured in 1987. The annual averages of all onsite, major operating area, perimeter, and near and distant community samples are shown in Table C.5, Appendix C. The 1988 perimeter and distant community averages were less than 0.1 aCi/m³, or less than 0.0005% of the DCG of 20,000 aCi/m³.

The most recent regional data for $^{239,240}Pu$ reported by the EPA for Seattle, Spokane, and Portland for 1983 through 1988 (EPA 1983a-1988c) are compared in Figure 4.9 with measurements at the Hanford southeast perimeter and Tri-Cities composite locations. Onsite measurements were obtained from the routine

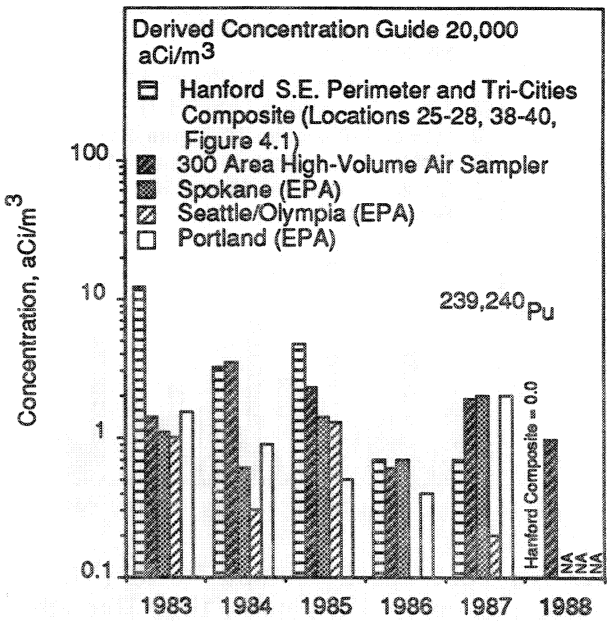

FIGURE 4.9. Annual Average Plutonium-239, 240 ($^{239,240}Pu$) Air Concentrations in the Northwest and Hanford Environs, 1983 Through 1988 (NA: EPA data for 1988 were not yet available)

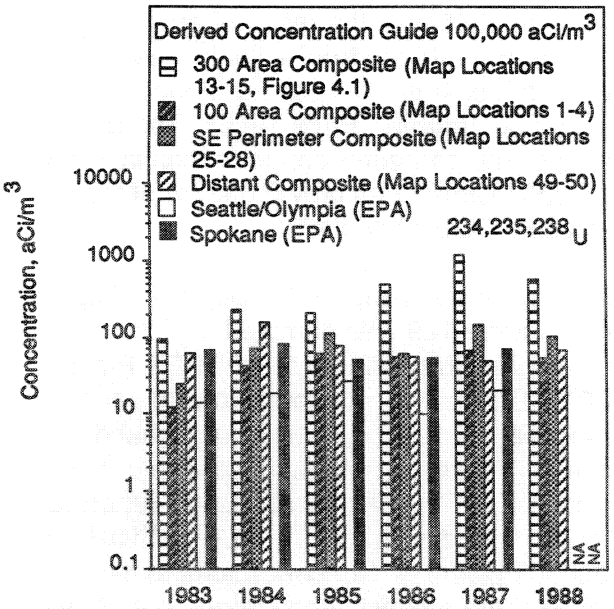

FIGURE 4.10. Annual Average Uranium (^{234}U, ^{235}U, and ^{238}U) Air Concentrations in the Northwest and Hanford Environs, 1983 through 1988 (NA: EPA data for 1988 were not yet available)

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. 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 (Price 1985). A further decrease in 1986 followed the installation of additional source controls at the PUREX Plant in late 1985.

Uranium concentrations (^{234}U, ^{235}U, and ^{238}U) in airborne particulate matter in 1988 were higher at the perimeter than at the distant communities (Table C.5, Appendix C) as well as being elevated relative to values typical of Seattle/Olympia and Spokane as reported by EPA and shown in Figure 4.10. This increase is due to the wind resuspension of soil in and around the 300 Area as reflected in the 300 Area air concentrations shown in Figure 4.10.

The 1988 annual average concentrations in the southeast perimeter composite (map locations 25-28, Figure 4.1) of 105 aCi/m³ was 0.1% of the DCG of 100,000 aCi/m³.

Ruthenium-106, ^{131}I, and ^{137}Cs were routinely monitored through gamma energy analyses of the monthly composite sample. However, even the maximum concentrations were near detection limits. The results obtained for 1988 are included in Tables C.5, Appendix C. The annual average ^{106}Ru, ^{131}I, and ^{137}Cs concentrations at the perimeter were less than 0.004% of their DCGs.

The comparisons of radionuclide concentrations discussed in the previous paragraphs are based on 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 contain radionuclides from natural and worldwide fallout sources, and the average at the downwind perimeter of the Hanford Site, which represents natural and worldwide fallout sources and any Hanford contributions. The 1988 average Hanford Site perimeter concentrations of ^{3}H, ^{90}Sr, ^{137}Cs, and uranium were numerically greater than levels measured at distant monitoring stations, but the differences were not statistically significant (5% significance level). Krypton-85 and ^{129}I concentrations were numerically greater at the downwind perimeter stations than at the distant stations, and the differences were statistically significant (beyond the 5% significance level).

Nitrogen dioxide data collected in 1988 (Table C.4, Appendix C) indicate that the highest annual average (<0.005 ppm) was observed at five of the seven sampling locations (Figure 4.2, map location numbers 1, 3, 4, 6, and 7). All locations were below the applicable federal and Washington State annual average ambient air standard for NO_2, which is 0.05 ppm.

4.2 SURFACE-WATER MONITORING

R. L. Dirkes

The Columbia River was one of the primary environmental exposure pathways to the public during 1988 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 1988 were also in compliance with applicable standards.

Three onsite ponds were 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 1988 were similar to those observed 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 a variety of recreational activities, including hunting, fishing, boating, water skiing, and swimming. Water from the Columbia River downstream of Hanford is also used for crop irrigation.

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 (McCormack and Carlile 1984). Effluents from each direct discharge point are routinely monitored and reported by the responsible operating contractor, and are summarized in Section 4.7 and Appendix G. Direct discharges are identified and regulated for nonradiological constituents under the National Pollutant Discharge Elimination System (NPDES). The NPDES permitted discharges at Hanford and the regulated parameters are listed in Table B.7, Appendix B.

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. Water quality criteria are presented in Table B.1, Appendix B. The State of Washington and EPA Drinking Water Standards (DWS) used in evaluating radionuclide concentrations in Columbia River water are provided in Table B.2, Appendix B.

Sample Collection and Analysis

Samples of Columbia River water were collected throughout 1988 at the locations shown

in Figure 4.11. 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 were collected from the 300 Area water intake and the Richland Pumphouse to identify any influence on contaminant concentrations at these locations from Hanford operations. The Richland Pumphouse is the first downstream point of river water withdrawal for a public drinking water supply.

Radiological analyses on water samples included gross alpha, gross beta, gamma scan, ^{3}H, ^{89}Sr, ^{90}Sr, ^{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 provide the ability to detect numerous specific radionuclides (listed on page D.1, Appendix D), most of which are not found in measurable quantities in the Columbia River. 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. 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 water sampler at Priest Rapids Dam is positioned approximately midstream within the dam and collects water from the reservoir behind the

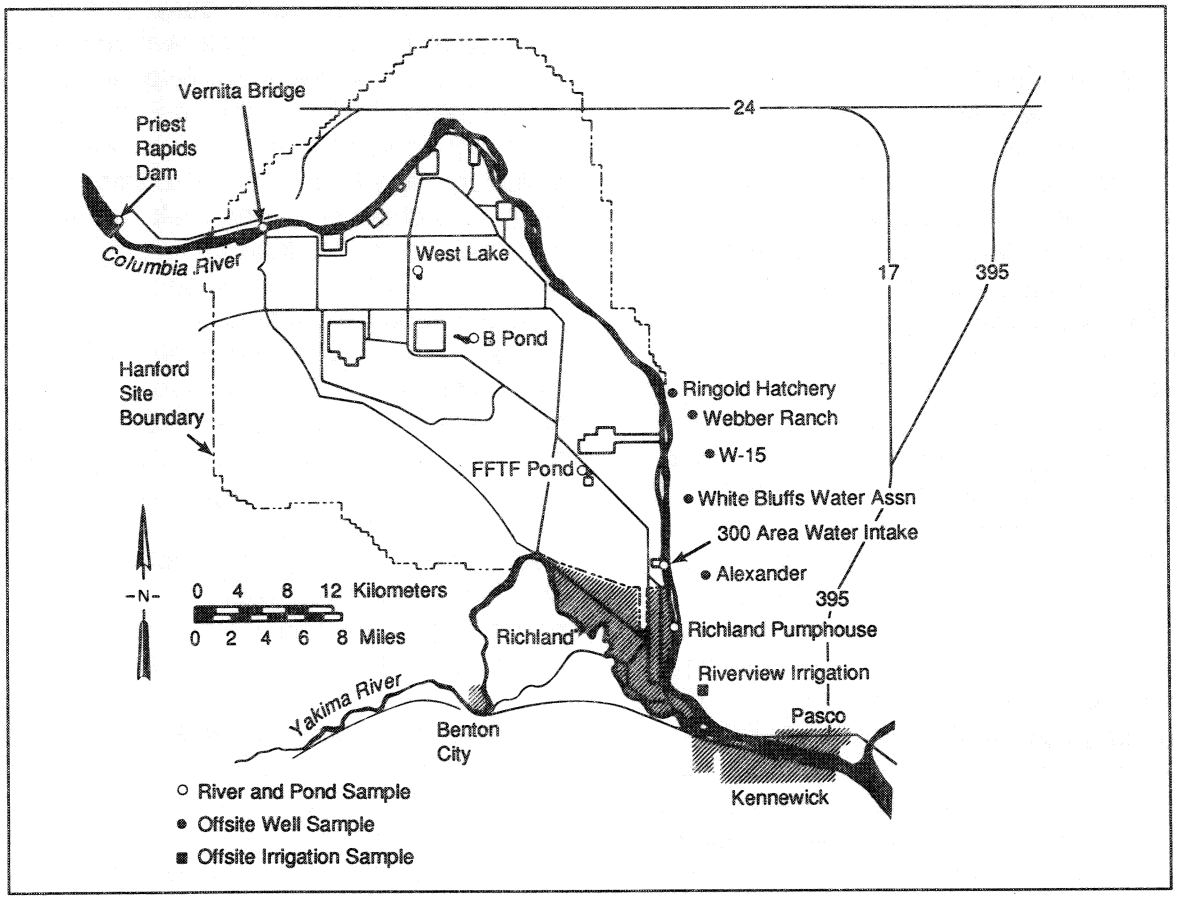

FIGURE 4.11. Onsite Pond, Columbia River, and Offsite Water Sampling Locations in 1988

impoundment. 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. 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 a valuable historical database 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 levels of ^{3}H and uranium (see "Ground-Water Protection and Monitoring Program," Section 5.0).

The Richland Pumphouse is located approximately 3 km downstream of the Site boundary and about 5 km downstream of the most downstream effluent discharge. The water intake is located with the city of Richland drinking water supply intake on the Benton County shoreline, approximately 9 m into the river. The city of Richland is the first community downstream from Hanford using Columbia River water as its source of drinking water. Historical environmental monitoring reports indicate this to be the drinking water supply having the maximum radionuclide concentrations downstream of Hanford (Foster and Wilson 1964; Foster and Wilson 1965; Foster 1966; Honstead 1967; Corley and Woolridge 1969; Fisher and Wilson 1970; Corley 1970; Corley 1973). 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, continued into 1988, and will be completed in 1989.

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.

Composite sampling systems were operated at Priest Rapids Dam, the 300 Area water intake, and the Richland Pumphouse. 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 at Priest Rapids Dam and the Richland Pumphouse, 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. The system at the 300 Area was identical to the others except that samples were collected monthly and composited for quarterly analysis. 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. In addition, weekly alpha and beta analyses were performed on an aliquot of the composite sample from the Richland Pumphouse.

Continuous sampling systems were located at Priest Rapids Dam, the 300 Area water intake, and the Richland Pumphouse. A special, continuously flowing system was used to separate 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 changed 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 $^{239,240}Pu$.

Monthly grab samples of Columbia River water were collected from shoreline sites near the Vernita Bridge and near the Richland Pumphouse for analysis of various nonradiological water quality parameters. 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 laboratory where processing was initiated promptly to ensure sample integrity. Water quality analyses performed during 1988 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 U.S. Geological Survey (USGS) at Vernita Bridge and Richland. The USGS samples were 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.

Samples of Columbia River sediment were also collected during 1988. Sediment samples were collected behind Priest Rapids Dam, upstream of the Hanford Site, and behind McNary Dam, downstream of the Site. Samples were obtained from approximately 15 cm of the top sediment material using a Ponar dredge sampler. Analyses of the sediment samples included gamma scans, ^{90}Sr, ^{235}U, ^{238}U, ^{238}Pu, and $^{239,240}Pu$.

Results

Results of the radiological analysis of Columbia River water samples collected at Priest Rapids Dam, the 300 Area, and the Richland Pumphouse during 1988 are summarized in Tables C.6, C.7, and C.8, Appendix C, respectively. Tables C.6 through C.8 contain all radionuclides for which detectable concentrations were observed during the year. Levels throughout the year were extremely low, being essentially undetectable without the use of special sampling techniques and analytical procedures. Concentrations of ^{95}Nb, ^{95}Zr, ^{106}Ru, ^{134}Cs, and ^{238}Pu, reported in previous annual reports, were below detection levels in all samples and thus were omitted from the tables. Radionuclides consistently existing in measurable quantities in river water during 1988 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.

Significant results are discussed and illustrated in the following paragraphs, with comparisons to previous years provided. Statistical analysis of the differences between radionuclide concentrations at Priest Rapids Dam and the Richland Pumphouse provide an indication of the influence, if any, of Hanford Operations on the city of Richland drinking

water source. Annual average radionuclide concentrations are also compared to applicable State of Washington and EPA DWS. All radionuclide concentrations during 1988 were below the State and EPA DWS.

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 1988 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 4.12 and 4.13 illustrate the annual average gross alpha and gross beta concentrations, respectively, at Priest Rapids Dam and the Richland Pumphouse during the past 6 years. The 1988 gross beta concentrations were similar to those of 1987, with no significant increases or decreases observed. Gross alpha concentrations at both locations decreased slightly in 1988 and in most cases (70%) were less than the analytical detection limit. The increase in concentrations observed at the Richland Pumphouse during past years was not evident in 1988. Statistical analysis (i.e., paired sample comparison and t-test of differences) of

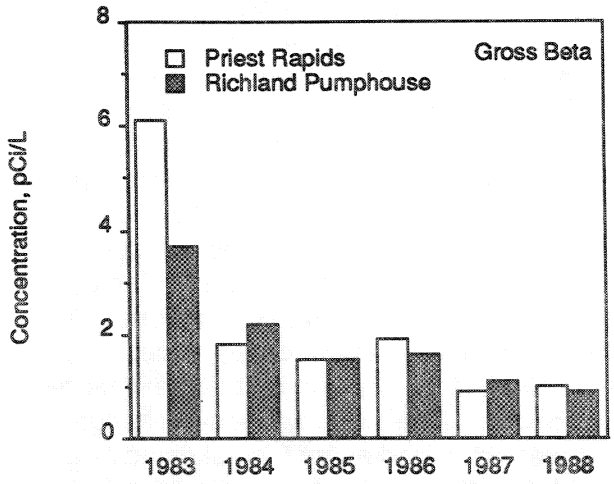

FIGURE 4.13. Annual Average Gross Beta Concentrations in Columbia River Water, 1983 Through 1988

gross alpha and gross beta concentrations at Priest Rapids Dam and the Richland Pumphouse indicated the differences were statistically not significant (5% significance level) in both cases (Snedecor and Cochran 1980).

Annual average ^3H concentrations measured at Priest Rapids Dam and the Richland Pumphouse during 1988 were 70 and 132 pCi/L, respectively. Figure 4.14 compares the annual average ^3H concentrations at Priest

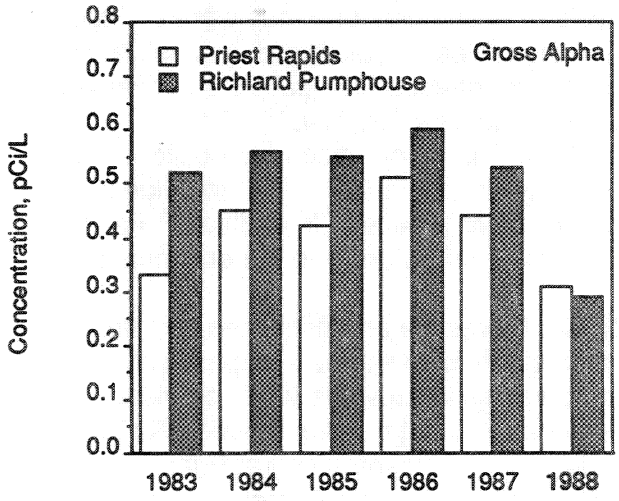

FIGURE 4.12. Annual Average Gross Alpha Concentrations in Columbia River Water, 1983 Through 1988

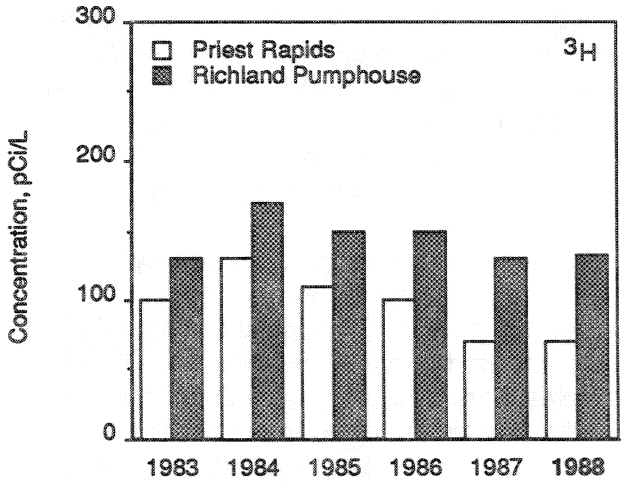

FIGURE 4.14. Annual Average Tritium (^3H) Concentrations in Columbia River Water, 1983 Through 1988

Rapids Dam and the Richland Pumphouse from 1983 through 1988. Tritium concentrations in Columbia River water during 1988 were similar to those during recent years and were comparable to measurements reported by the State of Washington (WDSHS 1987). Figure 4.15 provides a comparison of monthly ^{3}H concentrations in river water during 1988, showing that concentrations at the Richland Pumphouse were continually higher during the year than those at Priest Rapids Dam. Statistical analyses (paired sample comparison, t-test of differences) indicated that the difference between the ^{3}H concentrations at these locations was significant (5% significance level). Tritium sources entering the river were effluent releases from the N Reactor and ground-water seepage into the river along the Site (see "Effluent Monitoring," Section 4.7, and "Ground-Water Protection and Monitoring Program," Section 5.0). All ^{3}H concentrations were at least a factor of 100 below the State of Washington and EPA DWS of 20,000 pCi/L.

The annual average ^{90}Sr concentrations measured at Priest Rapids Dam and the Richland Pumphouse during 1988 were 0.10 and 0.12 pCi/L, respectively. Figure 4.16 shows the annual average ^{90}Sr concentrations at these locations from 1983 through 1988.

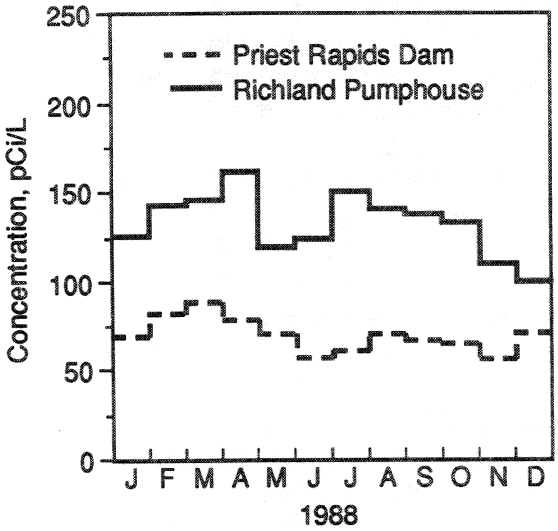

FIGURE 4.15. Monthly Tritium (^{3}H) Concentrations in Columbia River Water During 1988

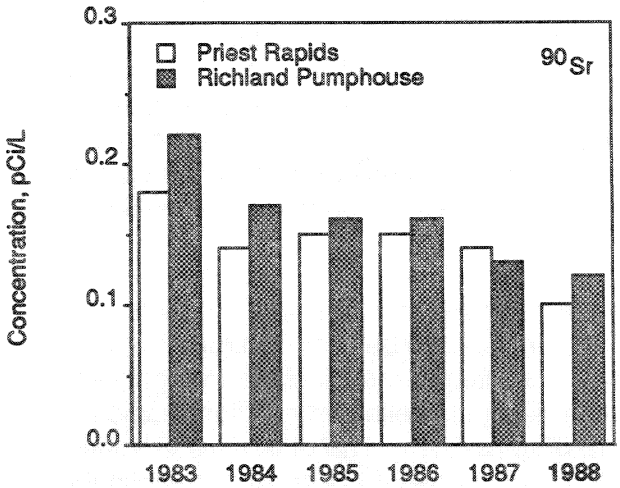

FIGURE 4.16. Annual Average Strontium-90 (^{90}Sr) Concentrations in Columbia River Water, 1983 Through 1988

Although the Richland Pumphouse annual average concentrations were generally higher than those at Priest Rapids Dam, the differences since 1983 were slight, especially when the uncertainty associated with the averages was considered. Figure 4.17 shows monthly ^{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 significant at the 5% significance level. The

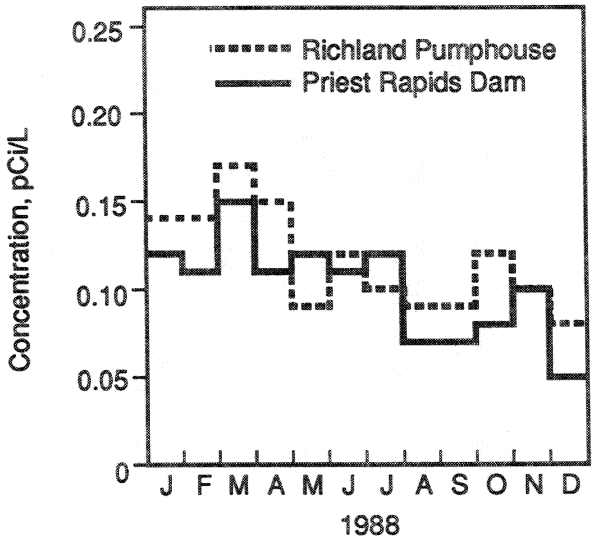

FIGURE 4.17. Monthly Strontium-90 (^{90}Sr) Concentrations in Columbia River Water During 1988

primary source of ^{90}Sr entering the Columbia River was the 100-N Area Liquid Waste Disposal Facilities (LWDF), which are known to discharge to the river via ground-water seepage. Strontium-90 concentrations during 1988 in Columbia River water remained below the State of Washington and EPA DWS of 8 pCi/L.

Annual average uranium concentrations in 1988 continued to be slightly higher in river water collected at the Richland Pumphouse than in samples collected at Priest Rapids Dam (Figure 4.18). The difference in annual averages (0.04 pCi/L) is small and within the level of uncertainty associated with the means. Monthly values during the year were not consistently higher at any one location (Figure 4.19). There was no consistently measurable contribution to Columbia River water uranium concentrations at the Richland Pumphouse attributable to Hanford operations. Statistical analyses showed that the differences during the year were statistically not significant (5% significance level). 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

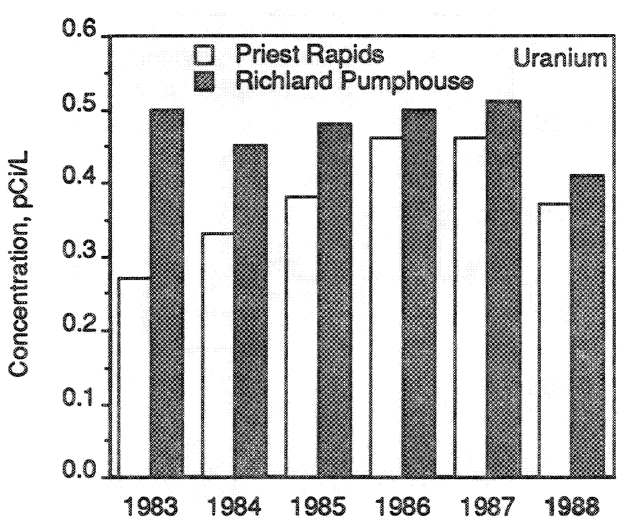

FIGURE 4.18. Annual Average Uranium Concentrations in Columbia River Water, 1983 Through 1988

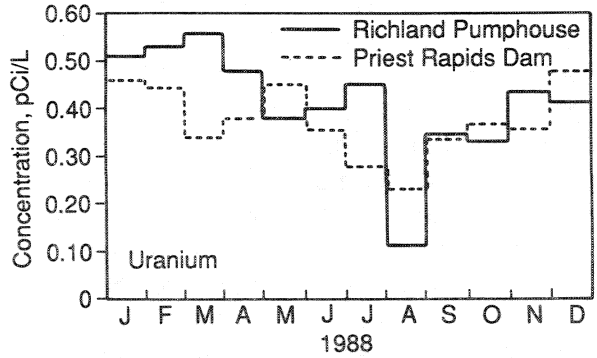

FIGURE 4.19. Monthly Uranium Concentrations in Columbia River Water During 1988

Protection and Monitoring Program," Section 5.0) and has been detected at elevated levels in riverbank springs in this area (McCormack and Carlile 1984). All uranium concentrations were below those that would result in doses exceeding EPA and State of Washington DWS of 4 mrem/year.

As in past years, ^{129}I concentrations, while extremely low, continue to be statistically significantly (5%) higher at the 300 Area water intake and at the Richland Pumphouse than at Priest Rapids Dam. Average ^{129}I concentrations in Priest Rapids Dam, 300 Area, and Richland Pumphouse river water during 1988 were 16 aCi/L, 91 aCi/L, and 100 aCi/L, respectively. Iodine-129 in the river downstream of Hanford is attributable to the flow of ground water, which is contaminated as a result of past waste disposal practices, from the unconfined aquifer into the river (McCormack and Carlile 1984). Figure 4.20 provides the annual average ^{129}I concentrations from 1983 through 1988. The differences during 1988 among the Priest Rapids Dam, 300 Area, and Richland Pumphouse concentrations were similar to the differences in past years. Figure 4.21 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 1988 were extremely low, at least a factor of 10,000 below the EPA and State of Washington DWS of 1 pCi/L.

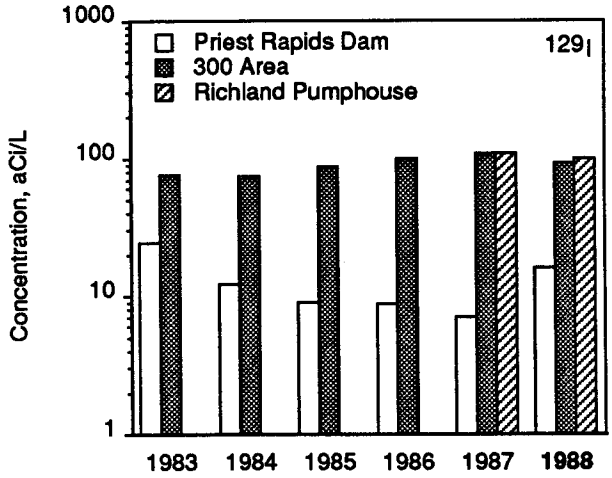

FIGURE 4.20. Annual Average Iodine-129 (^{129}I) Concentrations in Columbia River Water, 1983 Through 1988

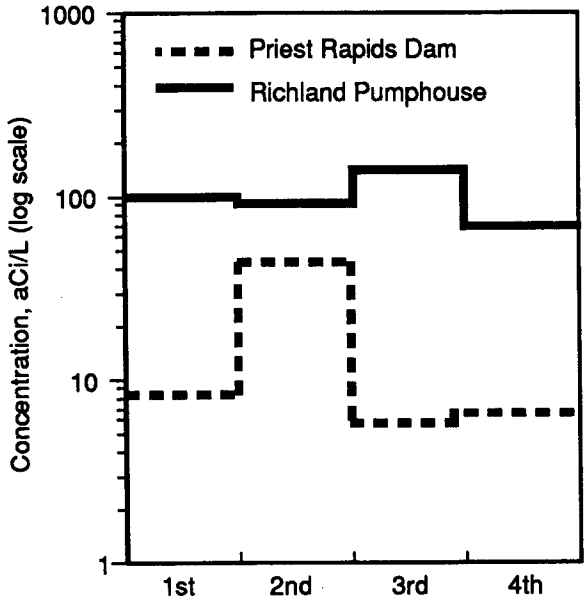

FIGURE 4.21. Quarterly Iodine-129 (^{129}I) Concentrations in Columbia River Water During 1988

During 1988, ^{60}Co and ^{131}I were not consistently found in measurable quantities in the Columbia River at Priest Rapids Dam, the 300 Area water intake, or the Richland Pumphouse. Likewise, ^{89}Sr and ^{137}Cs were generally below the detection level throughout the year. Concentrations of $^{239,240}Pu$ were extremely low and were similar at these locations, indicating no measurable effect due to Hanford operations. All ^{60}Co, ^{89}Sr, ^{131}I, ^{137}Cs, and $^{239,240}Pu$ concentrations during the year were below the State of Washington and EPA DWS (Tables C.6, C.7, and C.8, Appendix C).

Analytical results for the sediment samples collected from the Columbia River during 1988 are presented in Table C.9, Appendix C. Surface sediments behind McNary Dam are known to contain low levels of Hanford origin radionuclides (Robertson and Fix 1977; Beasley et al. 1981). As expected, concentrations of ^{60}Co, ^{90}Sr, ^{134}Cs, ^{137}Cs, ^{238}Pu, and $^{239,240}Pu$ were higher in sediments from behind McNary Dam than from behind Priest Rapids Dam. Uranium concentrations were found to be similar at the two sample locations during 1988.

Nonradiological water quality data compiled by PNL and the USGS during 1988 are summarized in Table C.10, Appendix C. The data include a number of parameters for which no regulatory limit exists. These parameters are, however, useful as indicators of water quality. The PNL and USGS results, when duplicated, were in general agreement and were comparable to levels in recent years. In general, applicable standards for Class A-designated water were met. There was no indication during 1988 of any significant deterioration of the water quality along this stretch of the Columbia River resulting from Hanford operations. Potential sources of 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 4.22 shows Vernita Bridge and Richland results during 1983 through 1988 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 acceptable range for Class A waters with the exception of one USGS measurement at each of the locations.

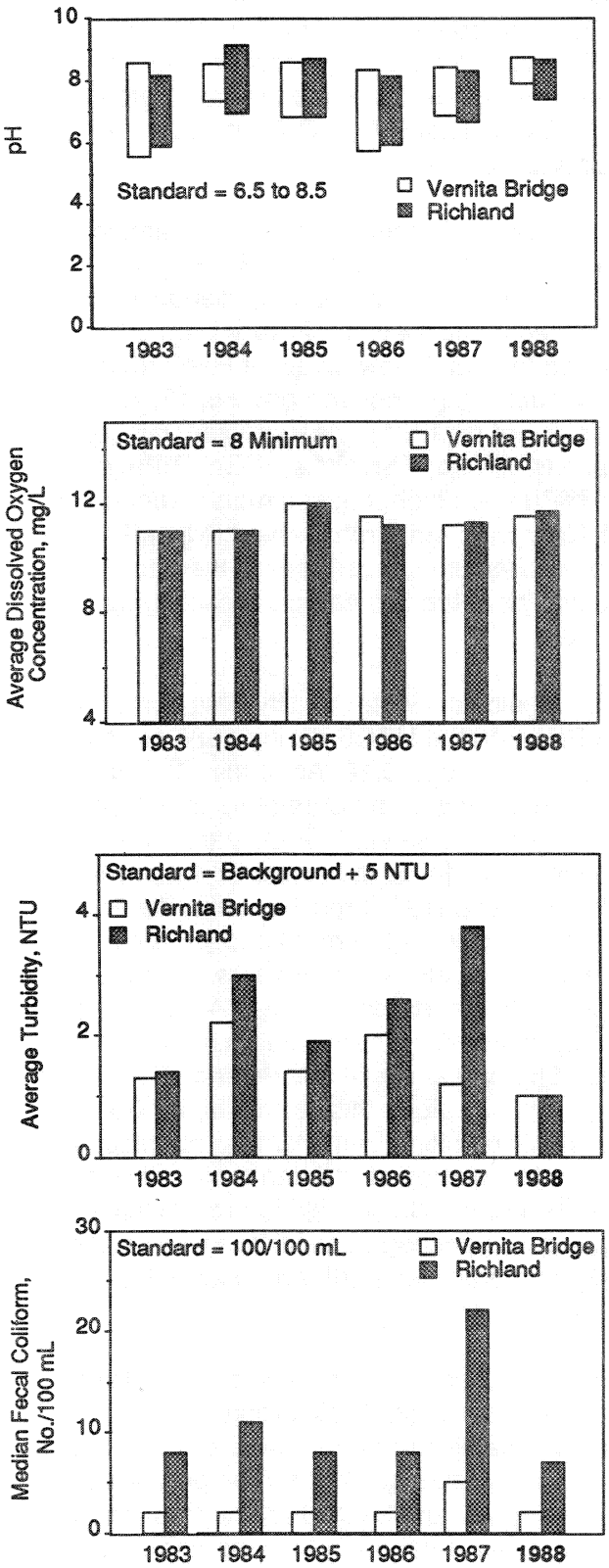

FIGURE 4.22. Columbia River Water Quality Measurements, 1983 Through 1988

Turbidity, median fecal coliform, and dissolved oxygen concentrations at both locations during 1988 were in compliance with Class A requirements.

The annual average flow rate of the Columbia River was 2830 m^3/s during 1988, similar to 1987 and slightly lower than recent years. The monthly average flow rates at Priest Rapids Dam during the year are shown in Figure 4.23. The peak monthly average flow occurred during December (3735 m^3/s), and the lowest average monthly flow occurred during April (2190 m^3/s). Daily average flow rates varied from 1190 to 4530 m^3/s during 1988.

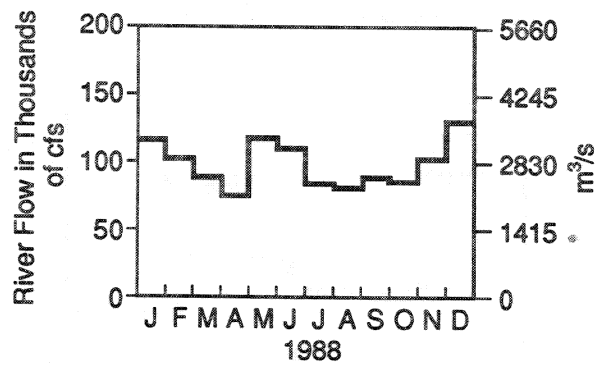

FIGURE 4.23. Monthly Average Flow Rates of the Columbia River During 1988

Average monthly Columbia River water temperatures at Priest Rapids Dam and the Richland Pumphouse are shown in Figure 4.24. The major source of heat to the Columbia River in the Hanford Reach is solar radiation (Dauble et al. 1987). River temperatures and the differences between Priest Rapids Dam and Richland Pumphouse temperatures during 1988, 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 at Priest Rapids Dam during January through September 1988. Cooler monthly average temperatures were observed at the Richland Pumphouse during November and December. Monthly average emperatures at the two locations were the same during October.

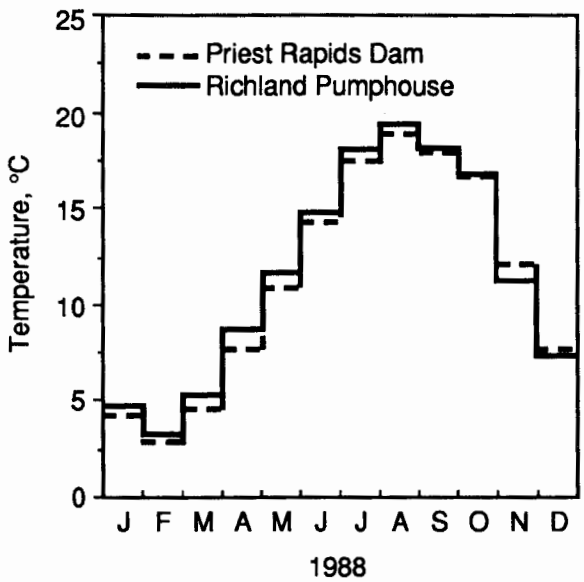

FIGURE 4.24. Monthly Average Temperatures in the Columbia River Water During 1988

ONSITE PONDS

Three onsite ponds (see Figure 4.11) located near operating areas were sampled periodically during 1988. Gable Mountain Pond, sampled in previous years, was eliminated during 1987. Decommissioning activities on Gable Mountain Pond were completed during 1987, 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. B Pond, located near the 200-East Area, was excavated in the mid-1950s for disposal of process cooling water and other liquid wastes occasionally containing low levels of radionuclides. West Lake, also located near the 200-East Area, is recharged from the ground water. This pond has not received direct-effluent discharges from Site facilities. The third onsite pond [Fast Flux Test Facility (FFTF) Pond], located near the 400 Area, was excavated in 1978 for the disposal of cooling water from various facilities in the 400 Area.

Westinghouse Hanford Company is responsible for monitoring effluents discharged to the ponds and for operational surveillance of the ponds (Cooney et al. 1988). Although the ponds were inaccessible to the public and did not constitute a direct offsite environmental impact during 1988, 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 1988, 10-L grab samples were collected quarterly 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 provide indications of process failure.

Results

Analytical results from pond samples collected during 1988 are summarized in Table C.11, Appendix C. Maximum, minimum, and average concentration values are provided for various radionuclides at each pond. Further discussion of individual constituents and comparisons with results obtained during previous years are provided below for each pond.

Annual average radionuclide concentrations in B Pond are shown in Figure 4.25. Gross alpha concentrations during the year were similar to those observed during previous years and remained just above the analytical detection level. Gross beta concentrations, also very close to the detection level, were up slightly from those observed during 1986 and 1987 but were in the range reported during the previous 5 years. As in the case of gross beta, the ^{90}Sr concentrations were elevated slightly over those in 1986 and 1987 and were comparable to those observed in 1985. Concentrations of tritium in B-Pond water remained below the detection level as has been the case in recent years. Cesium-137 concentrations were also generally below the

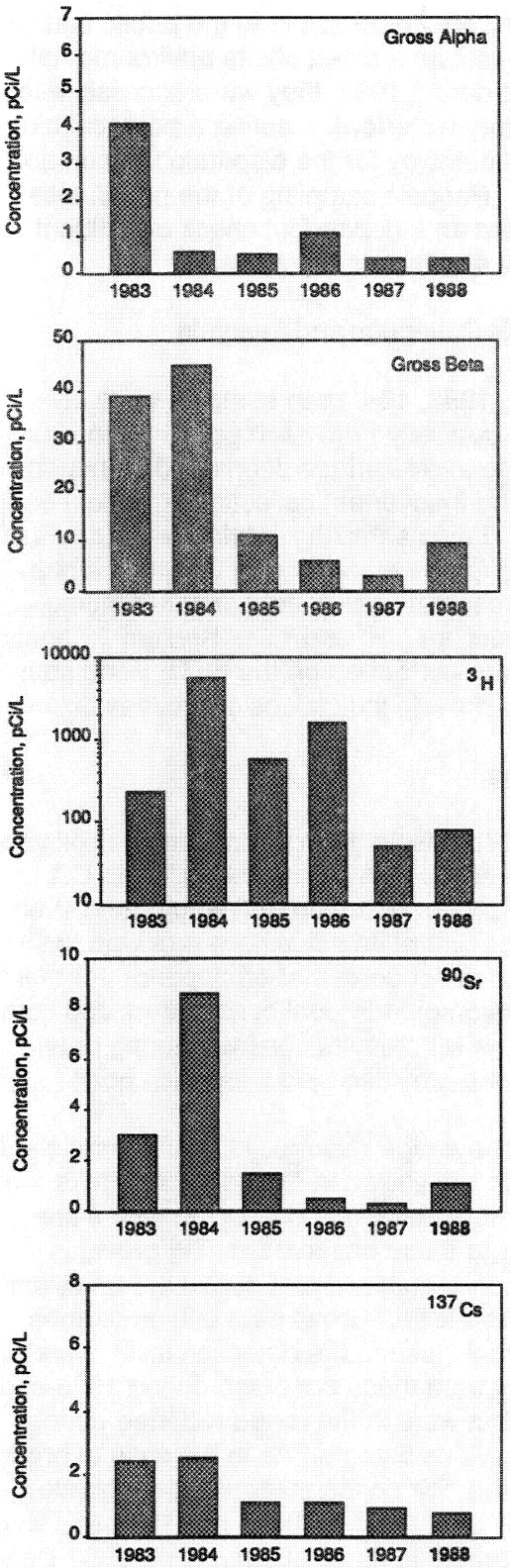

FIGURE 4.25. Annual Average Radionuclide Concentrations in B Pond, 1983 Through 1988

detection level during 1988 and similar to concentrations observed in recent years. In general, radionuclide concentrations in B-Pond water during 1988 were comparable to those observed during the previous 5 years.

Figure 4.26 illustrates the annual average gross beta and tritium concentrations measured in the FFTF Pond during 1988. As in the past, gross alpha, ^{90}Sr, and ^{22}Na concentrations were below the detection level during 1988 and were omitted from this figure. Gross beta concentrations in FFTF Pond water were similar to those reported during the previous 5 years. The concentrations of tritium were also comparable to those measured in the FFTF Pond since the completion of a new water supply well in 1986.

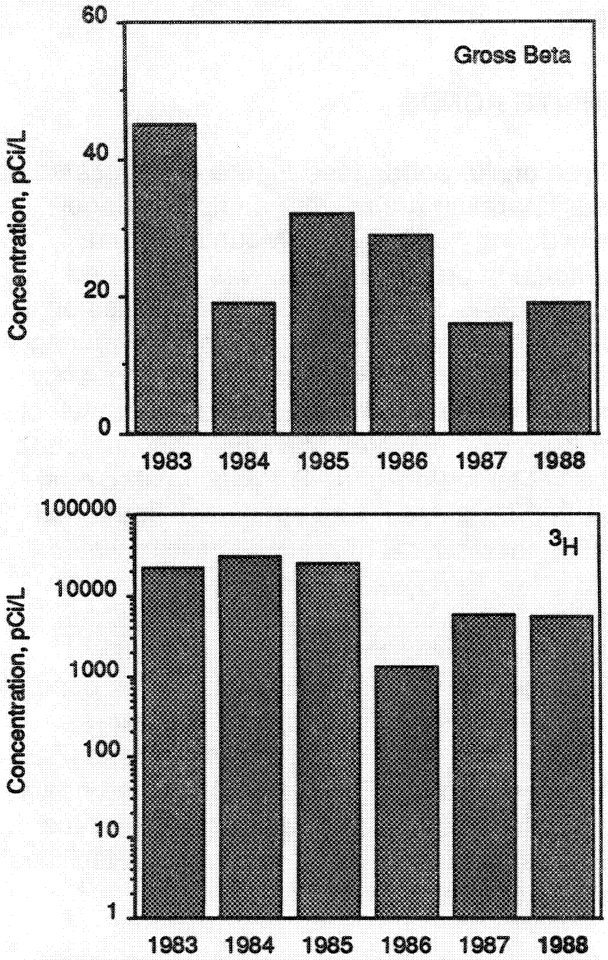

FIGURE 4.26. Annual Average Radionuclide Concentrations in FFTF Pond, 1983 Through 1988

The 1988 annual average radionuclide concentrations in West Lake were comparable to those observed during recent years (Figure 4.27). Gross alpha concentrations averaged slightly higher than those observed in past years. Gross beta concentrations have remained relatively stable over the years. The 1988 concentration was within the range observed during the previous 5 years. Gross alpha and gross beta concentrations in West Lake, which is recharged from ground water (Gephart et al. 1976), continued to be higher than the gross alpha and gross beta levels found in the other onsite ponds. This is believed to result from high concentrations of naturally occurring uranium (Speer, Fix, and Blumer 1976). Annual average uranium concentrations were slightly elevated during 1988, and substantiate the elevated gross alpha and gross beta measurements. Strontium-90 concentrations during 1988 remained similar to those observed during the previous 5 years. Tritium concentrations in West Lake during 1988 were similar to those observed in 1987, were slightly lower than the previous 4 years, and remained similar to those observed in the local ground water.

OFFSITE WATER

Water samples were collected from several wells directly east of and across the Columbia River from the Hanford Site during 1988. Samples were also collected from an irrigation canal, which obtains water from the Columbia River downstream of Hanford. Wells across the river are used extensively as a source of drinking water and for crop irrigation. Sampling was initiated to document the levels of radionuclides in the water used by the public and as a result of public concerns about the potential for contaminants associated with Hanford ground water being present in offsite ground water. Consumption of food irrigated with Columbia River water from downstream of the Site has been identified as one of the primary pathways contributing to the dose to the maximally exposed individual (Jaquish and Mitchell 1988).

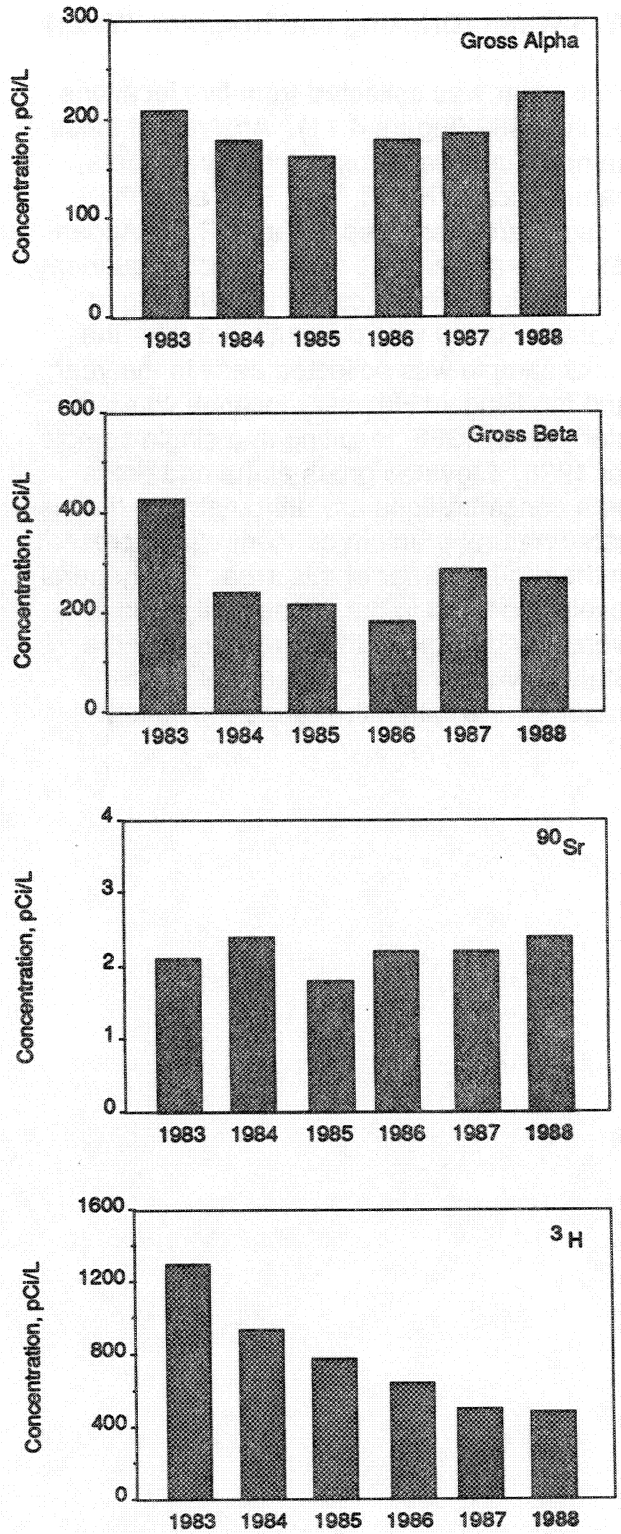

FIGURE 4.27. Annual Average Radionuclide Concentrations in West Lake, 1983 Through 1988

Well Water (Drinking and Irrigation Water)

Well water was collected from five locations during 1988 (Figure 4.11). Analysis of these samples included gross alpha, gross beta, gamma scan, ^{3}H, ^{129}I, ^{234}U, ^{235}U, and ^{238}U. Results are presented in Table C.12, Appendix C. Grab samples were collected quarterly, with the following exceptions; sampling at Webber Ranch was discontinued after the initial sample was collected early in the year; and the Ringold Hatchery location was initiated late in 1988, resulting in a single sample for 1988. Elevated gross alpha and gross beta concentrations are attributable to the elevated natural uranium concentrations present in the ground water of this area. The general levels observed in the offsite well samples were comparable to those reported by the State of Washington. Iodine-129 concentrations were within the range previously reported in offsite wells (WDSHS 1987). Annual average radionuclide concentrations in offsite well water during 1988 were within applicable DWS.

Irrigation Water

The Riverview irrigation canal was sampled three times during the irrigation season. These samples were analyzed for gamma emitters and ^{90}Sr. Results are presented in Table C.12, Appendix C. Strontium-90 was the primary nuclide of concern because it has been identified as the primary contributor to the calculated hypothetical dose to the public via the water pathway (Jaquish and Mitchell 1988). Gamma emitters were below the detection level in all samples. The concentration of ^{90}Sr during 1988 was similar to that reported for the Columbia River at the Richland Pumphouse and the 300 Area.

4.3 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 surrounding the Hanford Site during 1988 (Figure 4.28). Samples were collected primarily from locations in the prevailingly downwind directions (i.e., to the south and east of the Site) where airborne effluents from Hanford could be expected to be deposited. 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. Alfalfa and foodstuff samples were analyzed for one or more of the following radionuclides: ^{3}H, ^{90}Sr, ^{129}I, ^{137}Cs, ^{131}I, and $^{239,240}Pu$.

Low levels of ^{3}H, ^{90}Sr, ^{137}Cs, and ^{129}I were found in a number of foodstuff samples collected during 1988; 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 1988 Hanford Operations," Section 4.8).

MILK

Selected 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 with stippling in Figure 4.28, and results are listed in Table C.13, Appendix C. 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. Strontium-90 analyses were conducted on one sample per quarter, and ^{129}I analyses were conducted on one sample every 6 months.

A total of 94 samples of milk were collected and analyzed for ^{131}I during 1988. Results for three of the samples were slightly above the detection level. Two of these samples were collected from the Sagemore Area and the third from the Sunnyside Area. Because of the statistical nature of the analytical process, four to five (5%) of the 94 samples analyzed would be expected to erroneously exceed the detection level when in fact no ^{131}I was present in the sample. Moreover, a very small amount (about 1 mCi) of ^{131}I was released from Hanford during 1988 (Table G.1, Appendix G; an amount not expected to be identified in milk samples.

About 6% of the 96 milk samples collected and analyzed for ^{137}Cs in 1988 contained detectable levels of ^{137}Cs. All of the 21 samples analyzed for ^{90}Sr contained ^{90}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

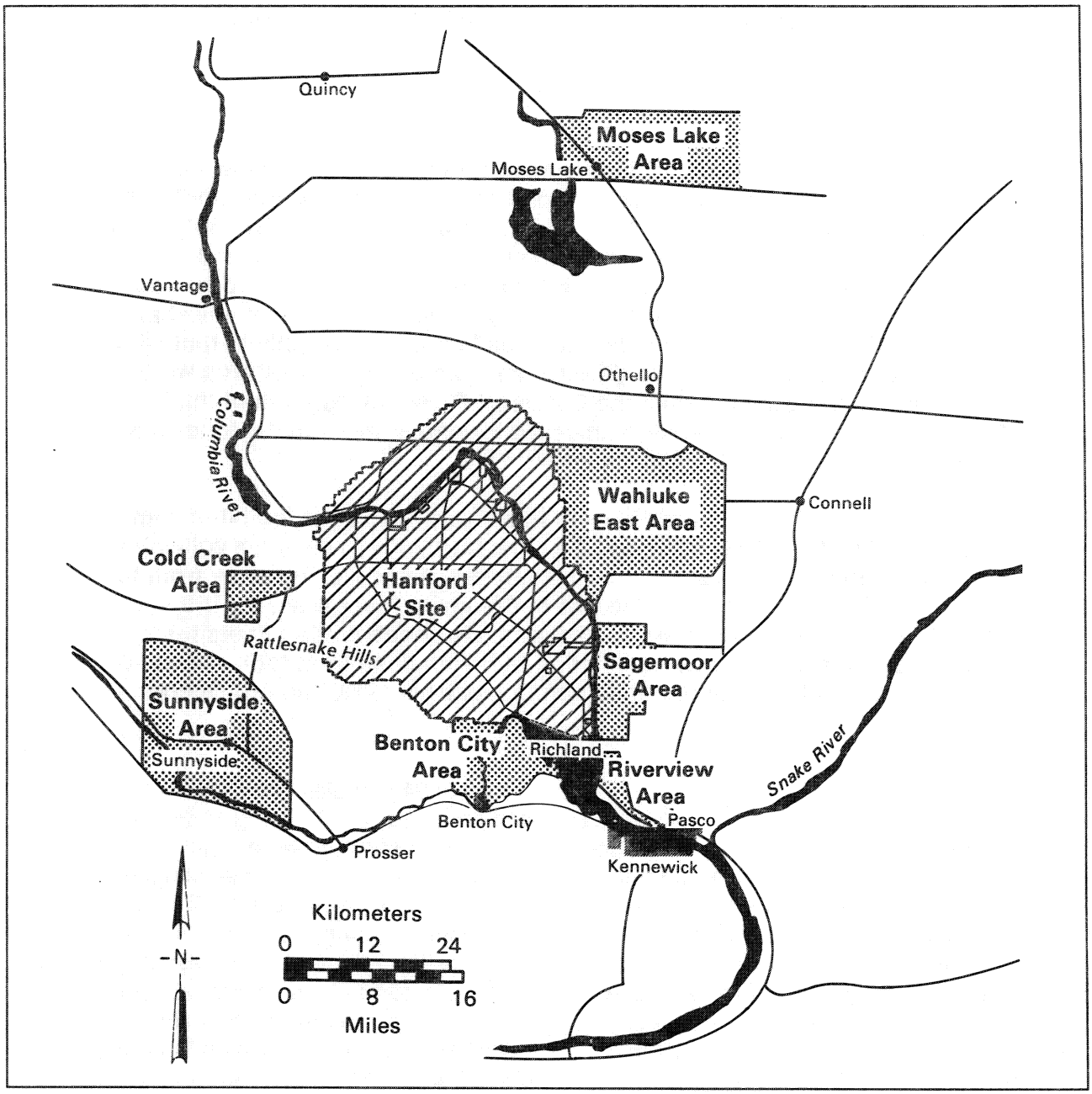

FIGURE 4.28. Foodstuffs Sampling Areas in 1988 (stippling indicates areas sampled)

through the air-pasture-cow-milk-food-chain. Results (Table C.13, Appendix C) indicate an even geographical distribution and are similar to results published by the EPA for the first quarter of 1988 (EPA 1988b). Figure 4.29 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 1988. Tritium was identified in about one-third of the samples. Iodine-129 was identified in all 12 samples tested. Concentrations were very low and similar to those obtained in recent years. No differences were

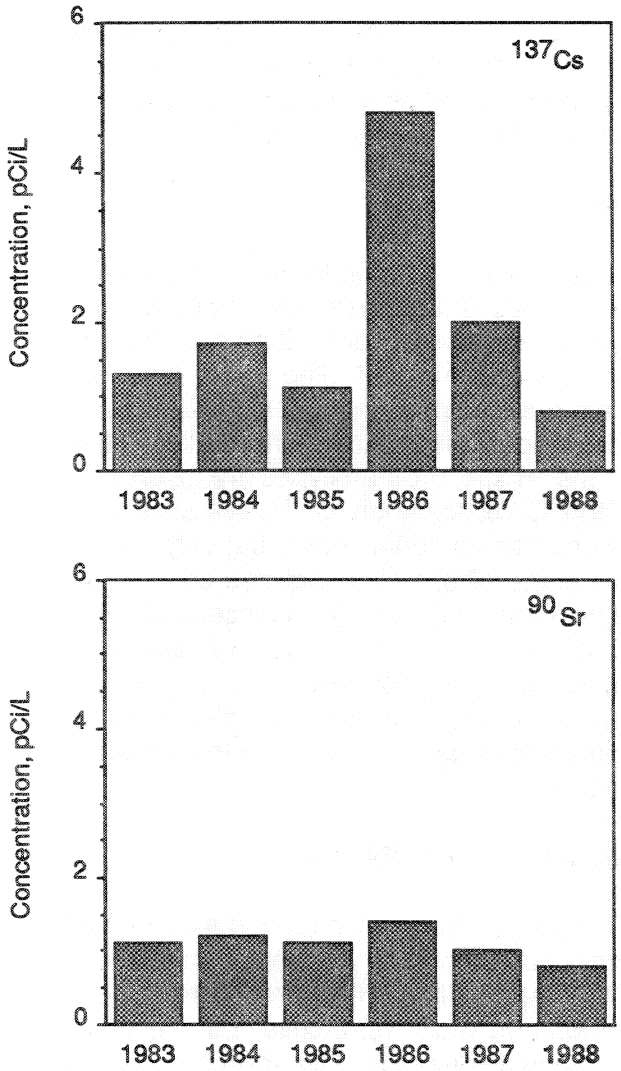

FIGURE 4.29. Annual Average Cesium-137 (^{137}Cs) and Strontium-90 (^{90}Sr) Concentrations in Milk, 1983 Through 1988

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

VEGETABLES

Samples of a leafy vegetable (cabbage) were obtained once during the summer from gardens located within the sampling areas listed in Table C.14, Appendix C. The leafy vegetable provided an indication of radionuclides present in locally grown produce. Three replicate samples, each composed of the edible portions of cabbage grown at the sampling locations, were analyzed for ^{90}Sr and ^{137}Cs. Results are provided in Table C.14, Appendix C. 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 4.30) and are attributed to worldwide fallout.

An important contributor to potential radiation dose has been ^{90}Sr from Columbia River water used to irrigate crops. Commercially grown crops of carrots and potatoes from the Riverview area were analyzed for ^{90}Sr, gamma-emitting radionuclides (^{137}Cs), and $^{239,240}Pu$. Concentrations found in potatoes from Riverview were similar to those from other areas, and no effect from the use of Columbia River water for irrigation could be detected. Carrot samples contained small amounts of ^{90}Sr and ^{137}Cs attributed to worldwide fallout. Plutonium-239,240 was not detected in potato samples. Results are shown in Table C.15, Appendix C.

FRUIT

Samples of apples, cherries, grapes, and melons were collected during harvest from the areas listed in Table C.16, Appendix C. Three replicate samples were collected at each sampling location, and the edible portions were analyzed for ^{3}H, ^{90}Sr, ^{137}Cs, and $^{239,240}Pu$. Results are provided in Table C.16, Appendix C.

Tritium, ^{90}Sr, and ^{137}Cs were identified in a few of the samples analyzed. Plutonium-239,240 was not detected in any samples. There were no detectable differences between fruit types or sampling locations. The concentrations of ^{3}H, ^{90}Sr, and ^{137}Cs were similar at all locations and attributed to worldwide fallout.

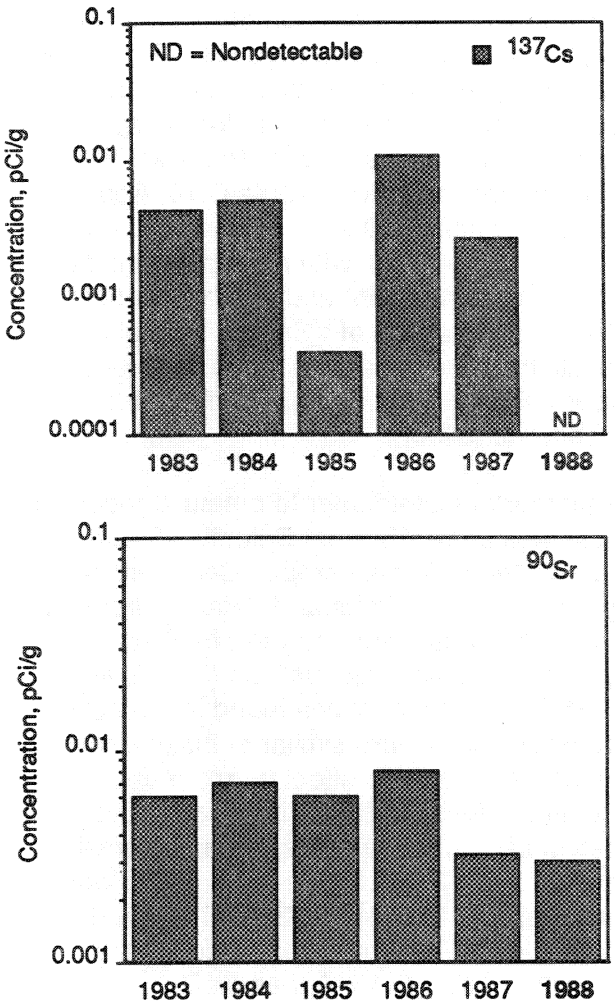

FIGURE 4.30. Annual Average Cesium-137 (^{137}Cs) and Strontium-90 (^{90}Sr) Concentrations in Leafy Vegetables, 1983 Through 1988

SPECIAL FRUIT AND VEGETABLE SAMPLES

Results from testing milk samples, and other types of samples collected over the years, indicate that ^{129}I is present in the Hanford environs from current and past operations. The levels of ^{129}I in various media are known to be quite low; however, samples of fruits or vegetables have not been analyzed in recent years. Special samples of selected fruits and vegetables were collected in 1988 and analyzed for ^{129}I. The types of samples and sampling locations are given in Table C.17, Appendix C. None of the samples tested positive for ^{129}I (Table C.17).

WINE

Locally produced wine (1988 vintage) was purchased and analyzed for ^{3}H and gamma-emmitting radionuclides. Both red and white wines were analyzed. The wines were made from grapes grown in the Columbia Basin and, for comparison, in the Yakima Valley. Results of the ^{3}H and ^{137}Cs analyses are given in Table C.18, Appendix C. Most samples contained trace amounts of ^{3}H, but only one sample of the 12 samples analyzed contained a detectable level of ^{137}Cs. Concentrations detected in wine were about the same as those commonly found in milk. The concentrations of radionuclides were similar for both sampling areas and attributed to worldwide fallout.

WHEAT AND ALFALFA

Samples of ripened wheat and mature alfalfa were collected from the areas listed in Table C.19, Appendix C. Three replicate samples of wheat and alfalfa were collected at each location and analyzed for ^{90}Sr and ^{137}Cs. Wheat samples from the Sagemoor area and Sunnyside area were also analyzed for $^{239,240}Pu$. Results are shown in Table C.19, Appendix C.

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 C.20, Appendix C. Table C.20 provides results of analyses for ^{90}Sr and ^{137}Cs. Concentrations were all low, generally near detection levels, and are attributable to worldwide fallout. Strontium-90 and ^{137}Cs concentrations in beef are shown in Figure 4.31 for the previous 5 years.

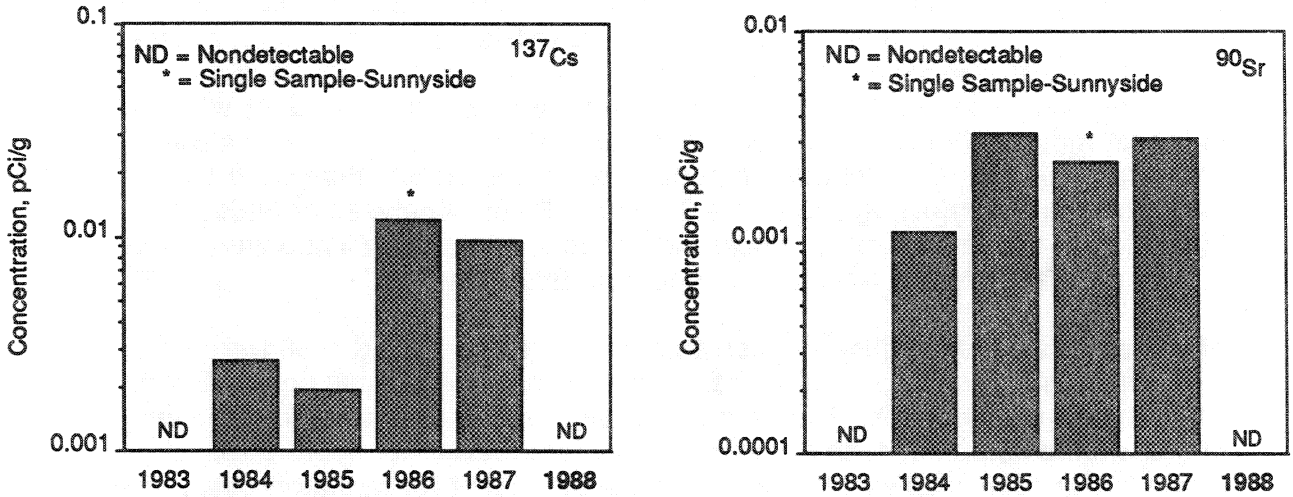

FIGURE 4.31. Annual Average Cesium-137 (^{137}Cs) and Strontium-90 (^{90}Sr) Concentrations in Beef, 1983 Through 1988

4.4 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., wastewater 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 1988 were similar to those observed in recent years. There are no radionuclide concentration limits for wildlife samples. The potential dose to a person who consumed any of the wildlife sampled, even at the maximum radionuclide concentrations measured in 1988, was well below applicable standards for radiation dose.

DEER

Samples taken from road kills (Figure 4.32) were used to provide an indication of the general levels of radionuclides in Hanford Site deer. Three deer were sampled and analyzed for ^{137}Cs in muscle and $^{239,240}Pu$ in liver. Muscle tissue (i.e., meat that could be used for human consumption) is analyzed for ^{137}Cs because it is most likely to contain ^{137}Cs when this radionuclide is present in the diet of deer. The liver could also be used for human consumption and is the organ most likely to retain $^{239,240}Pu$ from the diet of deer. Results indicated the presence of detectable levels of ^{137}Cs (0.010 pCi/g) in one muscle sample. Liver samples did not contain detectable levels of $^{239,240}Pu$. The ^{137}Cs concentrations were in the range generally attributed to worldwide fallout, and the median value[a] was consistent with those observed in previous years (Figure 4.33). Results for 1988 showing the maximum and average values are given in Table C.21, Appendix C.

FISH

Whitefish, bass, and salmon were collected at various locations along the Columbia River (see Figure 4.32). Boneless fillets were analyzed for ^{60}Co, ^{90}Sr, and ^{137}Cs.

The remaining carcasses were analyzed to estimate ^{90}Sr in bone. Whitefish were collected near the 100-D Area and upstream of Hanford near Priest Rapids Dam. Bass were collected near the 100-F Area. Maximum and

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(a) The median concentrations (i.e., the middle value of a series of values arranged from lowest to highest) rather than averages are plotted in text figures to illustrate the central tendency of wildlife data. The calculated average of a small number of highly variable results can distort the interpretation of the results in favor of an uncharacteristically high or low value. Maximum and average concentrations are provided in the appendix tables for comparison by the reader.

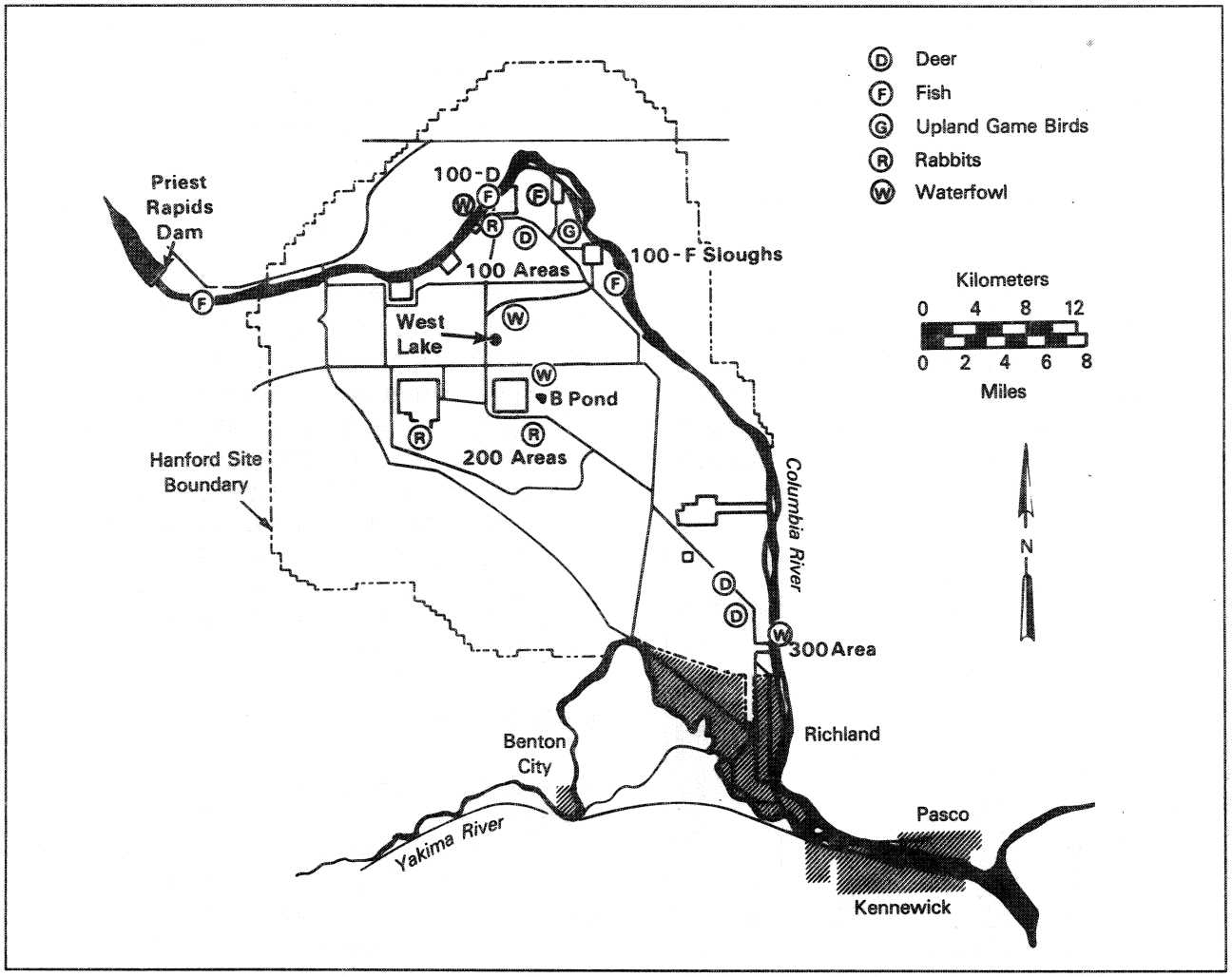

FIGURE 4.32. Wildlife Sampling Areas

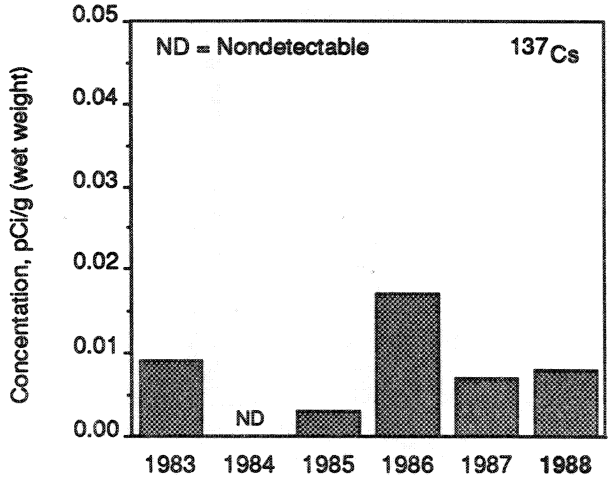

FIGURE 4.33. Median Concentrations of Cesium-137 (^{137}Cs) in Deer Muscle, 1983 Through 1988

average results for ^{60}Co, ^{90}Sr, and ^{137}Cs for 1988 are shown in Table C.22, Appendix C. Muscle samples from spawned-out fall Chinook salmon were collected at the Priest Rapids Dam hatchery and analyzed for ^{60}Co, ^{90}Sr, and ^{137}Cs as part of a special study. Samples from similar salmon were collected near White Bluffs (100-H Area) on the Hanford Reach for comparison. Results are shown in Table C.22, Appendix C.

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 samples

from the two locations. Median concentrations for ^{60}Co and ^{137}Cs in whitefish and bass in 1988 and recent years are shown in Figure 4.34. 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 ^{137}Cs concentrations slightly higher than those for whitefish. Results for radionuclide analyses of special muscle tissue samples from the spawned-out salmon collected at Priest Rapids Dam above Hanford were similar to samples from salmon collected near White Bluffs in the Hanford Reach. These results indicate no measurable influence on fish from radionuclides released to the Columbia River during current or past operations at Hanford.

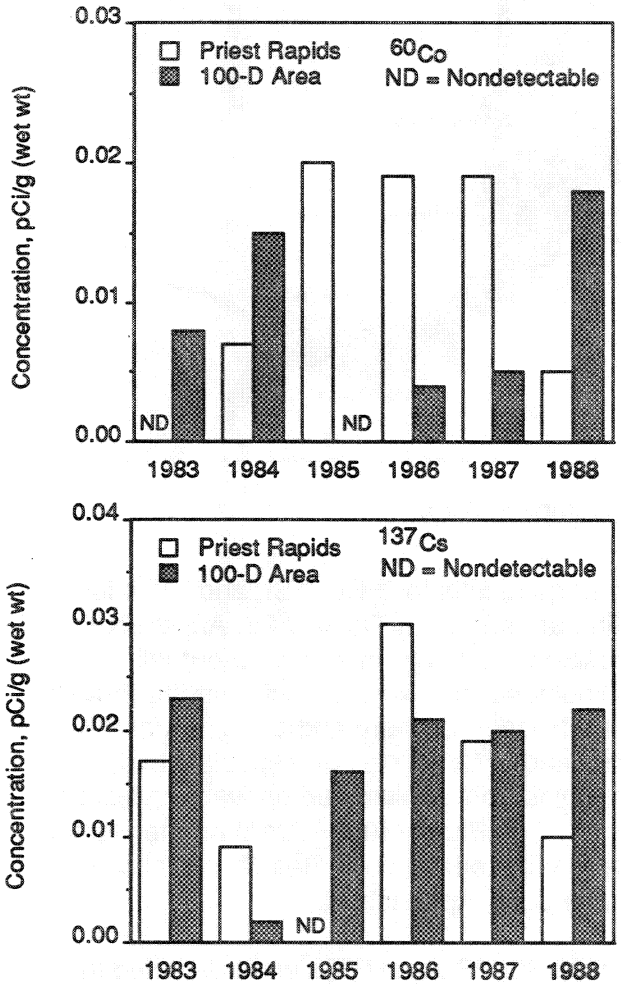

FIGURE 4.34. Median Concentrations of Cobalt-60 (^{60}Co) and Cesium-137 (^{137}Cs) in Whitefish Collected near Priest Rapids Dam and near the 100-D Area, 1983 Through 1988

UPLAND GAME BIRDS

Pheasants were collected from the 100 Areas (Figure 4.32). Samples of breast meat were analyzed for ^{60}Co and ^{137}Cs. Three of the birds showed detectable concentrations of ^{137}Cs. Cobalt-60 was not detected in any of the samples. Median concentrations for ^{137}Cs in birds from the 100 Areas (Figure 4.35) are within the ranges observed during previous years and are attributed to worldwide fallout. Maximum and average concentrations for 1988 for both nuclides are shown in Table C.23, Appendix C.

WATERFOWL

Mallard ducks were collected from the Columbia River near the 100-N Area, B Pond and West Lake in the 200 Areas, and the 300 Area trench (Figure 4.32). Approximately 0.5 kg of breast meat was analyzed for ^{90}Sr and ^{137}Cs. Results (Figure 4.36) continue to show concentrations of ^{137}Cs decreasing in ducks

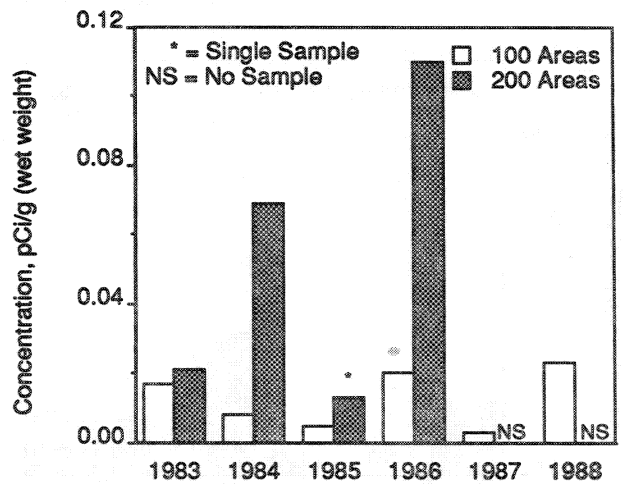

FIGURE 4.35. Median Concentrations of Cesium-137 (^{137}Cs) in Game Birds from the 100 Areas in 1987 and 1988 and from the 100 and 200 Areas, 1983 Through 1988

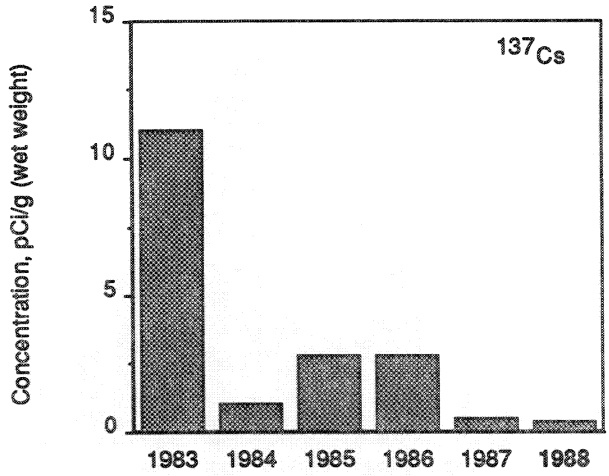

FIGURE 4.36. Median Concentrations of Cesium-137 (^{137}Cs) in Mallard Ducks from B Pond, 1983 Through 1988

collected from B Pond. Average concentrations of ^{137}Cs in samples collected from the 300 Area trench in 1988 were about one-third of the concentrations measured in ducks from B Pond. The concentrations of ^{90}Sr were low and at levels expected from worldwide fallout (Table C.24, Appendix C).

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 $^{239,240}Pu$ that may be present in food or water consumed by the animal.

Cottontail rabbits were collected near the 100-N Area, and black-tailed jack rabbits were collected near the 200 Areas during 1988. 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 4.37 and 4.38. Maximum and average concentrations for samples analyzed in 1988 are given in Table C.25, Appendix C.

The levels of ^{90}Sr in bone samples indicated that all of the rabbits at some time had consumed food or water contaminated with ^{90}Sr. One cottontail collected near the 100-N Area showed relatively high levels of ^{90}Sr in bone (180 ± 3 pCi/g) and $^{239,240}Pu$ in liver (6.7 ± 0.1 pCi/g). The same rabbit also tested high for ^{60}Co in muscle (17 ± 0.4 pCi/g) but low for ^{137}Cs in muscle (0.64 ± 0.038 pCi/g).

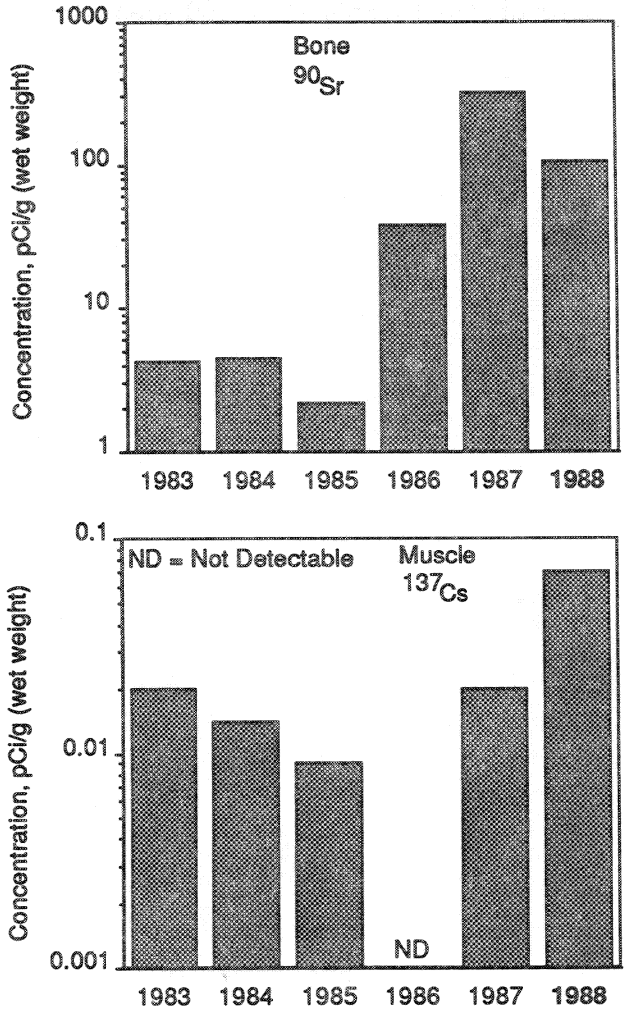

FIGURE 4.37. Median Concentrations of Strontium-90 (^{90}Sr) in Bone and Cesium-137 (^{137}Cs) in Muscle of Cottontail Rabbits in the 100 Areas, 1983 Through 1988

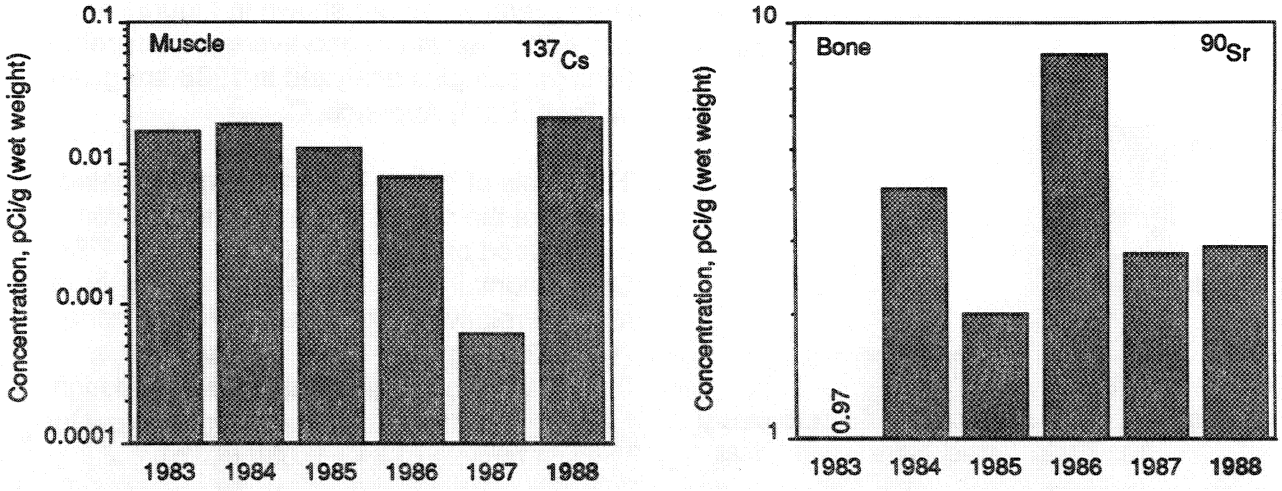

FIGURE 4.38. Median Concentrations of Cesium-137 (^{137}Cs) in Muscle and Strontium-90 (^{90}Sr) in Bone of Jack Rabbits in the 200 Areas, 1983 Through 1988

4.5 SOIL AND VEGETATION MONITORING

K. R. Price

Surface soil and rangeland vegetation samples were collected at a number of locations during 1988, both on and off the Hanford Site. The purpose of sampling was to detect the possible build-up of radionuclides from the deposition of airborne effluents released from Hanford facilities. Samples were collected at nonagricultural, relatively undisturbed sites so that natural deposition and build-up processes would be represented. Because the radionuclides of inteest were present in worldwide fallout or occurred both naturally and in Hanford effluents, their presence was expected in all samples.

An assessment of radionuclide contributions 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 1988 were compared to results obtained from the same location in previous years. Evaluations of 1988 results provided no indication of trends or increases in the concentrations of radionuclides in the offsite environment that could be attributed to Hanford operations. [a]

SAMPLE COLLECTION AND ANALYSIS

Soil and vegetation samples were collected at 15 onsite and 23 Site perimeter and offsite locations (Figure 4.39). 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 also were 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 sampling 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 ^{238}U.

When soil samples were collected, samples of perennial vegetation also were 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

(a) The median concentrations (i.e., the middle value of a series of of values arranged from lowest to highest) rather than averages are plotted in text figures to illustrate the central tendency of soil and vegetation data. The calculated average of a small number of highly variable results can distort the interpretation of the results in favor of an uncharacteristically high or low value. Individual and average concentrations are provided in the Appendix tables for comparison by the reader.

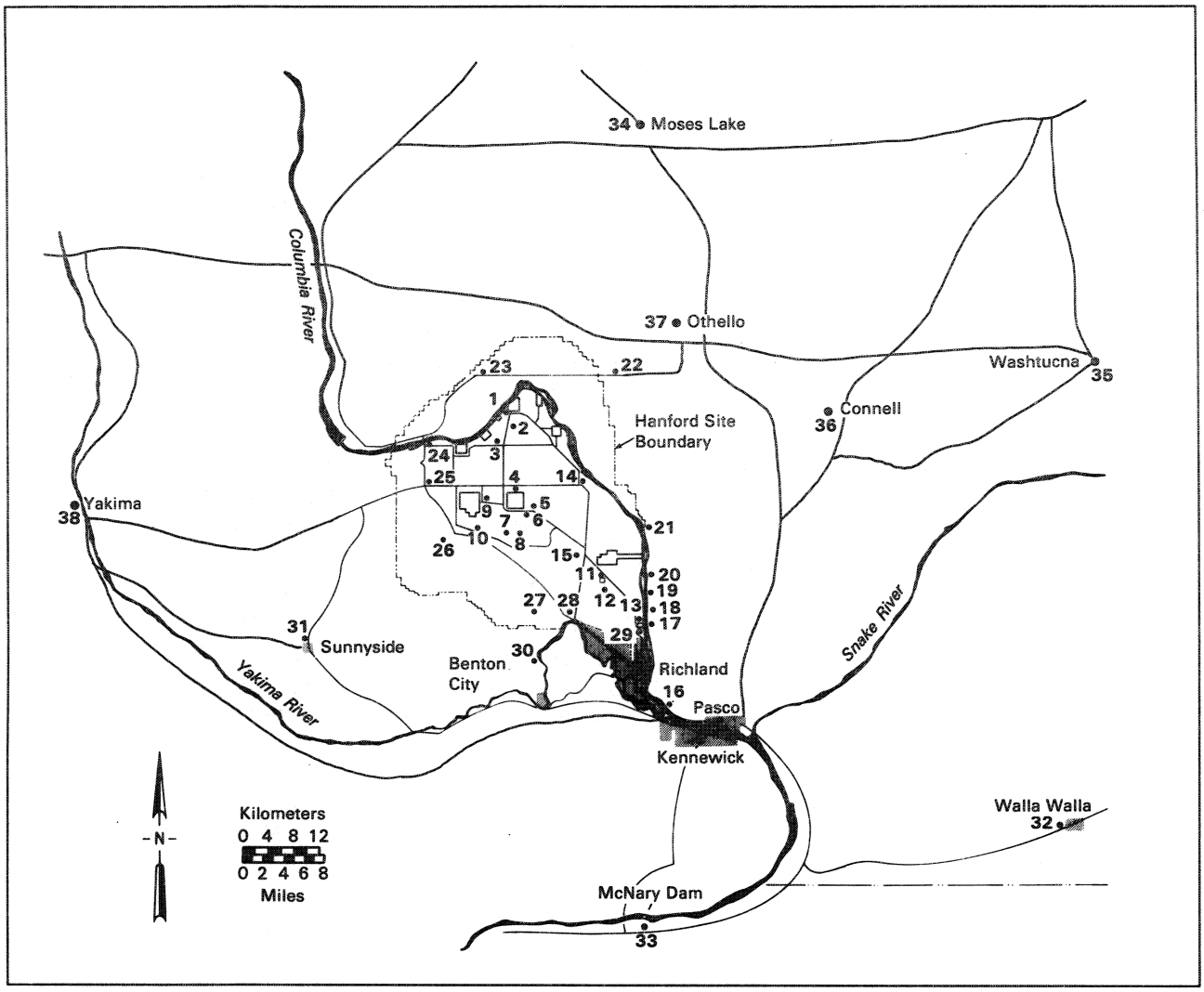

FIGURE 4.39. Onsite and Offsite Sampling Locations for Soil and Vegetation in 1988

was dried and ground, and aliquots were taken for analysis. Vegetation samples were analyzed for gamma-emitting radionuclides, ^{90}Sr, $^{239,240}Pu$, and total uranium.

SOIL RESULTS

Analytical results from soil samples collected on and off the Site during 1988 are reported in Tables C.26 through C.29, Appendix C. Also included in the tables are results for the previous 5 years from each location. For comparative purposes, averages of the results from all onsite and offsite locations are provided. No new sample locations were added in 1988.

The method used to analyze soil samples for uranium changed in 1988. Prior to 1988, the samples were leached with acid and the leachate analyzed for uranium. The new technique involves analyzing the entire sample, without acid treatment, using a low-energy photon detector (LEPD) system. The new analysis is specific for the ^{238}U isotope and results in numerical values greater than uranium analysis by the old technique.

Radionuclide concentrations in onsite soil samples during 1988 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 concentrations for a few radionuclides. Specifically, the 200-East Area north-central (Figure 4.39, number 4) sample had elevated levels of ^{90}Sr and ^{137}Cs, and the sample taken east of the 200-West Area (Figure 4.39, Number 9) had elevated levels of ^{137}Cs and $^{239,240}Pu$, as in previous years. The offsite soil sample results were similar to those obtained during the past several years. Histograms in Figure 4.40 display median (middle) values for ^{90}Sr, ^{137}Cs, $^{239,240}Pu$, and ^{238}U for all samples collected on and off the Site during 1988. Radionuclide concentrations, except uranium, were 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.

VEGETATION RESULTS

Analytical results from samples of mature, perennial vegetation collected during 1988 are provided in Tables C.30 through C.33, Appendix C. Individual results for the previous 5 years at each location are given in the tables, along with the average of onsite and offsite results for the same time period. New sample locations were added in 1986 and 1987.

Radionuclide concentrations in vegetation samples collected on and off the Site in 1988 were similar to those observed at the same locations during previous years. Figure 4.41 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

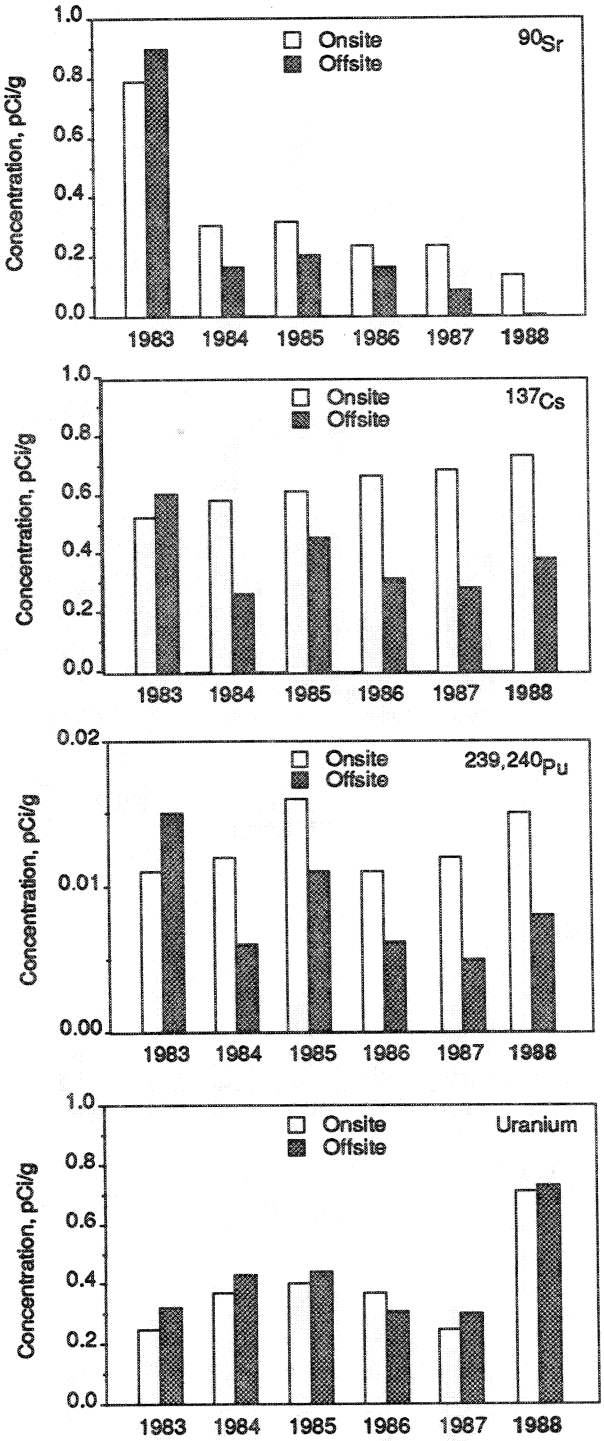

FIGURE 4.40. Median Strontium-90 (^{90}Sr), Cesium-137 (^{137}Cs), Plutonium-239, 240 ($^{239,240}Pu$), and Uranium[a] Concentrations Measured in Soil at Onsite and Offsite Locations, 1983 Through 1988

(a) Uranium-238 beginning in 1988.

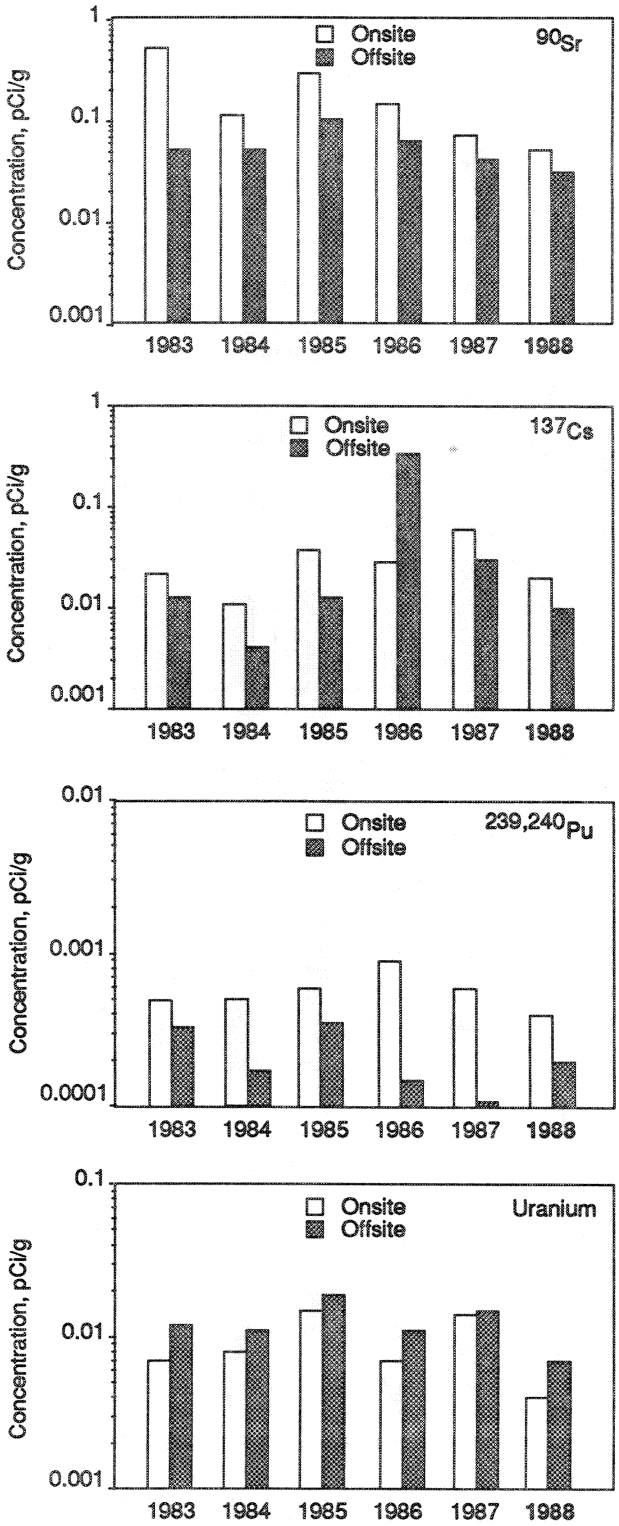

FIGURE 4.41. Median Strontium-90 (^{90}Sr), Cesium-137 (^{137}Cs), Plutonium-239,240 ($^{239,240}Pu$), and Uranium Concentrations in Vegetation at Onsite and Offsite Locations, 1983 Through 1988

Chernobyl incident. The effect of Chernobyl was not noted in the results for subsequent years. 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.

4.6 PENETRATING-RADIATION MONITORING

L. A. Rathbun and J. J. Fix

Dose rates from penetrating radiation (gamma rays) were measured at a number of locations in the Hanford environs during 1988. 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 from worldwide fallout, was recorded at all dosimeter locations. Dosimeters also measured dose rates from exposure to radioactive materials associated with Hanford activities. Results obtained both on and off the Site were slightly higher than those of past years. The cause for the increase is attributed to variability in naturally occurring dose rates from year to year and statistical uncertainty in conducting low-level environmental dose measurements. The increase is not attributed to changes in Hanford operations. 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 inactive waste disposal sites located outside of operating areas were surveyed routinely during 1988. These surveys were designed to identify increases in levels of radioactivity. Survey results for 1988 were comparable to those of past years. No increases in radiation levels were observed on Site highways or railroads.

PENETRATING-RADIATION MEASUREMENTS

The penetrating-radiation (gamma ray) doses measured during 1988 were intended to identify changes in radiation levels that may indicate the presence and concentration of either naturally occurring or Hanford-related radionuclides. Knowledge of changes in Hanford-related radionuclide concentrations in the environment is important in assessing environmental impact, determining compliance with pertinent regulations, and evaluating onsite waste handling practices. Long-term (1 to 3 months) measurements of penetrating radiation were made with thermoluminescent dosimeters (TLDs). Instantaneous dose rates were measured with survey meters and large sodium iodide crystals.

Penetrating 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. With the exception of the shoreline locations, the location of TLDs coincided with air monitoring stations. This placement scheme was based on convenience and security considerations. 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 70 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. 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. (It is actually a few percent less than 1). Nonetheless, it is assumed to be 1.0 throughout this report. This bias, being consistent, does not affect the ability to distinguish differences in direct radiation levels between various locations.

Dosimeters were placed at numerous locations in the vicinity of Hanford and at several locations more distant from the Site (Figure 4.42). Dose rates measured at each

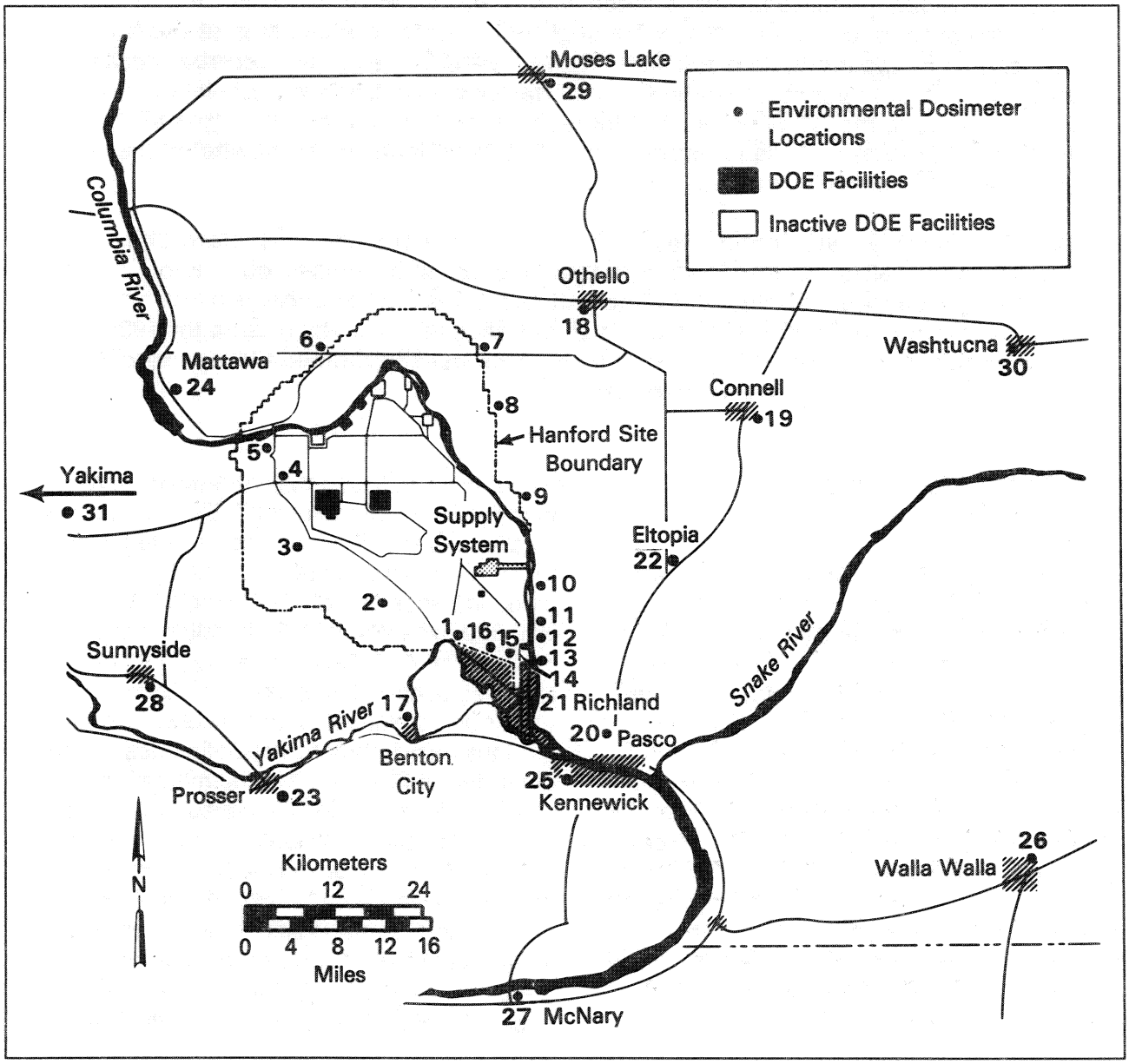

FIGURE 4.42. Environmental Dosimeter Locations at the Site Perimeter and at Nearby and Distant Communities in 1988 (see location number key in Table C.34)

location during 1988 are given in Table C.34, Appendix C. Offsite dosimeter locations were chosen to represent areas that could have been inhabited continuously. Dose measurements at all locations are reported in mrem/yr.

The 1988 dose measurements were higher than those observed in 1987 for the same locations. The cause for this increase is attributed to variability in naturally occurring dose rates from year to year and statistical uncertainty in conducting low-level environmental dose measurements. The increase is not attributed to changes in Hanford operations. The background dose rate, calculated from the annual average dose rates observed at distant locations, was 78 mrem/yr (0.009 mrem/h), in contrast to the 72 mrem/yr reported last year. Dose rates measured at Seattle and Spokane in 1985 by the Washington State Department of Social and Health Services (WDSHS) were 56 mrem/yr and 88 mrem/yr, respectively (WDSHS 1987).

Figure 4.43 shows average annual dose rates measured at perimeter and distant locations during 1988 and the previous 5 years. Dose rates for the years 1983-1986 have been corrected to remove previous biases. In this

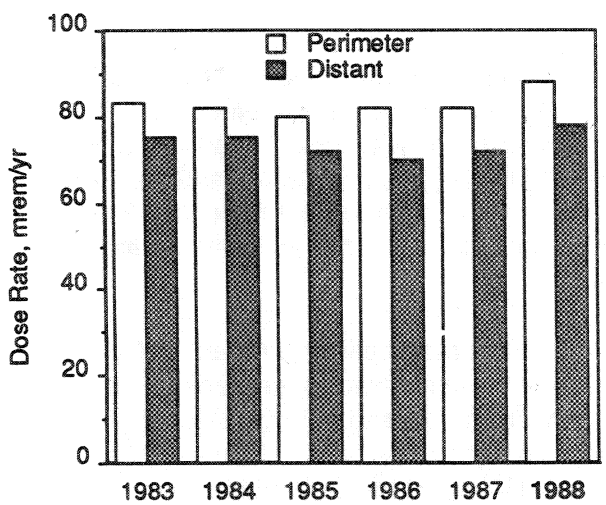

FIGURE 4.43. Annual Average External Dose Rates at Perimeter and Distant Locations, 1983 Through 1988. (The dose rates for the years 1983-1986 have been corrected to eliminate previous biases.)

figure, some year-to-year natural variability is apparent. The natural variability is due to several weather and climatic factors and to solar flare activity. It is difficult to quantify, but year-to-year variations of 10% are not unlikely (NCRP 1987). The below normal precipitation in 1988 may account for more dose from the soil reaching the TLDs.

Figure 4.43 also shows that dose rates at perimeter stations generally averaged 10 mrem/yr higher than at distant locations. The larger difference between perimeter and distant location doses in recent years is due, at least in part, to the addition of low-dose distant locations. The difference is attributed to natural geographic variations in terrestrial radiation and variations resulting from human activities. The perimeter locations are generally sites with unaltered radiation fields, whereas the distant locations are in the vicinity of public buildings. The land near the public buildings has been substantially altered by paving, gravel, etc. These alterations tend to lower the penetrating-radiation doses relative to natural conditions. Because of the natural variability, the difference between the perimeter and distant location doses would have to increase to approximately 15 mrem/yr before a Hanford impact could be observed.

Dosimeters were submerged in the Columbia River at Coyote Rapids and the Richland Pumphouse (Figure 4.44) to provide an estimate of penetrating dose rates that could be received by a person immersed in the river. The measurements, shown in Table C.35, Appendix C, indicated a dose rate less than the background dose rate of 0.0095 mrem/h measured on land. The average dose rates at the Coyote Rapids and the Richland Pumphouse locations were 0.006 mrem/h and 0.005 mrem/h, respectively, during 1988. 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

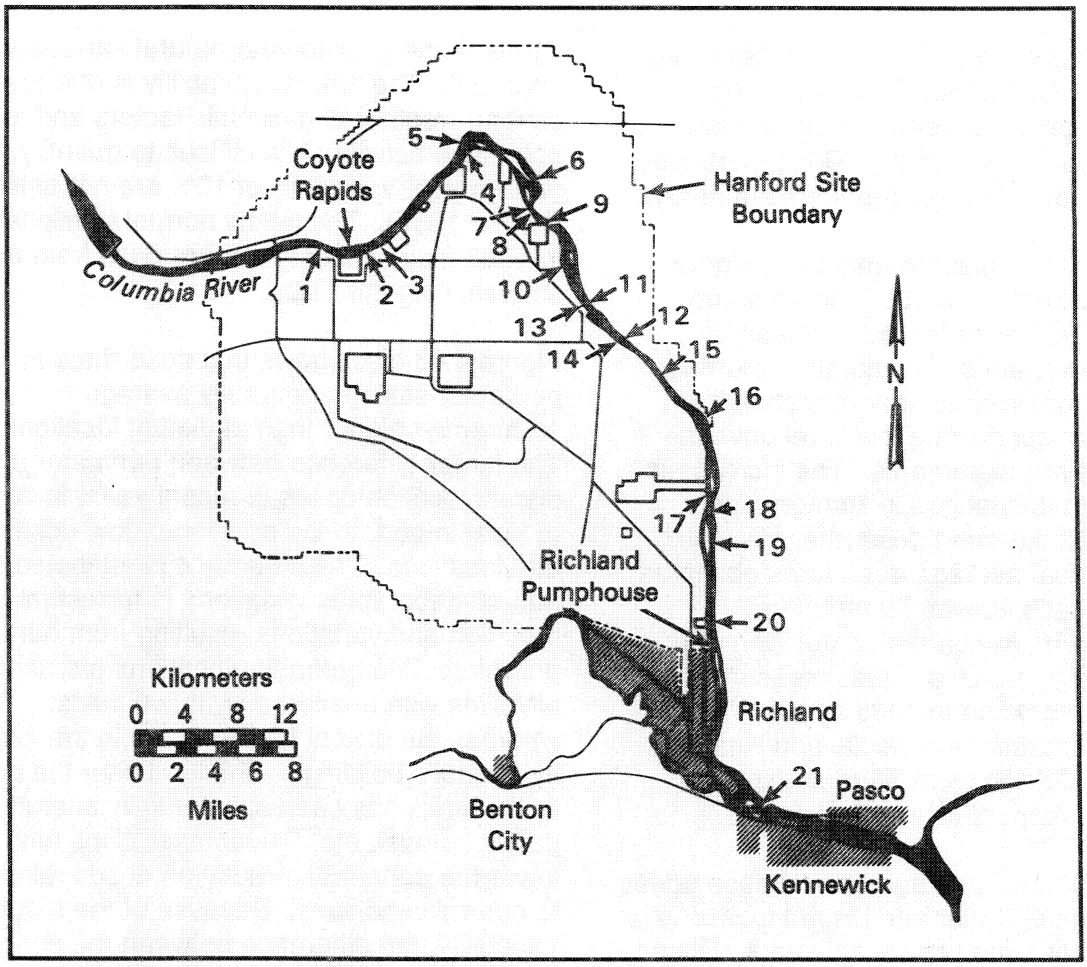

FIGURE 4.44. Environmental Dosimeter Locations Along the Hanford Reach of the Columbia River (see location number key in Table C.37)

(Figure 4.45). Locations included the Columbia River shoreline near the 100-N Area, a parking lot near the west perimeter of the 300 Area, and the parking lot near the Visitors Center at the 400 Area. Results for 1988 are shown in Table C.36, Appendix C. 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 0.042 mrem/h; the average varied between 0.020 and 0.029 mrem/h. Dose rates in this vicinity were attributed to waste-management activities within the 100-N Area.

The dose rates near the Visitors Center at the 400 Area and the west perimeter of the 300 Area were at background, indicating that penetrating radiation at these locations could not be attributed to the Fast Flux Test Facility (FFTF) or other research activities during 1988.

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 4.44) where

Figure removed as per DOE guidance.

FIGURE 4.45. Environmental Dosimeter Locations at Publicly Accessible Onsite Locations in 1988 (see location number key in Table C.36)

dose rates were determined to be slightly elevated with respect to background levels. Table C.37, Appendix C, provides results of measurements taken at these locations during 1988. Dose rates measured during 1988 were slightly higher than those observed in

recent years. This increase is similar to that seen at other locations and is thought to be due to natural variability.

Onsite external penetrating radiation was measured at the locations shown in Figure 4.46. Results of these measurements are given in Table C.38, Appendix C. Dose rates above background levels were observed at only one onsite location during 1988. The rate in excess of background observed near the 100-N Area was attributed to direct radiation from waste-handling and storage facilities.

Dose rates around the 200, 300, and 400 Areas were within the expected background levels.

ENVIRONMENTAL DOSIMETER INTERCOMPARISON

During the last quarter of 1988, PNL participated in an intercomparison of environmental dosimeter measurements. Other participants included the Washington Public Power Supply System (Supply System), the Oregon State Health Department, and the Washington State

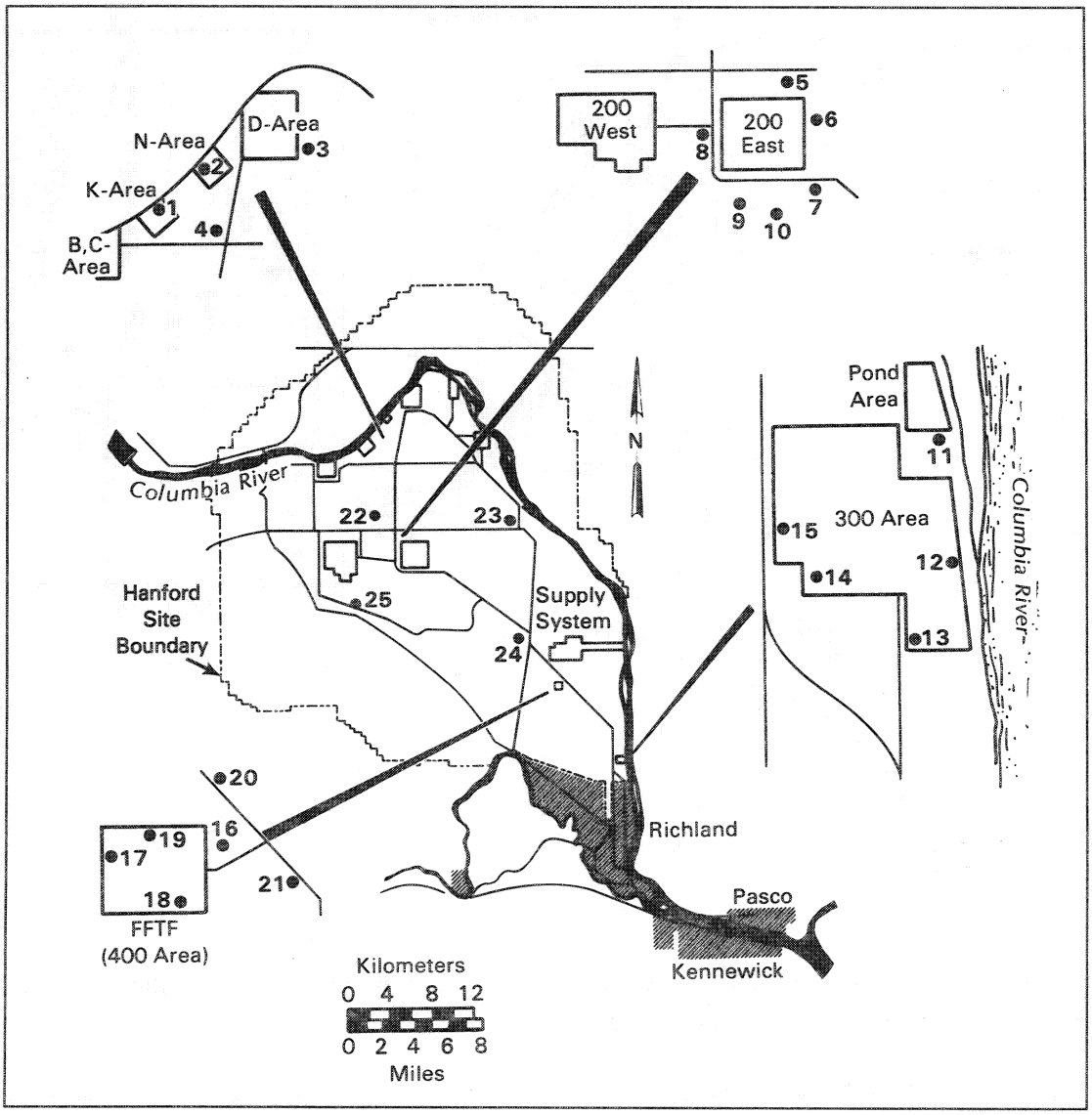

FIGURE 4.46. Environmental Dosimeter Locations on the Hanford Site (see location number key in Table C.38)

Department of Social and Health Services. Small groups of environmental dosimeters from each participant were exposed to ^{226}Ra, ^{60}Co, and ^{137}Cs gamma rays under laboratory conditions. Other dosimeters were placed at an environmental site for 3 months. Results are listed in Table C.39, Appendix C.

The following observations can be made from these data:

- The State of Oregon results are relatively low compared with others for ^{137}Cs and ^{60}Co irradiations. This is a direct result of their calibration with a ^{226}Ra source.

- PNL, Supply System, and Washington State results are very close for ^{137}Cs and ^{60}Co. Each of these organizations calibrate with ^{137}Cs.

- Washington State and PNL TLD-700 dosimeter results show a similar higher response, relative to a ^{137}Cs response, for the ^{226}Ra exposures.

- Supply System dosimeters show an even higher over-response to ^{226}Ra compared to the ^{137}Cs response. This is attributable to the significant over-response of the $CaSO_4$ phosphor used in these dosimeters.

- Greater variability was observed for the quarter-long deployment of dosimeters from each organization at environmental location #46 on Wahluke slope (Table C.39, Appendix C).

RADIATION SURVEYS

Onsite roads, railroads, and inactive radioactive-waste disposal sites outside of operating areas were surveyed routinely during 1988 to detect increased 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 1988. Specific routes and frequencies for surveys conducted during 1988 were defined in a master schedule developed by PNL.

Roads shown in Figure 4.47 were surveyed routinely at 10 mph using four scintillation detectors positioned approximately 0.5 m above the ground, evenly spaced across the width of a vehicle. No increased radiation readings were observed on Site roadways during 1988. Railroad routes (Figure 4.47) were surveyed at 10 mph using a small railcar with two scintillation detectors mounted approximately 0.3 m directly above the tracks. Surveys conducted during 1988 did not reveal any increased readings on Site railways.

Inactive waste disposal sites outside operating-area perimeter fences were surveyed during 1988 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 1988 showed levels comparable to those observed in past years.

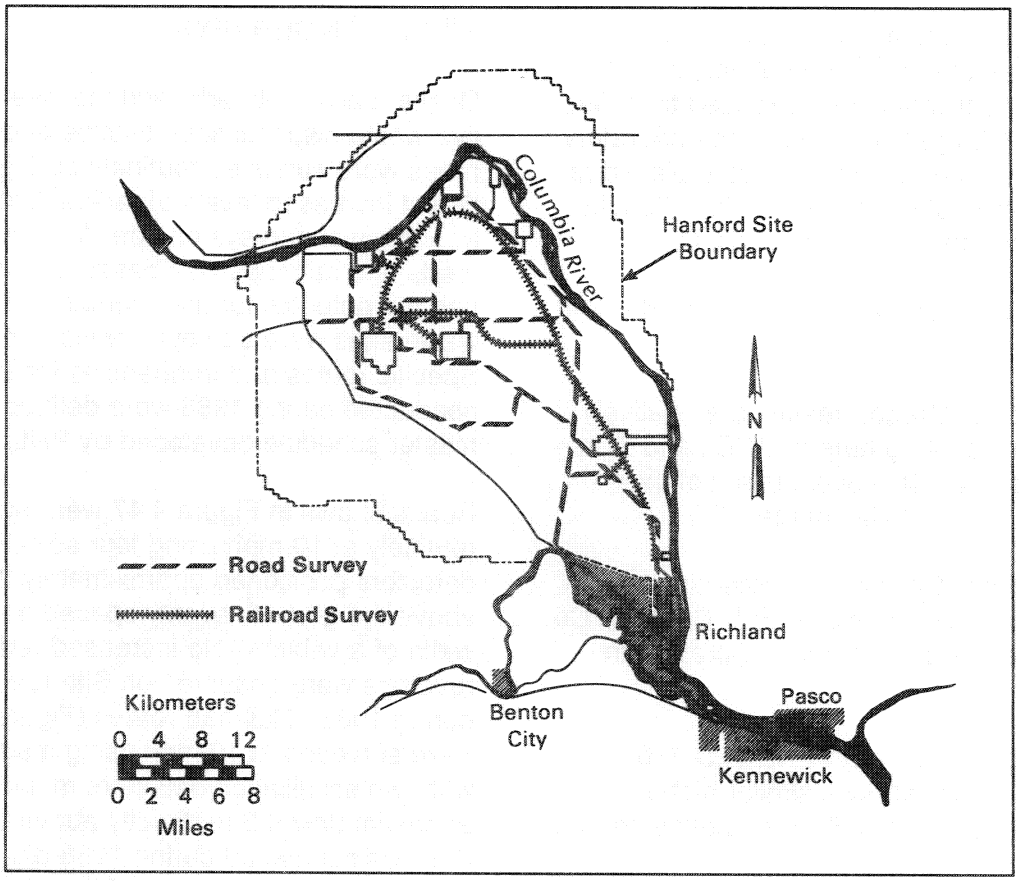

FIGURE 4.47. Road and Railroad Survey Routes in 1988

4.7 EFFLUENT MONITORING

D. J. Rokkan, Westinghouse Hanford Company

Westinghouse Hanford Company, the prime operating and engineering contractor at Hanford, quantifies and documents the amounts of radioactive and nonradioactive liquids, gases, and solids released or disposed to the environment from its operations. These tasks are performed by the effluent monitoring program that assesses compliance with applicable federal, state, and local regulations and permits. Monitoring results are also used in pollution abatement programs to assess the effectiveness of effluent treatment and control. Pacific Northwest Laboratory monitors the effluents from its research activities.

AIR EMISSIONS

Major air emission points are located in the 100 Areas (reactor areas), 200-East and 200-West Areas (separations areas), 300 Area and 400 Area (research and development areas), 1100 Area (stores, warehouses, shops, and offices), and the 600 Area (all remaining areas on the Hanford Site). A brief description of the gaseous emission sources in these areas is presented below.

- The 100 Areas contain the N Reactor, the eight inactive production reactors, and associated support facilities. During operation, N Reactor is the main contributor of radioactive emissions in the 100 Areas, with lesser contributions from various building ventilation systems. Nonradioactive pollutants are emitted from the 184-N powerhouse. There are 16 airborne emission sources in the 100 Areas.

- The 200 Areas contain the chemical separations/processing facilities and the waste handling/disposal facilities. Radioactive emission sources include the Plutonium Uranium Extraction (PUREX) Plant, the Uranium Oxide (UO_3) Plant, the Plutonium Finishing Plant (PFP), B Plant, the Reduction Oxidation (REDOX) Plant, T Plant, the 222-S Laboratory, the Critical Mass Laboratory, the Laundry Facility, underground storage tanks, waste evaporators, and tank farms. The PUREX Plant, UO_3 Plant, and powerhouses also emit nonradioactive pollutants. There are 77 airborne emission sources in the 200 Areas.

- The 300 Area consists primarily of laboratories and research facilities, as well as the N Reactor Fuel Fabrication Facility and the steam plant. Radioactive emissions arise from the operation of the Fuel Fabrication Facility (currently inactive) and various laboratory hoods. Nonradioactive emissions originate from the steam plant, an incinerator located in coal-fired burners, and a thermal treatment facility. There are 13 airborne emission sources in the 300 Area.

- The 400 Area contains the Fast Flux Test Facility (FFTF), the Maintenance and Storage Facility (MASF), and the Fuel Materials Examination Facility (FMEF). Effluents from these facilities consist of both radioactive and nonradioactive particulates. There are four airborne emission sources in the 400 Area.

- The 600 Area comprises all areas of the Site other than those assigned to the 100, 200, and 400 Areas. Two facilities in the 600 Area currently discharge gaseous effluents.

- The 1100 Area is located outside the Hanford Site. It contains warehouses, vehicle maintenance shops, excess equipment and

materials storage, and office buildings. The 1100 Area emissions are generated from heating plants. Three oil-fired boilers emit only nonradioactive effluents.

The radioactive airborne effluents from facilities at the Hanford Site include volatile forms of radionuclides, noble gases, and radioactive particles. Every radioactive effluent stream is monitored that has a potential to exceed 10% of a discharge limit, and every nonradioactive effluent stream is monitored with a potential to exceed 50% of the discharge limit. Nonradioactive airborne effluents are monitored for particulate and gaseous discharges.

Annual effluent discharge release reports are generated for each of the major operating areas and are submitted to the DOE Richland Operations Office (DOE-RL). The DOE requirement to report radioactive effluent and onsite discharge data to the Idaho National Engineering Laboratory (INEL) is met through submittal of the Effluent Information System/ Onsite Discharge Information System (EIS/ ODIS) report in April of each year (DOE-ID 1987). A summary is published annually for external distribution, based on input from the various DOE sites. Notification requirements for asbestos handling are included in National Emission Standards for Hazardous Air Pollutants (NESHAP) regulations. A summary of air emissions from the Hanford Site for 1988 is given in Table G.1, Appendix G.

LIQUID EFFLUENTS

Liquid effluents are generated from facilities in all areas of the Hanford Site. Liquid effluent sources generate over 350 radioactive and nonradioactive liquid waste streams that discharge to the Columbia River, soil column, and/or sewer disposal systems. Total effluent discharge volume has averaged about 150 billion gallons annually. Approximately 98% of the total volume consists of cooling water and other National Pollutant Discharge Elimination (NPDES) discharges.

The purpose of liquid effluent monitoring is to ensure that all release sources are monitored and that allowable limits set for the release of liquid effluents to the environment are not exceeded. Discharges are monitored for both radioactive and nonradioactive constituents. Radioactive effluent monitoring is performed in the 100, 200-East and 200-West, and 300 Areas. Radioactive liquid effluents generated at the 400 Area are shipped to the 200 Areas for disposal. The 600 and 1100 Areas do not generate radioactive liquid effluents. Nonradioactive liquid effluent monitoring is conducted in the 100, 200, 300, and 400 Areas.

Liquid effluent monitoring results are reported to the EIS/ODIS. Monitoring results for waste streams covered by the NPDES permit are reported monthly to EPA. A summary of 1988 liquid effluents is given in Table G.3, Appendix G.

SOLID WASTE

Hanford Site generated solid wastes are classified as radioactive, nonradioactive, and mixed waste. Waste consists of transuranic, high-level, and low-level wastes. Radioactive mixed waste consists of wastes that have both radioactive and dangerous components. The nonradioactive wastes are composed of hazardous and nondangerous wastes. Hazardous waste consists of dangerous wastes and extremely hazardous wastes, as defined in Washington State Department of Ecology (WDOE) Dangerous Waste Regulations.

Radioactive and mixed wastes are currently handled in various ways. High-level wastes are stored in double-shell tanks. Low-level wastes are stored in double-shell tanks, storage pads, or buried, depending on the source, composition, and concentration. Transuranic wastes are retrievably stored in vaults or underground storage pads.

Approximately 120 facilities on the Hanford Site generate dangerous waste. The Annual

Dangerous Waste Report (DOE-RL 1988a) lists the dangerous wastes and extremely hazardous wastes generated, treated, stored, and disposed of on Site and off Site. Dangerous wastes are treated, stored, and prepared for disposal at several Hanford Site facilities. Dangerous wastes generated at the Hanford Site are shipped off Site for disposal, destruction, or recycling. In calendar year 1988, 445,000 kg of dangerous wastes and 104,000 kg of extremely hazardous wastes were shipped off Site for disposal or recycling.

Nondangerous wastes generated by Hanford Site contractors are buried in the Hanford Site Central Landfill. All of the process and nonprocess areas at the Hanford Site generate these wastes, which include construction debris, office trash, cafeteria waste, and packaging materials. The wastes also include solidified filter backwash and various forms of sludge from the treatment of river water; failed and broken equipment and tools; air filters; noncontaminated used gloves and other clothing; and certain chemical precipitates, such as oxalates. Nonradioactive friable asbestos is also buried in designated areas at the Hanford Site Central Landfill. With the exception of ash generated at the 200-East and 200-West Area powerhouses and demolition waste from the 100-Areas decontamination and decommissioning activities, all nondangerous wastes are buried at the Hanford Site Central Landfill. The demolition waste from decontamination and decommissioning projects is buried in situ or in designated sites in the 100 Areas.

Solid wastes are appropriately monitored. A summary of solid waste effluents is shown in Table G.6, Appendix G. Solid waste program activities are related to Resource Conservation and Recovery Act (RCRA) and Toxic Substances Control Act (TSCA) regulations and are further discussed in Section 2.0.

4.8 POTENTIAL RADIATION DOSES FROM 1988 HANFORD OPERATIONS

J. K. Soldat

An assessment was made of the potential radiation doses that the public could have received as a result of Hanford operations during 1988. These doses were calculated as the committed dose equivalents to individual body organs and the effective dose equivalent to a hypothetical maximally exposed individual. In addition, the committed dose equivalents and the effective dose equivalent were calculated for the general public residing within 80 km of the Hanford Site. These doses were calculated from the effluent releases reported by the operating contractors using Version 1.272 of the GENII code (Napier et al. 1988a,b,c) and Hanford Site-specific parameters.

The effective dose equivalent to the hypothetical maximally exposed individual from 1988 operations was calculated to be 0.08 mrem (0.0008 mSv), compared to 0.05 mrem (0.005 mSv) reported for 1987. The population effective dose equivalent from 1988 operations was calculated to be 5 person-rem (0.05 person-Sv), compared to 4 person-rem reported for 1987. The current DOE radiation standards for an individual member of the public are 100 mrem/yr (1 mSv/yr) for prolonged exposures and 500 mrem/yr (5 mSv/yr) for occasional annual exposures.[a]

The 1988 radiation doses are not directly comparable with values reported for previous years. During the past few years, the computer codes used for dose calculations have changed. In addition, for 1988 a different location for the hypothetical maximally exposed individual was selected.

Radioactive materials were released to the environment in gaseous and liquid effluents from Hanford operations during 1988. Potential radiation doses to the public that resulted from these releases were evaluated in detail, as required by DOE Order 5484.1 (DOE 1981b), to determine compliance with pertinent regulations and standards.

The potential radiological impacts of 1988 Hanford operations were assessed in terms of the following:

- maximum dose rate from external radiation at a publicly accessible location on or within the Site boundary (this quantity is also termed the "fence-post" dose rate)

- committed (50-yr) dose equivalents and the effective dose equivalent to a hypothetical maximally exposed individual at an offsite location

- committed (50-yr) dose equivalents and the effective dose equivalent to the population residing within 80 km of the onsite operating areas.

(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.

To the extent possible, radiation dose assessments should be based on direct measurements of radiation exposure rates and radionuclide concentrations in the surrounding environment.

The amounts of most radioactive materials released during 1988 were too small to be measured directly once they were dispersed in the offsite environment. For many of the measurable radionuclides, it was not possible to distinguish levels that resulted from worldwide fallout from levels that resulted from Hanford effluent releases. Therefore, in nearly all instances, potential offsite doses were estimated using environmental pathway models that calculated concentrations of radioactive materials in the environment from effluent releases reported by the operating contractors. The models used are described in Appendix F, and the effluent data are shown in Tables G.1 through G.6, Appendix G.

The two radionuclides ^{3}H and ^{129}I were measurable in water samples from the Columbia River and Fast Flux Test Facility (FFTF) drinking water well. Supplemental dose calculations were made on the basis of these measured concentrations. In addition, air concentrations of ^{85}Kr and ^{129}I measured at the location of the hypothetical maximally exposed individual were compared with the concentrations of these two radionuclides calculated by the atmospheric transport model.

Estimated potential radiation doses to the public were small. Although the accuracy associated with the radiation dose calculations has not been quantified, whenever Hanford-specific data were not available for parameter values (i.e., plant uptake and consumption factors) realistic upper limit values 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 1988 Hanford operations.

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 radiation dosimeters placed at locations of expected maximum dose rates on Site and at representative locations off Site. 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 4.6. 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 were consistently above background dose rates. The highest average dose rate observed along the shoreline during 1988 was 0.03 mrem/h (0.0003 mSv/h), or about three times the background dose rate normally observed at offsite shoreline locations (0.009 mrem/h or 0.00009 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 1988 at this location showed essentially normal background radiation levels (0.009 mrem/h or 0.00009 mSv/h).

These "fence-post" dose rates should not be used to calculate annual doses to the general public because no one can actually reside at any of these "fence-post" locations.

MAXIMALLY EXPOSED INDIVIDUAL DOSE

The maximally exposed individual is a hypothetical person, living at a single location, who has a postulated lifestyle that results in him/her receiving the maximum calculated radiation dose. This individual's characteristics were chosen to maximize the potential combined doses from all realistic, available environmental pathways for exposure to releases from 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 and the Columbia River. Such a combination of maximized parameters is unlikely to occur.

The location selected for the hypothetical maximally exposed individual can vary with time depending upon the relative importance of the several sources of radioactive effluents released to the air and to the Columbia River from Hanford facilities. For several years, the maximally exposed individual has been assumed to reside at the Riverview irrigation district across the river from Richland. At that location, the individual could be exposed not only to airborne pathways but also to drinking water and to irrigated crops, both of which rely on the Columbia River for their water source. In recent years, the quantity of radionuclides discharged to the Columbia River has decreased to the point where the water pathways have ceased to be the predominate contributor to the maximally exposed individual's radiation dose.

A new location, Ringold, was selected for the maximally exposed individual that is closer to the sources of airborne effluents and that still includes exposure to most of the river water pathways. Ringold is one of the few farming areas using Columbia River water drawn downstream of the N Reactor for irrigation. Drinking water at Ringold is obtained from deep wells. Ringold contains several farms along the Columbia River across from the Hanford Site. At Ringold, the maximally exposed individual is 26 km east-southeast from the 200 Areas, 30 km southeast of the 100-N Area, 13 km north of the 300 Area, and 11 km northeast of the 400 Area.

Except for drinking water, the hypothetical maximally exposed individual at Ringold can be exposed to all the same environmental pathways as the former maximally exposed individual was at Riverview.

The following exposure pathways were included in the calculation of doses to the hypothetical maximally exposed individual for 1988: 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, 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 1988 was postulated to be an individual who:

- was a resident of the Ringold area 26 km east-southeast of the 200 Areas
- consumed homegrown foodstuffs irrigated with Columbia River water
- 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 measurements of ^{3}H and ^{129}I in the Columbia River as input to the GENII code.

The calculated committed dose equivalent to specific organs and the effective dose equivalent for the maximally exposed individual are summarized in Table 4.2. These values include the doses received from exposure to liquid and airborne effluents during 1988, as well as from potential exposure beyond 1988 from radionuclides that were deposited in the

TABLE 4.2. Calculated Committed Dose Equivalent and the Effective Dose Equivalent to the Hypothetical Maximally Exposed Individual from 1988 Hanford Operations (mrem)

Pathway		Committed Dose Equivalent					Effective Dose Equivalent[b]
		Red Marrow	Bone Surfaces	Lung	GI[a]	Thyroid	
Air	- Direct [c]	0.003	0.02	0.01	0.002	0.02	0.005
	- Food [d]	0.01	0.006	0.009	0.01	2.	0.06
Water[e]	- Foods[f]	0.03	0.07	0.004	0.01	0.007	0.01
	- River Recreation[g]	0.02	0.04	0.006	0.01	0.006	0.01
	Total	0.07	0.1	0.03	0.03	2.	0.08

(a) Gastrointestinal tract (lower large intestine).
(b) Effective dose equivalent is compiled from the product of each organ's committed dose equivalent 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 deposition from the air.
(e) Includes ground-water seepage to the river.
(f) Includes consumption of all foodstuffs contaminated via irrigation water and exposure to ground contaminated via irrigation.
(g) Includes consumption of fish taken from the Columbia River and external exposure during recreation.

body during 1988 via inhalation and ingestion of fish and farm products.

The total effective dose equivalent to the hypothetical maximally exposed individual in 1988 was calculated to be 0.08 mrem (0.0008 mSv) compared to 0.05 mrem (0.0005 mSv) in 1987. The primary pathways contributing to the 1988 effective dose to the maximally exposed individual were:

- consumption of food irrigated with Columbia River water (10%)

- consumption of food containing radionuclides deposited from the air (80%)

- consumption of fish from the Columbia River (10%).

The effective dose equivalent limit for any member of the general public from all routine DOE operations are 500 mrem/yr (5 mSv/yr) for occasional annual exposures and 100 mrem/yr (1 mSv/yr) for prolonged exposure periods. The calculated effective dose for the hypothetical maximally exposed individual was 0.08% 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. The dose to this organ was 2 mrem or 0.04% of the limit.

Site-specific parameters for food pathways, diet, and recreational activity used for the dose calculations are defined in Tables F.9 to F.12, Appendix F.

The effective dose equivalent for a maximally exposed individual located at Ringold from 1988 Hanford operations is compared with the doses reported for 1985, 1986, and 1987 in

Figure 4.48. The calculated committed organ dose equivalent and effective dose equivalent for 1985 through 1988 are in Table 4.3.

Comparison of the 1988 radiation doses with values reported for previous years is not completely straight forward. During the past few years, the computer codes used for dose calculations have gradually evolved into the new system of radiation dosimetry required by DOE.

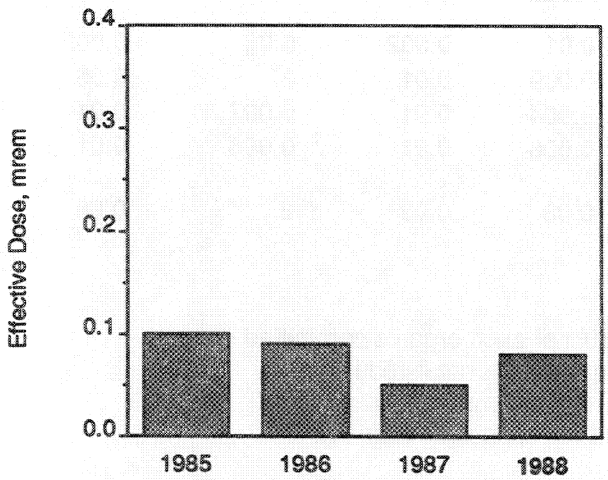

FIGURE 4.48. Calculated Effective Dose Equivalent to the Maximally Exposed Individual for 1985 Through 1988

The newer International Commission on Radiological Protection (ICRP) system was initiated in 1985 through the use of a temporary code, PABKID, that replaced the older dose conversion factors with those recommended by the ICRP. PABKID was used to calculate the radiation doses reported in the reports for CY 1985 and 1986. For the CY 1987 and 1988 reports, the doses were calculated by the new computer code, GENII (Napier et al. 1988a,b,c), designed to fully implement the recommendations of the ICRP. However, for the CY 1988 dose calculations, a different location (Ringold) for the hypothetical maximally exposed individual was selected. The principal reason for the difference between the 1987 and 1988 doses to the maximally exposed individual is this change of location.

TABLE 4.3. Calculated Committed Dose Equivalent and Effective Dose Equivalent to the Hypothetical Maximally Exposed Individual from Hanford Operations, 1985 Through 1988 (mrem)

Committed Dose[a] Equivalent	1985	1986	1987	1988
Red Marrow	0.3	0.3	0.07	0.07
Bone Surfaces	0.7	0.6	0.1	0.01
Lung	0.07	0.03	0.02	0.03
GI[b]	0.09	0.04	0.03	0.03
Thyroid	1.0	0.09	0.9	2
Effective Dose[c] Equivalent	0.1	0.09	0.05	0.08

(a) Total committed dose equivalent 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 committed dose equivalent and its weighting factor, and includes some organs not listed here.

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 1988 air emissions resulted in doses of 0.3 mrem to the whole body and 3 mrem to the maximally exposed organ (thyroid). These are 1% and 4% of the whole-body and organ dose limits, respectively. Thus, the calculated maximum hypothetical annual doses for 1988 Hanford airborne effluent releases were well below the Clean Air Act standard. The doses calculated to demonstrate compliance with the Clean Air Act were performed using AIRDOS-EPA and RADRISK, which include dose factors based on ICRP Publication 2. The doses calculated to meet the DOE Order requirements are based on the newer methodology from ICRP Publication 26. For this reason, the two dose results are not directly comparable.

POPULATION DOSE

The regional population dose from 1988 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 4.4, in terms of the committed dose equivalent and the effective dose equivalent. 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.

The effective dose equivalent to the population was calculated to be 5 person-rem (0.05 person-Sv) in 1988, compared to 4 person-rem (0.04 person-Sv) in 1987. The small increase in the estimated radiation doses for 1988 reflects the small increase in the reported release rate of ^{129}I to the environment from the PUREX Plant.

TABLE 4.4. Calculated Committed Dose Equivalent and the Effective Dose Equivalent for the 80-km Population from 1988 Hanford Operations (person-rem)

Pathway		Committed Dose Equivalent					Effective Dose Equivalent[b]
		Red Marrow	Bone Surfaces	Lung	GI[a]	Thyroid	
Air	- Direct[c]	0.3	2	1	0.2	2	0.4
	- Foods[d]	0.5	0.3	0.4	0.5	140	4
Water[e]	- Foods[f]	0.03	0.07	0.004	0.01	0.009	0.01
	- Drinking Water	0.2	0.03	0.1	0.1	0.1	0.1
	- River Recreation[g]	0.1	0.02	0.004	0.006	0.004	0.006
	Total	1	3	2	0.8	140	5

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

A comparison of the 80-km population doses attributed to 1985 through 1988 Hanford operations is given in Figure 4.49 and Table 4.5.

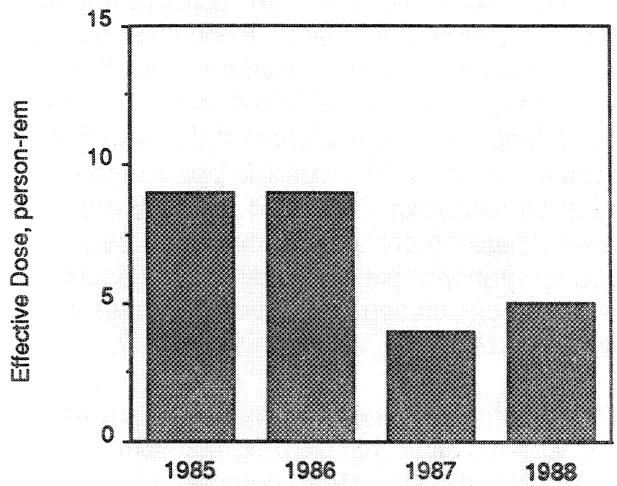

FIGURE 4.49. Calculated Effective Dose Equivalent to the 80-km Population for 1985 Through 1988

The primary pathways contributing to the 1988 effective dose equivalent for the population were:

- inhalation of and submersion in the radionuclides released to the air from the PUREX Plant (8%)

- consumption of foodstuffs contaminated with radionuclides released with gaseous effluents from the PUREX Plant stack (80%).

Inhalation of ^{3}H, ^{14}C, and isotopes of plutonium released from the 200 Areas accounted for 60% of the radiation dose to the bone surface. The dose to the thyroid resulted primarily 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 1988 Hanford operations, based on a population of 340,000 within 80 km, was 0.01 mrem

TABLE 4.5. Calculated Committed Organ Dose Equivalent and Effective Dose Equivalent to the 80-km Population from Hanford Operations, 1985 Through 1988 (person-rem)

Committed Dose[a] Equivalent	1985	1986	1987	1988
Red Marrow	6	5	0.9	1
Bone Surfaces	30	10	2	3
Lung	10	7	1	2
GI[b]	4	4	0.7	0.8
Thyroid	100	120	110	140
Effective Dose Equivalent[c]	9	9	4	5

(a) Total committed dose equivalent 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 committed dose equivalent and its weighting factor, and includes some organs not listed here.

(0.0001 mSv). This dose 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 4.50. The estimated per capita dose to individual members of the public from Hanford sources is only a small fraction of the annual per capita effective dose equivalent (300 mrem) from natural background and medical sources of radiation 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).

POTENTIAL RADIATION DOSES FROM PAST OPERATIONS

Measured levels of certain radionuclides in the Columbia River have been attributed to past operations at Hanford (See "Surface-Water Monitoring," Section 4.2). 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 4.8. (See also "Penetrating-Radiation Monitoring," Section 4.6).

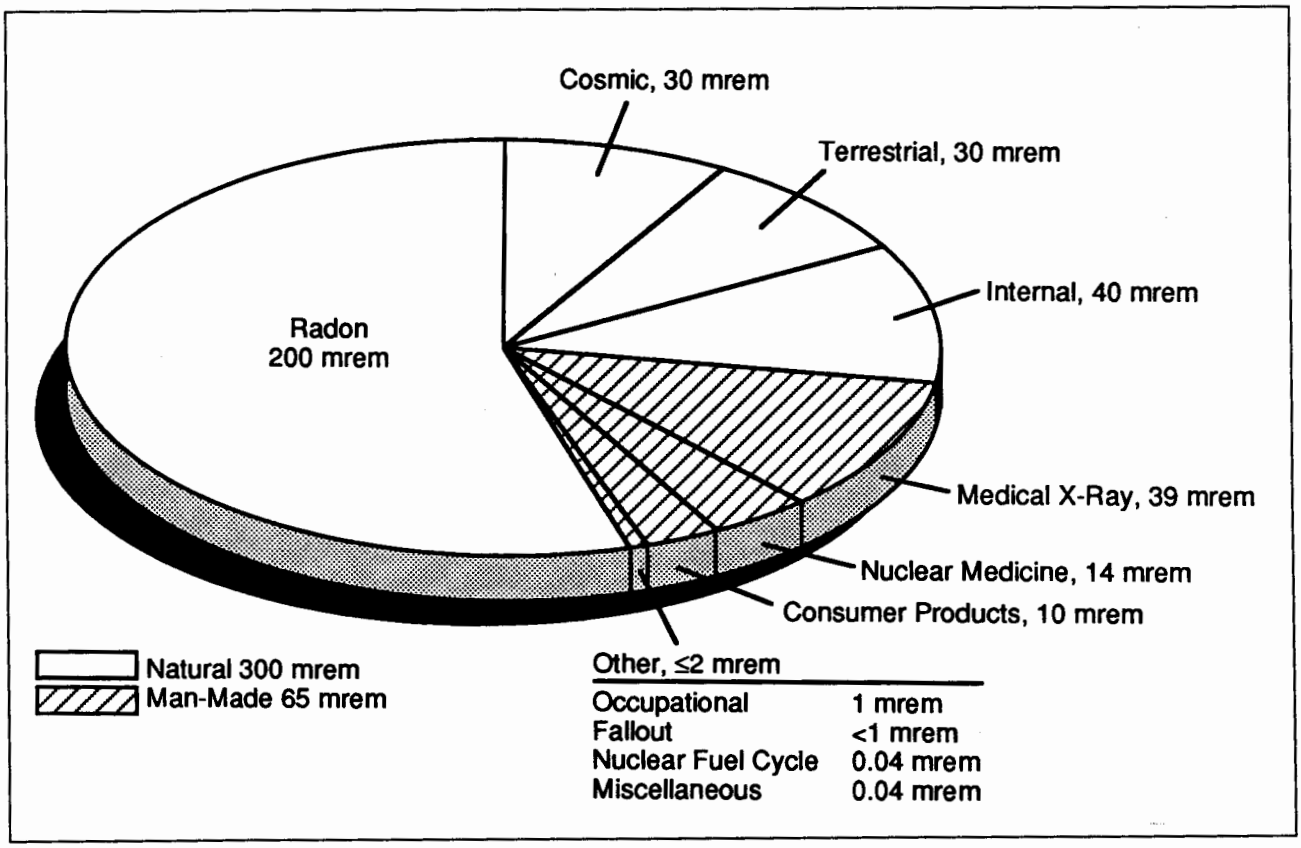

FIGURE 4.50. Annual Radiation Doses from Various Sources (mrem) (NCRP 1987)

Although ^{129}I was not released directly to the Columbia River from Hanford facilities in 1988 (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 measurements made in effluents from Hanford facilities reaching the Columbia River further upstream. The difference can be attributed to seepage from ground water.

The effective dose equivalent that can be attributed to the differential concentrations of ^{3}H and ^{129}I in the river is estimated to be 0.003 mrem (0.00003 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 4.2 and 4.4. Also included are the small radiation doses calculated on the assumption that the small quantities of radionuclides disposed to the ground at 300 Area (Table G.3) might potentially reach the river.

POTENTIAL RADIATION DOSES FROM PUREX PLANT OPERATIONS

In addition to the dose contributions identified earlier from PUREX Plant operations, other minor dose contributions are discussed here. Over 99% of the radionuclides emitted to the air from the PUREX Plant in 1988 was the 200,000 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 inhaling other radionuclides. Consequently, even though the curie quantity of this radionuclide was large, it was a minor contributor to the radiation dose. The annual average air concentration of ^{85}Kr measured in 1988 at the Ringold monitoring station was 76 pCi/m^3. This value was in good agreement with the ^{85}Kr concentration of 110 pCi/m^3 predicted by the GENII code. The air submersion dose from exposure for 100% of the year to the predicted concentration was 0.001 mrem (0.00001 mSv).

The annual average air concentration of ^{129}I at Ringold for 1988, predicted from the reported release of 0.6 Ci from the PUREX stack, was 3 x 10-4 pCi/m^3, which is about 50 times the measured concentration of 6 x 10-6 pCi/m^3. However, the concentrations of ^{129}I in both the effluent and in the ambient air are extremely low and difficult to measure accurately. In view of these difficulties, the higher value and its corresponding doses as predicted by the GENII code were used for the dose summary in Table 4.2. The predicted doses were a dose equivalent to the thyroid of 0.01 mrem and an effective dose equivalent of 0.004 mrem.

In 1988, there was 0.0002 Ci of $^{239,240}Pu$ in airborne emissions from the PUREX Plant (see Table G.1, Appendix G) compared to 0.004 Ci in 1987. Plutonium-239,240 was a minor contributor to the calculated dose from 1988 Hanford operations, with a maximum potential effective dose equivalent of 3×10^{-4} mrem (3×10^{-6} mSv) to the maximally exposed individual.

RADIATION DOSES FROM ONSITE DRINKING-WATER WELLS

During 1988, ground water was used as the source of drinking water for the 400 Area (FFTF), the Yakima Barricade Guardhouse, the Rattlesnake Mountain Observatory, 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 1988 were well below applicable drinking water standards (DWS).

Results for 1988 were similar to those observed in 1987. The concentrations of ^{3}H measured in the FFTF drinking water decreased from 22,000 pCi/L in 1985 to less

than 10,000 pCi/L after a new deeper well was drilled for the water source. The average concentration measured in 1988 was 7300 pCi/L, compared to 4100 pCi/L in 1987 and 8500 pCi/L in 1986. The effective dose equivalent to a worker drinking 250 L of water containing the concentration of ^{3}H measured at FFTF in 1988 was calculated to be 0.1 mrem (0.001 mSv) or 3% of the Washington State DWS of 4 mrem/yr. No detectable concentrations of gross alpha, ^{90}Sr, and ^{131}I were found in water samples collected from this well in 1988.

One sample of FFTF drinking water was analyzed for ^{129}I in 1988. The result was 0.0046 pCi/L. The effective dose from consuming 250 L of such water would be 3×10^{-4} mrem (3×10^{-6} mSv); the corresponding thyroid dose would be 0.01 mrem (0.0001 mSv). These doses are well below Washington State DWS. Nonradiological and radiological results from the Hanford Sanitary Water Quality Surveillance Program are discussed in more detail and reported annually by HEHF (Somers 1989).

5.0 GROUND-WATER PROTECTION AND MONITORING PROGRAM

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Radiological and chemical constituents in ground water were monitored during 1988 throughout the Hanford Site in support of the overall objectives described in "Environmental Program Information," Section 3.0. 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 present in ground water as a result of Site operations. To comply with the Resource Conservation and Recovery Act (RCRA), additional monitoring was conducted to assess the impact that specific facilities have had on ground-water quality (Fruland and Lundgren 1989). The quality of the ground water in the 200 Areas and surrounding region was evaluated by Westinghouse Hanford Company 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. 1989). Six hundred and twenty four wells were sampled during 1988 by all Hanford ground-water monitoring activities. Samples from 328 of these wells were analyzed for chemical constituents; samples from 511 wells were analyzed for radionuclides.

Analytical results for samples were compared to EPA Drinking Water Standards (DWS) (Tables B.2 and B.3, Appendix B) and DOE's Derived Concentration Guides (DCG) (Table B.6, Appendix B). Ground water beneath the Hanford Site is used for drinking at four locations, as described in "Potential Radiation Doses from 1988 Hanford Operations," Section 4.8. In addition, water supply wells for the city of Richland are located adjacent to the southern boundary of the Hanford Site.

Radiological monitoring results indicate that gross alpha, gross beta, ^{3}H, ^{60}Co, ^{90}Sr, ^{99}Tc, ^{106}Ru, ^{129}I, and ^{137}Cs concentrations near operating areas were at levels above the DWS. Concentrations of ^{234}U and ^{238}U in the 200-West Area were above the DCG. Concentrations of ^{3}H in the 200 Areas and ^{90}Sr in the 100-N and 200-East Areas were also above the DCG. Iodine-131 and ^{103}Ru activities in ground water have dropped below detectable levels as a result of placing the N Reactor on cold standby. 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 operating areas. Nitrate concentrations resulting from Site operations exceeded the DWS at isolated locations in the 100, 200, and 300 Areas and in several 600 Area locations. Chromium concentrations were above the DWS at 100-D, 100-H, 100-K, and the surrounding areas. Chromium concentrations above the DWS were also found in the 200-East and 200-West Areas. Cyanide was detected in ground water in and north

of the 200-East Area and at several isolated locations within the 200-West Area. Concentrations of fluoride were above the DWS in a few wells in the 200-West Area. Concentrations of carbon tetrachloride and trichloroethylene were above the DWS in wells in the 200-West Area. Trichloroethylene was also found at levels exceeding the DWS at wells in and near the 100-F Area, 300 Area, and Solid Waste Landfill. Sampling of new and existing monitoring wells near Richland water supply wells showed that concentrations of regulated ground-water constituents in this area are below DWS, and in general below detection levels.

A comprehensive review of all ground-water monitoring work on the Site is published semiannually. The most recent of these reports is Evans, Bryce, and Sherwood (1989). These reports contain a complete listing of all radiological and chemical data collected during the report period.

SAMPLE COLLECTION AND ANALYSIS

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 constructed with well screens or perforated casing generally in the upper 3 to 6 m of the aquifer. The water table allows sample collection near the top of the aquifer, where maximum concentrations for some radionuclides were measured at a few locations on 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 (PNL 1989) based on EPA guidelines (EPA 1986b). Wells fitted with submersible pumps were sampled after pumping for a sufficient time 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 total organic halogen (TOX) or volatile organic analyses (VOA) were taken without head space to prevent loss of volatile constituents and sealed immediately with septum-sealed caps. 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, then a sample was collected in a plastic bottle. Trace metal and some radiochemical samples were preserved by acidification at the time of collection. All samples were immediately placed in ice chests 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^-, TOX, and VOA). 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.

Analytical techniques used are described in "Analytical Procedures and Sampling Summary," Appendix D. All analyses except the high sensitivity ^{129}I were performed by United States Testing Company, Inc. (UST). The mass spectrometric analysis of ^{129}I samples was performed by PNL. A list of the species analyzed for is presented in Table 5.1.

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

TABLE 5.1. Radionuclides and Chemicals Analyzed for in Site-Wide Ground-Water Monitoring Program

Radiological Parameters	Chemical Parameters
^{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
^{3}H	Ca, V, Cr, Mn, Fe
^{14}C	Ni, Cu, Zn, Sr, Ag
^{63}Ni	Cd, Sb, Ba
^{89}Sr	F^-, Cl^-, NO_3^-, SO_4^{2-}, PO_4^{3-}
^{90}Sr	As, Se, Pb, Bi
^{99}Tc	Hg
^{129}I	CN^-
Uranium Isotopes	NH_3
Uranium (total)	Volatile Organics
Plutonium Isotopes	Semivolatile Organics
Gross Alpha	
Gross Beta	

Radiological Analysis

Ground-water samples were collected for radiological analysis from 511 monitoring wells during 1988. These samples were collected as part of the Hanford Site-Wide Ground-Water Monitoring Project and numerous other projects to assess the impact of specific facilities on ground-water quality. Facility-specific monitoring was conducted to comply with RCRA (DOE 1987b). The monitored facilities are listed in Table 5.2. The 600 Area is that area inside the Hanford Site boundary but outside all other designated areas. Additional monitoring was conducted by Westinghouse Hanford Company to evaluate the quality of the ground water in the 200 Areas and surrounding region, to ensure compliance with Westinghouse Hanford Company and 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. 1989).

Most samples for the Hanford Site-Wide Ground-Water Monitoring Project were analyzed for ^{3}H and NO_3^-. Selected samples were subjected to more extensive radiological analysis by alpha-, beta-, and gamma-counting techniques, in many cases accompanied by

TABLE 5.2. Facility-Specific Monitoring

Area	Facility
100-H	183-H Solar Evaporation Basins
100-N	1301/1325-N Liquid Waste Disposal Facilities (LWDFs)
100-N	1324-N Facilities
200 Areas	216-A-10 Crib
200 Areas	216-A-29 Ditch
200 Areas	216-A-37B Crib
200 Areas	Low-Level Burial Grounds
300 Area	Process Trenches
600 Area	Nonradioactive Dangerous Waste (NRDW) Landfill
600 Area	Solid Waste Landfill
600 Area	216-B-3 Pond
600 Area	Grout Treatment Facility

selective radiochemical separations. The radiological monitoring network is shown in Figure 5.1. Selected well locations and facilities for the 200-East and 200-West Areas are identified in Figures 5.2 and 5.3.

Chemical Analysis

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 known waste inventories (Stenner et al. 1988). Table 5.3 lists the major contaminants found in each area.

During 1988, 158 wells were sampled for chemical constituents by the Hanford Site-Wide Ground-Water Monitoring Project. These wells included some not previously sampled; a number of wells that showed no significant contamination or no significant changes in contaminant level after three sampling periods in 1988 were temporarily 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 projects on the Site are included in a single data base for purposes of interpretation. Chemical data were gathered in 328 wells during 1988, including wells in the RCRA compliance networks. Table 5.4 summarizes the number of wells sampled, the number of samples collected, and the number of results obtained during 1988.

Samples from wells selected for chemical characterization were analyzed extensively. The methods used for chemical analysis conform to guidelines established 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.

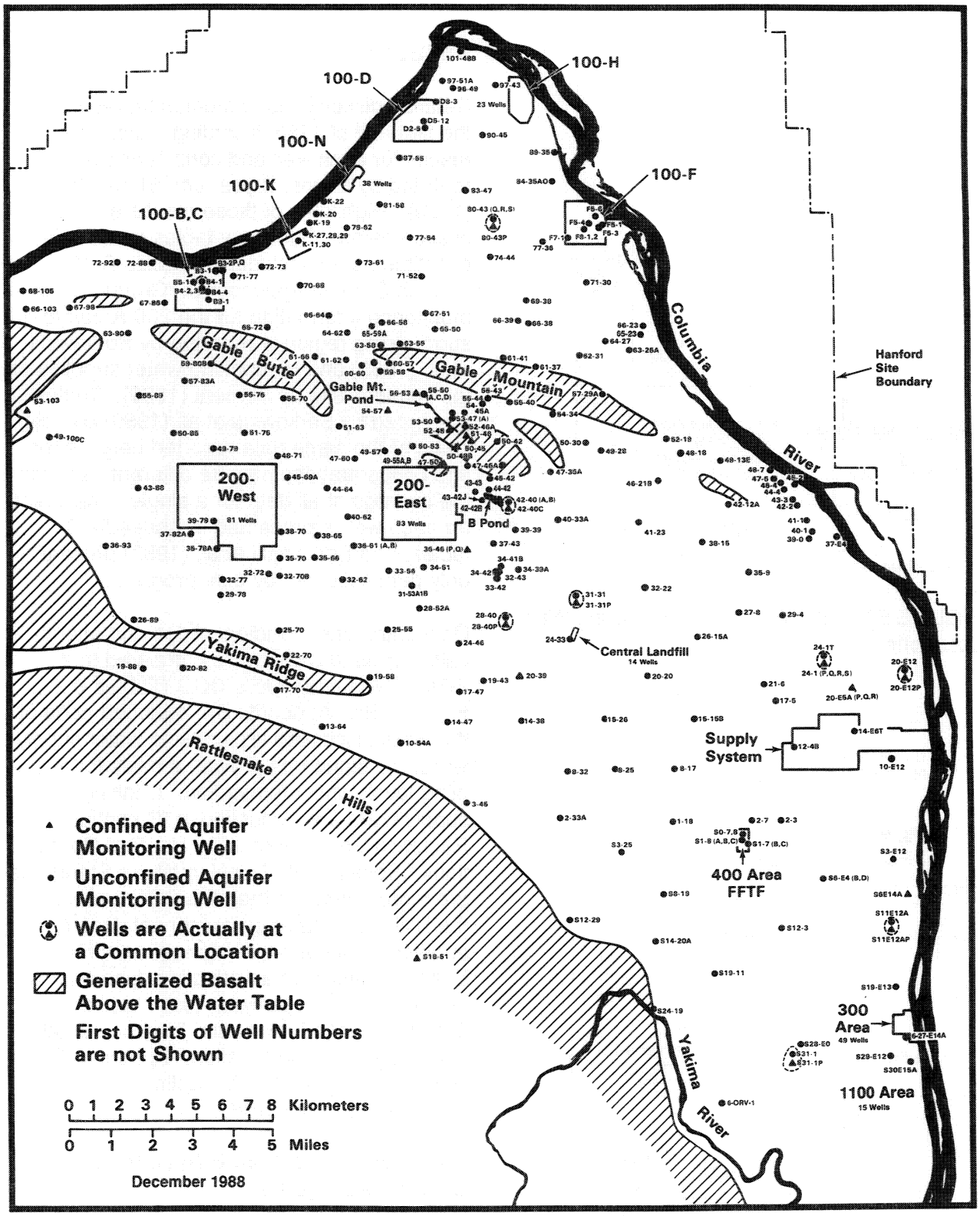

FIGURE 5.1. Hanford Site Monitoring Well Locations

RESULTS

Detailed discussions of monitoring results for the first half of 1988, including tables of all results for each well and constituent, are reported by Evans, Bryce, and Sherwood (1989). Highlights of those results are discussed below. Summary tables for selected constituents are included in Tables C.40 through C.45, in Appendix C. Ground-water monitoring information for the 200 Areas and surrounding region is reported by Serkowski et al. (1989) and for drinking water supplies on the Hanford Site by Somers (1989). Tables presented by Serkowski et al. (1989) contain some of the same data reported here. Average concentrations may be different because the average of all data for a single constituent for each well is presented in Appendix C tables, and Serkowski et al. (1989) present only data collected by their program.

Figure removed as per DOE guidance.

FIGURE 5.2. 200-East Area Monitoring Well Locations

Concentrations of radionuclides and chemicals in ground water were compared to the EPA's DWS and DOE's DCG (Tables B.2, B.3, and B.6, Appendix B). Although none of the wells discussed are drinking water supply wells, the standards provide a basis for evaluating levels of contamination. Drinking water supply wells are discussed in "Potential Radiation Doses from 1988 Hanford Operations," Section 4.8. Drinking Water Standards are more restrictive than the DCG because the DWS are based on an annual dose to the affected organ of 4 mrem per year and the DCG are based on an effective dose equivalent of 100 mrem per year (see "Applicable Standards and Permits and Environmental Compliance Documentation," Appendix B). Derived Concentration Guidelines are only available for radionuclides.

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Radiological Monitoring Results for the Unconfined Aquifer

Radiological constituents monitored at the Hanford Site were selected based on known operational and waste-management practices,

FIGURE 5.3. 200-West Area Monitoring Well Locations

TABLE 5.3. 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^-, Uranium
Plutonium Purification	200	CCl_4
Fuel Fabrication	300	Uranium, Cr^{6+}

TABLE 5.4. Number of Wells Sampled, Samples Collected, and Analytical Results for Ground-Water Monitoring Programs in 1988

Area	Number of Wells Sampled	Number of Samples Collected	Number of Analytical Results
100	90	437	23,209
200	221	1,200	52,761
300	47	377	17,849
400	7	32	783
600	259	1,107	32,554
Total	624[a]	3,153	127,156

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

physical and chemical properties of radionuclides of interest, and potential dose considerations. Radiological monitoring 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 in relation to site operations are shown in the Table 5.3.

Tritium Concentrations

Tritium is present in waste streams discharged to the soil column by Site operations. Tritium also is 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 5.4 illustrates the 1988 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 from up to 15 ^{3}H measurements was used. A summary of ^{3}H concentrations in wells sampled during 1988 is presented in Table C.40, Appendix C.

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 10 wells in the 200-East Area and in two wells in the 200-West Area. Well 199-K-30 continued to

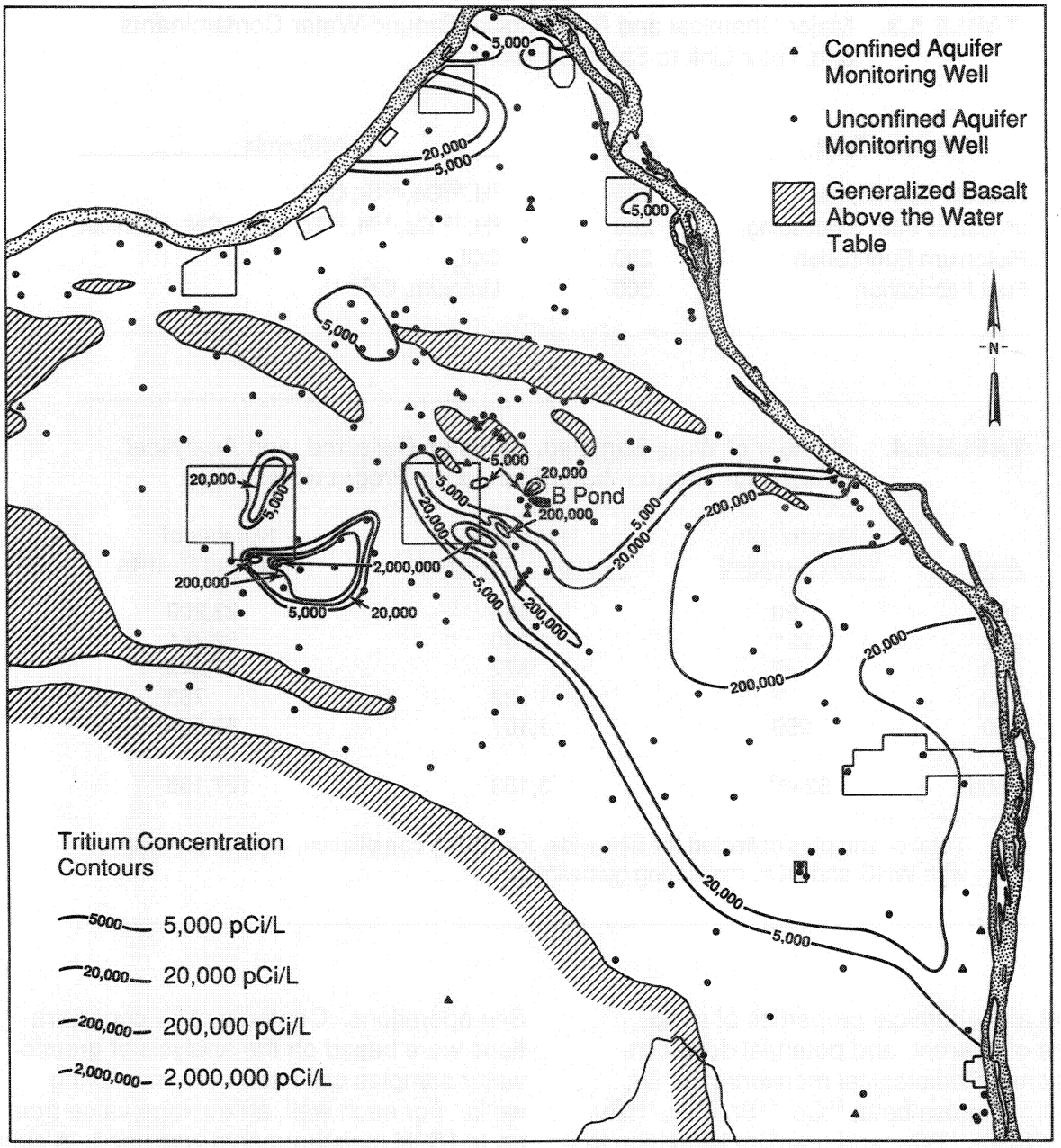

FIGURE 5.4. Tritium (^3H) Concentrations in the Hanford Site Unconfined Aquifer in 1988

contain the highest ^3H concentration within the 100 Areas, with a maximum concentration of 1,220,000 pCi/L.

The highest ^3H 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 Plutonium Uranium Extraction (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 affected by these cribs.

The movement of the widespread ^3H plume (see Figure 5.4) that extends from the

southeastern portion of the 200-East Area to the Columbia River was consistent with the patterns noted earlier (Jaquish and Mitchell 1988; Evans et al. 1988). Separate ^3H pulses associated with the two episodes of PUREX operations can be distinguished in the ^3H 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 the PUREX Plant from 1956 to 1972. Following an 11-year shutdown, plant operation began again in 1983. Elevated ^3H 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 ^3H 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 and discharges into the Columbia River. Migration of the plume continued farther to the south, as indicated by increased ^3H concentrations in wells near the 300 Area. Figure 5.5 is a trend plot of the tritium concentrations in well 699-S19-E13, located just north of the 300 Area. In recent years, this well has shown a steady increase in tritium, having reached a new maximum value of 7510 pCi/L in November 1988. The configuration of the western portion of the plume closely matches previous predictions of

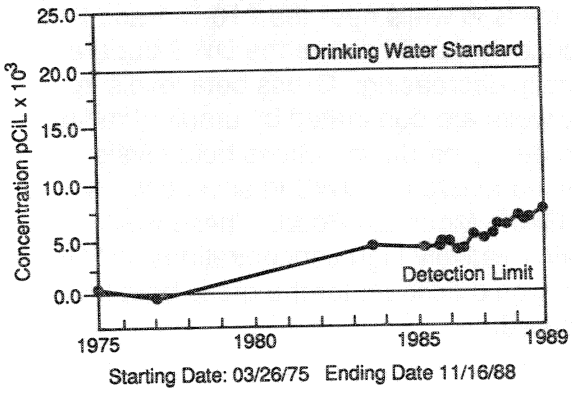

FIGURE 5.5. Tritium Concentrations in Well 699-S19-E13

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 steam condensate and process cooling water to B Pond since 1984 when Gable Mountain Pond was deactivated.

The movement of ^3H plumes in the 200-West Area was also consistent with previous observations. The plume that extends from near the Reduction Oxidation (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 ^3H concentrations consistently greater than the DCG. The maximum concentration in this well in 1988 was 7,560,000 pCi/L. Tritium concentrations in well 299-W23-4 increased rapidly, reaching a maximum of 5,450,000 pCi/L in February 1988, followed by a rapid decrease to far below the DCG during the remainder of the year. The explanation of this oscillation is unclear because that well had shown negligible tritium levels during 1987. 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 1988. Movement of the ^3H plume that extends north and east from the REDOX Plant was indicated by changes in the ^3H concentrations in several wells in the plume. Concentrations in well 699-35-70 continued to decrease slightly, indicating that peak concentrations have moved beyond this well. Concentrations in wells near the center of the plume remained relatively constant and concentrations in well 699-40-62 continued to increase as the plume moved 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 ^3H concentrations near the 300-pCi/L detection limit.

Gross Alpha Activities

Gross alpha activities were detected in ground water from wells in several areas and may be attributable to the presence of isotopes of plutonium and/or uranium; however, plutonium concentrations in all but two wells sampled during the year were below the detection limit attainable by the analytical laboratory. The DWS for gross alpha is 15 pCi/L, not including uranium. Those wells in the 100-F, 200, and 300 Areas where gross alpha exceeded 15 pCi/L contained uranium in levels that would account for the gross alpha level detected. Several wells in the 100-H Area also contained gross alpha levels exceeding the DWS. Although levels in a few wells in the 200-East Area remained somewhat above the DWS, gross alpha levels in most wells in the 200-East Area were low. The highest gross alpha levels measured on the Site continue to be in wells adjacent to the inactive 216-U-1 and 216-U-2 cribs. Concentrations in these wells continued to decrease slowly over the last year. Wells adjacent to the 216-U-1 and 216-U-2 cribs contained uranium levels that would account for the gross alpha levels detected. A summary of uranium levels in wells sampled during 1988 is presented in Table C.41, Appendix C.

Gross Beta Activities

Gross beta activities greater than the 50-pCi/L DWS were found in wells throughout the Site. Gross beta levels commonly can be attributed to the presence of one or more of the following radionuclides in ground water: ^{60}Co, ^{90}Sr, ^{99}Tc, ^{106}Ru, ^{125}Sb, ^{137}Cs, ^{234}Th, and ^{234}Pa (uranium radioactive decay products), and to a lesser extent ^{129}I. Occasionally, some shorter-lived beta emitters, such as ^{131}I, may also be present. Tritium is not normally detected by the method used for assay of gross beta. The beta activity in most cases derives from a combination of uranium and ^{99}Tc activity. Known exceptions include 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 levels greater than the DWS were widespread, the highest levels 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 the highest gross beta levels during 1988 reflect past disposal of liquid waste to the inactive 216-B-5 reverse well, BY cribs, and cribs near the PUREX Plant. Gross beta levels in well 299-E28-23 (11,600 pCi/L) near the 216-B-5 reverse well were the highest measured on the Site during 1988. Wells near this reverse well all contained elevated levels 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 (Stenner et al. 1988). The BY cribs received waste scavenged from U Plant. Wells monitoring the BY cribs (located at the north end of the 200-East Area) showed gross beta levels greater than the DWS, ranging from 62 to 2590 pCi/L. The BY crib monitoring wells generally contained ^{60}Co and ^{99}Tc.

The highest gross beta levels in the 200-West Area were found in wells near U Plant. Gross beta levels in wells near the 216-U-1 and 216-U-2 cribs remained above the DWS but are generally decreasing. Gross beta levels in these wells are dominated by uranium radioactive decay products. Gross beta levels 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 level measured.

Cobalt-60 Concentrations

Most ^{60}Co concentrations were consistently 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 Liquid Waste Disposal Facility (LWDF). The highest concentration of ^{60}Co in Hanford Site ground water during 1988 was found in well 699-50-53 (516 pCi/L). Cobalt-60 in this well appears to be highly mobile. This behavior is likely to be caused by the presence of a soluble cobalt-cyanide complex associated with the plume originating in the BY cribs. No wells exceeded the 5000-pCi/L DCG for ^{60}Co.

Strontium-90 Concentrations

Concentrations of ^{90}Sr were above the 8-pCi/L DWS in wells in the 100-B, 100-D, 100-F, 100-K, 100-N, 200-East, 200-West, and 600 Areas. Concentrations of ^{90}Sr were greater than the 1000-pCi/L DCG in the 100-N and 200-East Areas, ranging up to 10,400 pCi/L in the 100-N Area and up to 6270 pCi/L in the 200-East Area near the 216-B-5 reverse well. Concentrations of ^{90}Sr above the DWS but less than the DCG were detected in several wells near Gable Mountain Pond.

Technetium-99 Concentrations

An extensive program to analyze ground-water samples for ^{99}Tc was continued during 1988. 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 299-W19-24 (35,700 pCi/L), located downgradient of the inactive 216-U-1 and 216-U-2 cribs in 200-West Area. The ^{99}Tc concentrations in well 699-50-53 continued to increase slightly during 1988 to a maximum value of 32,700 pCi/L. Well 699-50-53 is located north of the BY cribs outside the 200-East Area.

Ruthenium-106 Concentrations

Because of its short half-life (367 days), ^{106}Ru is detected principally in wells located in areas near operating reactors or fuel reprocessing facilities, such as the 100-N Area and the 200-East Area near the PUREX Plant. Concentrations in wells in the 100-N Area continued to decline in 1988 because the N Reactor was in cold standby, and now fall below the detection limit of 172.5 pCi/L. Concentrations in wells near LWDFs receiving effluents from the PUREX Plant generally increased in 1988, with well 299-E24-12 reaching a maximum of 547 pCi/L (DWS = 200 pCi/L) in April 1988.

Antimony-125 Concentrations

Antimony-125 (^{125}Sb), a gamma emitter, was measured in 100-N Area wells near the 1325-N LWDF. Results ranged up to 172 pCi/L in well 199-N-45 and were generally slightly less than those reported in 1987. The DWS for ^{125}Sb is 300 pCi/L, and the DCG is 60,000 pCi/L.

Iodine-129 Concentrations

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), and its relatively low DWS (1 pCi/L). On the Hanford Site, the main contributor of ^{129}I to the ground water has been liquid discharges to cribs in the 200 Areas. A greatly expanded ^{129}I monitoring effort began in 1988 with results reported for a total of 168 wells. The highest concentrations reported were 87.8 pCi/L in well 699-38-70 located just outside the 200-West Area boundary and downgradient from the REDOX Plant. Many of the wells sampled in both the 200-West and 200-East Areas had

concentrations above the DWS; however, none were above the DCG (500 pCi/L). A number of the wells sampled in the 600 Area tritium plume also had ^{129}I concentrations above the DWS with the highest level found in well 699-41-23 (6.3 pCi/L). A summary of ^{129}I concentrations in wells sampled during 1988 is presented in Table C.42, Appendix C.

Iodine-131 Concentrations

Because ^{131}I has a short half-life (8.04 days), it typically has been detected in only ground water near discharge locations (100-N Area wells). Iodine-131 was not detected in any Hanford Site wells during 1988 because the N Reactor was in cold standby and ^{131}I was not discharged to ground water.

Cesium-137 Concentrations

Concentrations of ^{137}Cs were below the detection limit (23 pCi/L) in all wells, except two wells located near the 216-B-5 reverse well. Ground water sampled at well 299-E28-13 contained 1800 pCi/L and well 299-E28-25 contained 90 pCi/L. 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 (Stenner et al. 1988). The DWS for ^{137}Cs is 200 pCi/L, and the DCG is 3000 pCi/L.

Uranium Concentrations

The highest uranium levels in Hanford ground water are found in wells adjacent to the inactive 216-U-1 and 216-U-2 cribs. For example, the total uranium concentration in well 299-W19-3 dropped from 7040 pCi/L in July 1987 to 2195 pCi/L in July 1988. Uranium concentrations in other nearby wells also tended to decrease slowly over the year. Uranium levels increased sharply in two 100-F Area wells in 1987. Levels in well 199-F8-1 reached a maximum of 414 pCi/L in January 1988 and generally have tended to decrease somewhat over the year. A similar trend was observed in well 199-F8-2. 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. 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 up to 446 pCi/L. These concentrations were similar to those measured in 1987.

Chemical Monitoring Results for the Unconfined Aquifer

Chemical monitoring in 1988 revealed a number of chemical contaminants traceable to Hanford operations. Although the extensive distribution of NO_3^- from Hanford operations is documented in past reports, some of the other chemical results represent relatively recent findings. Species of interest include NO_3^-, cyanide, chromium, fluoride, carbon tetrachloride, and trichloroethylene.

Nitrate Concentrations

Although NO_3^- is associated primarily 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 5.6.

Most ground-water samples collected during 1988 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 129 ppm was

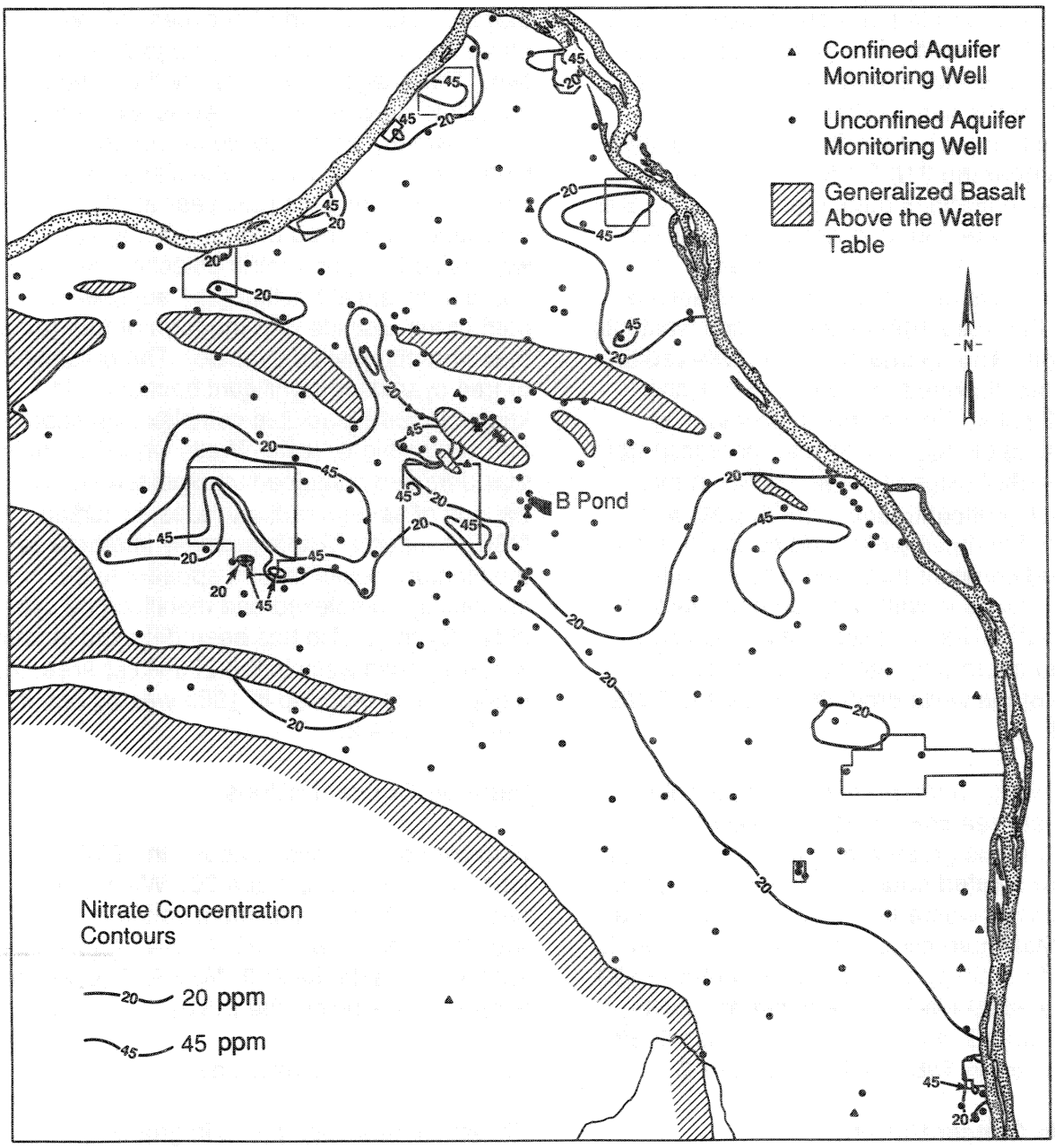

FIGURE 5.6. Nitrate (NO_3^-) Concentrations in the Hanford Site Unconfined Aquifer for 1988

observed north of the PUREX Plant near the eastern boundary of the 200-East Area. Nitrate concentrations in wells near the 216-A-10 and 216-A-36B cribs remained above the DWS even though these facilities were removed from service in 1987.

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 is shown in Figure 5.1. Increases in the volume of process cooling water discharged to B Pond may have resulted in the expanding area of lower NO_3^- concentrations in ground water to the east and south of that facility (see Figure 5.6).

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. The presence of nitrate in wells near this crib were observed prior to February 1988 when this crib went into operation. 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 (Stenner et al. 1988). A maximum NO_3^- concentration of 1270 ppm was measured in these wells, and concentrations remained constant throughout 1988. Nitrate concentrations in wells located near the 216-U-1 and 216-U-2 cribs west of U Plant continued to decrease, with concentrations in several of the wells dropping below the DWS in 1988.

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. Maximum concentrations in these wells ranged from 90 ppm in well 299-W14-5 to 699 ppm in well 299-W15-4. A summary of NO_3^- concentrations in wells sampled during 1988 is presented in Table C.43, Appendix C.

Cyanide Concentrations

Cyanide 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 1988 had a maximum reported cyanide concentration of 1690 ppb in well 699-50-53, with lesser amounts present in four other wells in or near the northern side of the 200-East Area. A recent evaluation of quality control data for the analytical results has suggested that the results reported in excess of 120 ppb may be erroneously high by up to a factor of two. The analytical uncertainty thus makes it difficult to determine if the levels are increasing; however, the existence of a cyanide plume is not in question. Speciation work carried out during the past year at PNL by an independent method (ion chromatography with pulsed amperometric detection) showed that a substantial fraction (i.e., approximately half) of the cyanide is in the form of free rather than iron-complexed cyanide. The presence of free cyanide is significant because it is known to form a soluble complex with cobalt and is also highly toxic. 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. Cyanide also has been detected in four widely spaced wells in the 200-West Area; the highest level reported in 1988 was 69 ppb in well 299-W14-2.

Fluoride Concentrations

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-W15-4. All wells sampled outside the 200-West Area contained fluoride levels below the DWS.

Chromium Concentrations

Chromium has been found in ground water collected from wells in the 100-B, 100-D, 100-H, and 100-K Areas. In addition, several wells in the 100-F Area had detectable hexavalent chromium. 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 found approximately 1 km west of the 100-H Area at 200 ppb, four times the DWS. Three other wells in the same area had chromium levels greater than the DWS in 1988.

Chromium contamination was widespread in the 200-West Area. Three wells showed concentrations above the 50-ppb DWS. The maximum chromium concentration found in the 200-West Area during 1988 was 339 ppb in well 299-W22-20. Ground-water samples from at least 12 other 200-West Area wells had detectable chromium. The distribution of chromium contamination appears to originate from 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 was in well 299-E13-14, with a chromium concentration of 67 ppb in November 1988. A summary of chromium concentrations in wells sampled during 1988 is presented in Table C.44, Appendix C.

Carbon Tetrachloride Concentrations

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 before 1973. A concentration of 8100 ppb was found in a newly installed well near Z Plant first monitored in October 1988. Numerous other wells in the area have carbon tetrachloride levels ranging from 1000 to 5000 ppb. The maximum contaminant level (MCL), or target concentration, of carbon tetrachloride for remediation under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 and the Superfund Amendments and Reauthorization Act of 1986 (CERCLA/SARA) is 5 ppb. The DWS 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 and chloroform. A summary of carbon tetrachloride concentrations in wells sampled during 1987 is presented in Table C.45, Appendix C.

Trichloroethylene Concentrations

Trichloroethylene (TCE) contamination in excess of the 5-ppb DWS was found at several other sites in 1988. Trichloroethylene was found in 600 Area wells to the west of the 100-F Area and on the west side of the 100-F Area. The highest level reported in 1988 was 35 ppb. Several wells at the Solid Waste Landfill were found to contain trichloroethylene slightly above the DWS up to a maximum of 9 ppb in 1988. Trichloroethylene and some of its partial degradation products [i.e., cis-dichloroethylene (1,2-DCE)] have been found in wells monitoring the lower portion of the unconfined aquifer in the 300 Area near the North Process Pond. Maximum concentrations found were 20 ppb TCE and 75 ppb DCE, respectively, in well 399-1-16B. Similar levels also were found in the nearby well 399-1-16C, which monitors the upper portion of the confined aquifer in that area. Trichloroethylene has not been found in the well monitoring the upper portion of the unconfined aquifer, 399-1-16A.

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^-, and gamma-emitting radionuclides. The results for ^3H and NO_3^- are summarized in Tables C.40 and C.43, respectively. Wells open to the confined aquifer (or a composite of the confined and unconfined aquifers) 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 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 previous years.

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 the confining basalt flow (Graham, Last, and Fecht 1984). The ^{129}I concentrations in this well were 5.96×10^{-3} pCi/L. Elevated levels of tritium (2220 pCi/L) and ^{129}I (0.15 pCi/L) were also present in ground water sampled from the Rattlesnake Ridge interbed in 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 level during several samplings in 1987. Nitrate levels in that well were below detection in 1988.

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.

Ground-Water Quality Near Richland Water Supply Wells

During the summer and fall of 1988, ground water from 12 monitoring wells in the southern portion of the Hanford Site was sampled and analyzed for hazardous chemicals and radiological constituents to assess water quality in the vicinity of the Richland water supply wells. Five of these wells were constructed adjacent to the North Richland well field by Westinghouse Hanford Company during 1988. Samples were also collected from 10 water supply wells in the area. Eight of the wells supply water to Richland, one of the wells is used for irrigation at the Horn Rapids Athletic Complex, and one of the wells supplies drinking water to the Horn Rapids Off Road Vehicle Park. No contaminants were observed in concentrations above the DWS.

Trace levels of several organic constituents were observed in individual monitoring wells. Wells 3000D-1 and 600-S36-E13A contained 10 ppb and 2 ppb trichloroethane (TCA), respectively. The DWS for TCA is 200 ppb. Several other wells contained chloroform, trichloroethane, trichloroethylene, bromodichloromethane, and perchloroethylene at concentrations less than 1/50 of the DWS. Trichloroethane (0.36 ppb) and trichloroethylene (0.45 ppb) were observed in one water supply well.

The origin of these organic chemicals is uncertain. They may be traceable to Hanford activities or may be attributable to other industrial facilities located near the southern border of the Hanford Site. Additional studies are planned to assist in identifying the source of constituents in ground water in the southern portion of the Hanford Site.

6.0 QUALITY ASSURANCE

J. A. MacLellan and R. L. Aaberg

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-water 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 condition 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 and exchanged 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 ensure 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-water 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 logbook. 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 Resource Conservation and Recovery Act (RCRA) monitoring programs.

ANALYTICAL LABORATORY QUALITY ASSURANCE

The routine radiochemical analyses for environmental monitoring were performed by PNL (water samples only) and United States Testing Company (UST) laboratories. An internal quality control program maintained by UST 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. Quality assurance data are summarized by UST in quarterly and annual reports to PNL. At the request of PNL, the format for these reports will be revised in 1989 to allow easier comparison with performance criteria.

Calibration standards traceable to the National Institute of Standards and Technology (formerly the National Bureau of Standards) were used for radiochemical calibrations when available. Both PNL and UST continued to participate in the DOE Quality Assessment Program, and UST participated in EPA's Laboratory Intercomparison Studies Program. These programs provide 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 of accurate evaluation of results and indication of where corrective actions were needed. Summaries of the 1988 UST results for the programs are provided in Tables 6.1 and 6.2. 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 the expected concentrations of radionuclides in the environment. All PNL results were within 3-sigma control limits (Table 6.3).

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 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 showed no significant deviations from the results of previous years. 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 1988 results is shown in Figure 6.1. An average bias of approximately -2.3% was observed between the known and the measured exposures. Variability of the results is greater than the normal from past years, but the accuracy was

TABLE 6.1. United States Testing Company Performance on DOE Quality Assessment Program Samples in 1988

Sample Media	Radionuclides	Samples Analyzed	Number Within Control Limits[a]
Air Filters	^{7}Be, ^{54}Mn, ^{57}Co, ^{60}Co, ^{90}Sr, ^{134}Cs ^{137}Cs, ^{239}Pu, ^{241}Am, ^{234}U, ^{238}U U(mass)	26	26
Soil	^{40}K, ^{90}Sr, ^{137}Cs, ^{239}Pu, ^{234}U, ^{238}U U(mass), U(pCI), ^{241}Am	14	10
Vegetation	^{40}K, ^{90}Sr, ^{137}Cs, 238Pu, ^{239}Pu	15	15
Water	^{3}H, ^{54}Mn, ^{57}Co, ^{60}Co, ^{90}Sr, ^{134}Cs ^{137}Cs, ^{239}Pu, ^{241}Am, ^{234}U, ^{238}U, U(mass)	26	26

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

TABLE 6.2. United States Testing Company Performance on EPA Intercomparison Program Samples in 1988

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	40	36
Water	^{226}Ra, ^{228}Ra, ^{238}U, U(nat) ^{239}Pu	15	12
Water	^{89}Sr, ^{90}Sr	8	7
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	6	6
Air filters	Gross Alpha, Gross Beta, ^{90}Sr, ^{137}Cs	8	7

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

TABLE 6.3. PNL Performance on DOE Quality Assessment Program Samples

Sample Media	Radionuclides	Samples Analyzed	Number Within Control Limits[a]
Water	^{3}H, ^{54}Mn, ^{57}Co, ^{60}Co, ^{90}Sr, ^{134}Cs, ^{137}Cs	14	14

(a) Control limits from Sanderson (1985) .

determined to be adequate to assess the doses from penetrating radiations in the environment.

During 1988, PNL and Washington State Department of Social and Health Services (WDSHS) shared 21 environmental dosimeter locations. The locations were on and around the Hanford Site, 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 quarterly mean daily exposure rates as determined by the two organizations are shown in Table C.46, Appendix C and Figure 6.2. No WDSHS exposure data

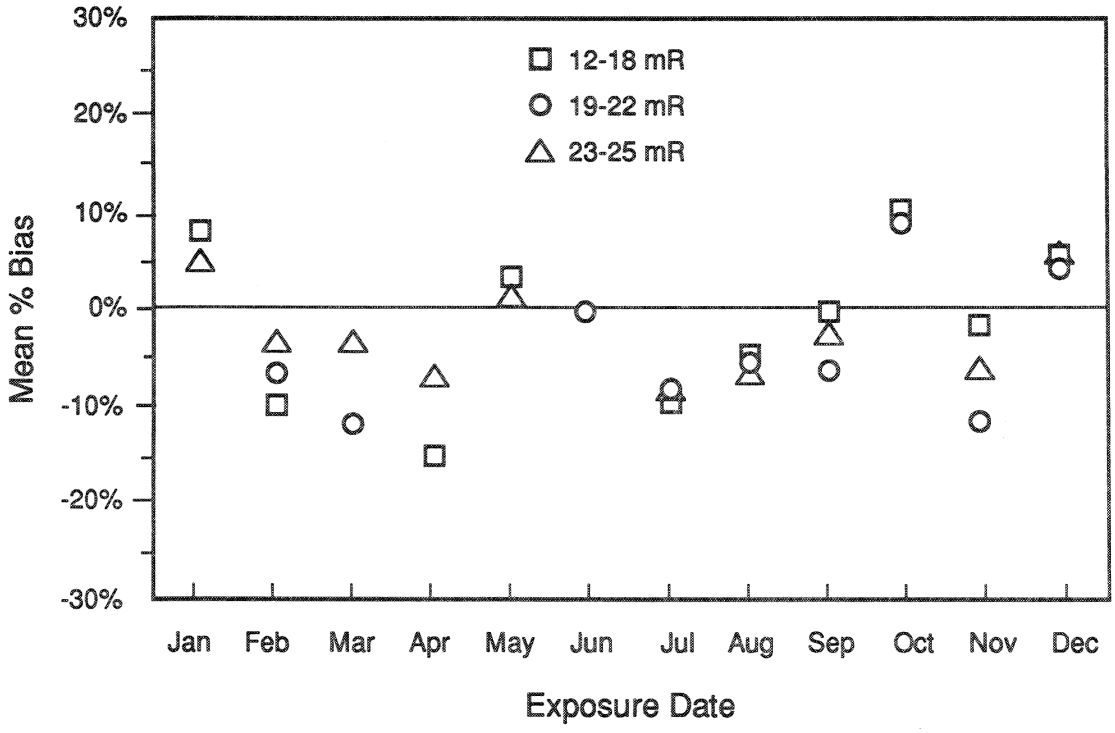

FIGURE 6.1. Comparison of Thermoluminescent Dosimeter Results with Known Exposures

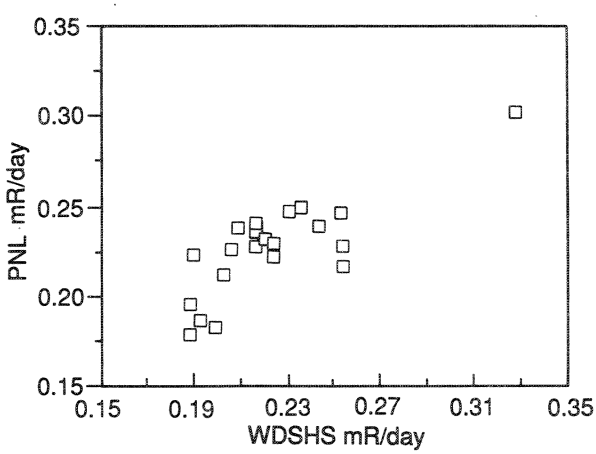

FIGURE 6.2. Comparison of Washington State Department of Social and Health Services and Pacific Northwest Laboratory's Environmental Exposure Rate Measurements

were available for the second quarter of 1988 because of equipment failure. The ratio of WDSHS and PNL average results for individual sites varied from -15% to +18%. The WDSHS results for all sites averaged 2% 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 was shown in PNL-WDSHS intercomparison tests to over-respond to low-energy photons (see Section 4.6).

In 1988, two special quality assurance efforts involved analyses of split environmental samples. In September 1988, the states of Washington and Oregon, UST, the Supply System, and SEARCH Technologies, Inc. conducted joint sampling of the Columbia River and adjacent springs. The samples were pooled and split among the participants and Oak Ridge National Laboratory (ORNL). Results (Table C.47, Appendix C) show good

agreement among participants. In July and August 1988, foodstuffs were also collected. The samples were split and separately analyzed by UST and the Food and Drug Administration Winchester Engineering and Analytical Center (Table C.48, Appendix C). Good agreement was again demonstrated.

Ground-Water Monitoring

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

Interlaboratory comparisons were conducted for anions, volatile organics, metals, and gross alpha and gross beta. Samples analyzed during 1988 showed that results from UST for these analyses were comparable to those from PNL laboratories. Differences in gross alpha and gross beta analyses were traced to differences in procedures used by the laboratories.

Blind standards for numerous organic and inorganic analyses were submitted quarterly to UST; blind standards for volatile organic analysis were submitted monthly. In general, UST's performance was very good. Excellent results were achieved consistently for most analytes. Overestimation of cyanide concentrations caused UST to reevaluate an analytical procedure.

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.

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APPENDIX A

GLOSSARY, ABBREVIATIONS, CONVERSION TABLE

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GLOSSARY, ABBREVIATIONS, CONVERSION TABLE

Activation Product - Material made radioactive by exposure to neutron radiation in a nuclear reactor.

Air Submersion Dose - Radiation dose received from external exposure to radioactive materials present in the surrounding atmosphere.

Aquifer - Permeable geologic unit that can transmit significant quantities of water.

Background Radiation - 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 - 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) - 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.

Composite Sample - Sample formed by mixing discrete samples taken at periodic points in time.

Confined Aquifer - An aquifer bounded above and below by less permeable layers. Ground water in the confined aquifer is under a pressure greater than atmospheric pressure.

Continuous Sample - Sample formed by the continuous collection of the media or contaminants within the media during the entire sample period.

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 that bombard the earth's atmosphere. Cosmic radiation is part of natural background radiation.

Counting Error - 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.

Derived Concentration Guides (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.

Detection Level - Minimum concentration of a substance that can be measured with a 99% confidence that the analytical concentration is greater than zero.

Dispersion - Process whereby solutes are spread or mixed as they are transported by ground water as it moves through sediments.

Dosimeter - Portable device for measuring the total accumulated exposure to ionizing radiation.

Effective Dose - See "Effective Dose Equivalent" under "Radiation Dose."

Effluent - 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.

Fallout - Radioactive materials mixed into the earth's atmosphere following a nuclear explosion. Fallout constantly precipitates onto the earth.

"Fence-post" Dose Rate - Dose rate measured or calculated at the point of highest exposure at publicly accessible locations on or near the Hanford Site.

Fission (fissioned) - Splitting or breaking apart 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 - Atoms formed when uranium is split in a nuclear reactor. Many fission products are radioactive.

Fuel Cladding - Metal skin used to retain the fuel pellets and separate the fuel and the coolant in a nuclear reactor.

Glaciofluvial Sediments - Sedimentary deposits consisting of material transported by, suspended in, or laid down by the meltwater streams flowing from melting glacier ice.

Grab Sample - Individual discrete sample collected over a period of time less than 15 minutes.

Ground Water - Subsurface water that is in the pore spaces of soil and geologic units.

Half-life - Length of time in which any radioactive substance will lose one-half of its radioactivity. Half-lives may range 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.

Isotopes - 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 - Sedimentary deposit consisting of material pertaining to, produced by, or formed in a lake or lakes.

Lithology - 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 - 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 - Average value of a series of measurements.

Median - 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 - 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 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.

Outfall - 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 - 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 - Closed system of piping that provides cooling water to the reactor. Heat energy is transferred to the secondary loop through a heat exchanger.

Radiation - 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** - Least penetrating type of radiation. Alpha radiation can be stopped by a sheet of paper or the outer dead layer of skin.
>
> **Beta Radiation** - A form of 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** - 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** - Amount of energy deposited by radiation in a given amount

of material. Absorbed dose is measured in units of "rads." (See "Dose Equivalent" below.)

Collective Dose Equivalent - Sum of the dose equivalents for individuals composing a defined population. The per capita dose equivalent is the quotient of the collective dose equivalent divided by the population size.

Committed Dose Equivalent - 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 - 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 - 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 - Property possessed by some elements, such as uranium, whereby alpha, beta, or gamma rays are spontaneously emitted.

Radioisotope - Radioactive isotope of a specified element. Carbon-14 is a radioisotope of carbon. Tritium is a radioisotope of hydrogen.

Radionuclide - 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 - Acronym for Roentgen Equivalent Man; a unit of radiation exposure that indicates the potential impact on human cells.

Sievert - 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 - An aquifer containing 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 - Area on or near a nuclear facility to which public access is not restricted.

Water Table - Theoretical surface represented by the elevation of water surfaces in wells penetrating only a short distance into the unconfined aquifer.

Whole-Body Dose - Radiation dose that involves exposure of the entire body.

Wind Rose - Star-shaped diagram showing how often winds of various speeds blow from different directions, usually based on yearly averages.

$\overline{X}$/Q' (chi over que) - A dispersion factor calculated from average annual meteorological data using an atmospheric dispersion model. 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

ALE	Arid Lands Ecology (Reserve)
APHA	American Public Health Association
ARPA	Archaeological Resources Protection Act
ASTM	American Society for Testing and Materials
BCSR	Boeing Computer Services Richland
BMI	Battelle Memorial Institute
BWIP	Basalt Waste Isolation Project
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
cfs	cubic feet per second
CLP	Contract Laboratory Program
DCE	dichloroethylene
DCG	Derived Concentration Guide
DOE	U.S. Department of Energy
DOE-RL	U.S. Department of Energy, Richland Operations Office
DWS	Drinking Water Standards
EIS	environmental impact statement
EIS/ODIS	Effluent Information System/Onsite Discharge Information System
EML	Environmental Measurements Laboratory
EPA	U.S. Environmental Protection Agency
FCP	Fuel Cycle Plant
FFTF	Fast Flux Test Facility
GC/MS	Gas Chromatography and Mass Spectrometry
GFAA	Graphite Furnace Atomic Absorption
HEHF	Hanford Environmental Health Foundation
HMS	Hanford Meteorology Station
IC	ion chromatography
ICP	Inductively Coupled Plasma
ICRP	International Commission on Radiological Protection
INEL	Idaho National Engineering Laboratory
KEH	Kaiser Engineers Hanford Company
LEPD	low-energy photon detector
LWDF	Liquid Waste Disposal Facility
MASF	Maintenance and Storage Facility
MCL	maximum contaminant level
MDA	minimum detectable amount
MDC	minimum detectable concentration
MI	maximally exposed individual
NCRP	National Council on Radiation Protection
NEPA	National Environmental Policy Act

NERP	National Environmental Research Park
NESHAP	National Emissions Standards for Hazardous Air Pollutants
NPDES	National Pollutant Discharge Elimination System
NTU	nephelometric turbidity unit
ORNL	Oak Ridge National Laboratory
PCB	polychlorinated biphenyl
PFP	Plutonium Finishing Plant
PNL	Pacific Northwest Laboratory
PSD	Prevention of Significant Deterioration
PUREX	Plutonium Uranium Extraction Plant
QA	Quality Assurance
QC	Quality Control
RCRA	Resource Conservation and Recovery Act
REDOX	Reduction Oxidation (Plant)
RI/FS	Remedial Investigation/Feasibility Study
SARA	Superfund Amendments and Reauthorization Act
SE	standard error
SI	International System of Units (metric)
TLD	thermoluminescent dosimeter
TCE	trichloroethylene
TOX	total organic halogen
TSCA	Toxic Substances Control Act
TSD	treatment, storage, or disposal (facility)
UO_3 Plant	Uranium Oxide Plant
USGS	U.S. Geological Survey
UST	United States Testing Company, Inc.

ABBREVIATIONS FOR UNITS OF MEASURE

Radioactivity		Volume	
Symbol	Name	Symbol	Name
Ci	curie	cm^3	cubic centimeter
mCi	millicurie (10^{-3} Ci)	L	liter
µCi	microcurie (10^{-6} Ci)	mL	milliliter (10^{-3} L)
nCi	nanocurie (10^{-9} Ci)	m^3	cubic meter
pCi	picocurie (10^{-12} Ci)	ppm	parts per million
fCi	femtocurie (10^{-15} Ci)	ppb	parts per billion
aCi	attocurie (10^{-18} Ci)		
Bq	becquerel		
Sv	sievert		

Length		Mass	
Symbol	Name	Symbol	Name
km	kilometer (10^3 m)	g	gram
m	meter	kg	kilogram (10^3 g)
cm	centimeter (10^{-2} m)	µg	microgram (10^{-6} g)
mm	millimeter (10^{-3} m)	ng	nanogram (10^{-9} g)
µm	micrometer (10^{-6} m)	t	metric ton (or tonne; 10^3 kg)

Area		Time	
Symbol	Name	Symbol	Name
ha	hectare (10,000 m^2)	yr	year
		d	day
		h	hour
		min	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

APPENDIX B

APPLICABLE STANDARDS AND PERMITS AND ENVIRONMENTAL COMPLIANCE DOCUMENTATION

APPENDIX B

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 1988 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 B.1. Drinking water standards promulgated by EPA (EPA 1976) are summarized in Tables B.2 and B.3. Benton, Franklin, Walla Walla Counties Air Pollution Control Authority air quality standards are shown in Table B.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 Council 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 B.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 Derived Concentration Guides (DCG) 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 (Table B.6). 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.

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 B.7.

Table B.8 lists the environmental impact statements and environmental assessments relating to the Hanford Site that were issued during 1988 in final form. These environmental compliance documents were prepared in accordance with federal, state, and regional environmental protection laws.

TABLE B.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.

TABLE B.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 for 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
^{14}C	Fatty Tissue	2,000
^{99}Tc	GI (LLI)[a]	900
^{103}Ru	GI (LLI)[a]	200
^{125}Sb	GI (LLI)[a]	300

(a) Gastrointestinal tract (lower large intestine).

TABLE B.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 mg/L
F	2 mg/L
Hg	2 µg/L
NO_3^-	45 mg/L
Pb	50 µg/L
Se	10 µg/L

TABLE B.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 B.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.

TABLE B.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
$^{14}C(CO_2)$	70,000	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
^{99}Tc	100,000	2,000
^{103}Ru	50,000	2,000
^{125}Sb	60,000	1,000

(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.

TABLE B.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. 17, issued to Pacific Northwest Laboratory for 1988, 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.

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

TABLE B.8. Hanford Site Environmental Impact Statements and Environmental Assessments Issued During 1988

Environmental Impact Statements

No draft or final environmental impact statement or environmental assessments were issued for the Hanford Site during 1988.

APPENDIX C

MONITORING RESULTS FOR 1988

TABLE C.1. Monthly Climatological Data from the Hanford Meteorology Station for 1988

	Temperatures (°C)								Precipitation (cm)				Relative Humidity (%)		50-Foot Wind				
	Averages				Extremes						Snowfall						Peak Gusts		
Month	Daily Maximum	Daily Minimum	Monthly	Departure[a]	Hightest	Date	Lowest	Date	Total	Departure	Total	Departure	Average	Departure	Average Speed (km/h)	Departure	Speed (km/h)	Direction	Date
J	3.7	-3.8	-0.1	+1.0	12.2	14	-10.0	9	1.2	-1.2	14.2	+0.5	75.8	-0.6	9.3	-1.1	60	SSW	16+ [b]
F	11.6	-1.6	5.0	+1.8	21.7	21	-12.8	2	T	-1.4	0	-4.6	59.0	-11.7	10.5	-1.0	82	SSW	12
M	14.7	0.8	7.7	+0.8	21.7	19	-4.4	17	1.0	-T	0	-1.3	50.1	-5.8	14.5	+0.6	80	SW	22
A	19.9	5.9	12.9	+1.6	28.3	13+	-0.6	7	2.8	+1.8	0.5	+0.5	51.7	+4.8	12.6	-2.2	101	SW	28
M	23.8	8.6	16.2	-0.1	34.4	12	1.7	7	0.8	-0.5	0		43.1	+0.1	13.8	-0.5	90	SSW	13
J	27.9	13.3	20.7	-0.1	37.2	16	5.6	8	0.3	-0.9	0		40.6	+0.9	13.5	-1.4	64	WNW	23
J	33.5	16.8	25.2	+0.4	40.6	26	8.3	6	0.3	-0.1	0		30.5	-1.7	14.6	+0.8	71	NW	31
A	32.9	15.1	24.0	+0.3	38.9	24	11.1	19	0	-0.7	0		33.6	-2.0	12.2	-0.6	71	WNW	19
S	27.3	10.0	18.7	-0.3	38.9	4	3.3	18	1.0	+0.2	0		43.8	+2.2	11.6	-0.3	68	SW	25
O	22.6	8.1	15.3	+3.6	31.1	1	0.0	27	T	-1.1	0		53.7	-3.1	9.8	-0.5	61	NW	26
N	11.5	2.1	6.8	+2.6	20.6	1	-2.2	30	2.1	+T	0	-3.6	73.7	+0.3	11.3	+1.6	68	SW	22
D	3.1	-3.3	-0.1	-0.7	13.9	12	-13.3	26	1.0	-1.4	8.9	-2.8	84.2	+4.2	7.7	-2.1	66	S	30
Y	19.4	6.0	12.7	+0.9	40.6	Jul 26	-13.3	Dec 26	10.5	-5.3	23.6	-11.3	53.3	-1.0	11.8	-0.6	101	SW	Apr 28

(a) Departure columns indicate positive or negative departure of meteorological parameters from 30-year (1951-1980) climatological normals.

(b) + after date indicates latest of several occurrences.

TABLE C.2. Temperature Summary of Monthly and Annual Temperatures (°C) from the Hanford Telemetry Network for 1988

Station Number	Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1	ProsBrcd	- 0.1	6.6	7.4	12.7	17.7	20.2	24.7	23.2	17.7	13.9	6.7	1.0	12.7
2	EOC	- 0.2	7.8	7.8	12.4	17.2	19.8	24.7	23.7	18.7	15.6	6.7	0.4	12.9
3	ArmyLoop	- 0.2	6.3	7.8	13.0	17.8	20.6	25.3	24.0	18.3	14.4	6.9	0.8	12.9
4	RsnkSpr	- 0.1	6.5	7.7	12.7	17.3	20.4	25.0	23.7	18.3	14.3	6.9	0.8	12.8
5	Edna	- 0.5	5.4	7.4	12.8	17.7	20.5	24.9	23.6	17.9	14.1	6.6	1.1	12.6
6	200-E	- 0.1	7.2	8.3	13.4	18.4	20.9	25.7	24.4	19.0	15.6	7.2	1.0	13.4
7	200-W	- 0.5	5.8	7.3	11.8	CMD	CMD	25.2	23.7	17.9	13.5	6.6	0.7	*
8	Wahluke	- 0.3	7.3	7.9	13.0	17.1	19.5	24.2	23.2	18.2	15.2	5.8	0.6	12.7
9	FFTF	- 0.3	6.8	7.9	12.9	17.7	20.4	24.9	23.7	18.4	14.9	6.9	1.2	12.9
10	YkmBrcd	- 0.8	6.6	7.3	12.3	17.8	21.1	CMD	23.8	18.3	14.7	5.9	0.1	*
11	300 Area	- 0.2	6.1	7.7	12.7	17.6	20.1	24.7	23.2	18.1	14.2	7.2	1.7	12.8
12	Wye Brcd	- 1.2	5.7	7.3	12.3	17.2	20.1	24.8	23.3	17.8	14.1	6.2	0.3	12.3
13	100-N	- 0.3	5.7	7.6	12.8	17.6	20.2	24.9	23.4	18.0	14.3	6.4	0.9	12.6
14	WPPSS	- 0.5	5.7	7.6	12.7	17.4	20.3	24.9	23.4	17.9	14.1	6.7	1.1	12.6
15	FrankCty	- 0.6	6.9	7.6	12.2	16.7	19.1	23.3	21.9	17.3	14.6	6.5	0.8	12.2
16	GableMtn	- 1.1	6.9	7.2	12.1	17.2	19.5	22.9	23.4	18.6	15.4	5.9	-0.3	12.3
17	Ringold	- 0.4	5.8	7.3	12.3	16.8	19.1	21.6	21.7	16.6	13.3	6.1	2.1	11.8
18	RichArpt	0.6	7.4	8.6	13.3	17.8	20.3	23.3	23.6	18.3	14.8	7.7	1.9	13.2
19	Sagehill	- 0.9	6.3	6.9	11.8	16.8	19.0	21.8	22.2	17.4	14.5	5.8	0.6	11.8
20	RsnkMtn	- 3.2	4.2	2.8	7.6	11.9	14.6	18.3	19.0	14.9	12.7	1.8	0.3	8.7
21	HMS	- 0.3	6.7	7.8	13.2	CMD	20.3	25.1	23.6	18.2	14.7	6.5	-0.2	*
22	PascoArpt	0.4	6.9	8.2	13.2	18.1	21.7	24.9	23.3	18.2	14.4	8.2	2.2	13.3
23	Gable-W	- 0.4	5.6	7.3	12.8	18.0	20.6	25.6	23.9	18.1	14.1	6.4	0.9	12.8
24	100-F	- 0.2	5.6	7.6	13.0	17.9	20.7	25.3	23.8	18.3	14.2	6.7	1.3	12.8
25	Vernita	- 0.4	5.7	7.1	12.4	17.4	20.1	24.9	23.6	18.9	14.7	6.3	0.8	12.6

CMD - Considerable missing data.
* - Incomplete record due to missing data.

TABLE C.3. Air Sampling Locations and Sample Composite Groups

Composite Group	Sampling Location	Map Location[a]
ON SITE		
100 Areas	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
	Pettett	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
Eltopia	Eltopia	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 4.1.

TABLE C.4. Ambient Nitrogen Dioxide (NO_2) Concentrations in the Hanford Environs for 1988

Location	Map Location[a]	Number of 24-h Samples	Annual Average[b] (ppm NO_2)	% Samples Less Than Detection Limit (0.003 ppm NO_2)	Maximum 24-h Sample (ppm NO_2)
ALE	1	204	<0.005 ± 0.012	38	0.050
200-West	2	302	<0.004 ± 0.005	32	0.017
100-B	3	114	<0.005 ± 0.007	33	0.022
100-D	4	222	<0.005 ± 0.007	32	0.027
Old Hanford Townsite	5	126	<0.003 ± 0.004	67	0.012
Army Barracks	6	251	<0.005 ± 0.006	20	0.015
400 Area	7	132	<0.005 ± 0.006	30	0.015

(a) Locations are identified in Figure 4.2.
(b) Annual averages ± 2 standard deviations. Samples less than detectable daily concentrations were assumed equal to the 24-h detection limit (0.003 ppm).

TABLE C.5. Airborne Radionuclide Concentrations in the Hanford Environs for 1988

Radionuclide	Composite Group[b]	No. of Samples	Concentration pCi/m^3[a] (10^{-12} µCi/mL) Maximum	Minimum	Average	Concentration Guide pCi/m^3[c]
^3H	On Site	78	0.1 ± 2.4	-1.7 ± 1.1	2.0 ± 0.5	200,000
	100 Areas	26	2.0 ± 0.9	-0.7 ± 1.4	1.4 ± 0.4	
	200 Areas	26	13.2 ± 2.4	-0.5 ± 0.8	2.4 ± 1.0	
	300 Area	13	7.2 ± 1.7	-1.3 ± 1.2	3.1 ± 1.2	
	400 Area	13	3.5 ± 2.1	-1.7 ± 1.1	2.3 ± 1.6	
	Perimeter	104	7.5 ± 2.1	-3.0 ± 1.1	1.2 ± 0.3	
	Nearby Communities	13	3.6 ± 0.9	-1.8 ± 0.9	1.4 ± 0.9	
	Distant Communities	25	6.3 ± 3.0	-3.6 ± 1.3	0.8 ± 0.9	
^{14}C	On Site	20	1.60 ± 0.10	1.00 ± 0.05	1.40 ± 0.10	500,000
	100 Areas	6	1.50 ± 0.14	1.00 ± 0.06	1.40 ± 0.20	
	200 Areas	7	1.60 ± 0.10	1.00 ± 0.08	1.50 ± 0.20	
	300 Area	7	1.50 ± 0.10	1.00 ± 0.05	1.30 ± 0.10	
	Distant Communities	12	1.60 ± 0.10	0.90 ± 0.08	1.30 ± 0.10	
^{85}Kr	On Site	23	1600 ± 210	22 ± 6	350 ± 190	60,000
	200 Areas	12	1600 ± 210	32 ± 8	600 ± 1000	
	300 Areas	11	140 ± 20	22 ± 6	70 ± 70	
	Perimeter	45	450 ± 60	3 ± 11	70 ± 20	
	Nearby Communities	29	120 ± 20	9 ± 9	40 ± 8	
	Distant Communities	25	46 ± 1	9 ± 6	30 ± 3	
^{90}Sr	On Site	32	0.00056 ± 0.00007	0.00000 ± 0.00003	0.00008 ± 0.00004	9
	100 Areas	4	0.00056 ± 0.00007	0.00001 ± 0.00002	0.00019 ± 0.00025	
	200 Areas	12	0.00016 ± 0.00008	0.00001 ± 0.00002	0.00006 ± 0.00003	
	300 Area	4	0.00020 ± 0.00009	0.00002 ± 0.00002	0.00009 ± 0.00008	
	400 Area	4	0.00017 ± 0.00005	0.00002 ± 0.00003	0.00008 ± 0.00007	
	Perimeter	24	0.00018 ± 0.00013	0.00001 ± 0.00005	0.00006 ± 0.00002	
	Nearby Communities	20	0.00015 ± 0.00011	0.00001 ± 0.00007	0.00006 ± 0.00002	
	Distant Communities	16	0.00015 ± 0.00008	-0.00001 ± 0.00007	0.00005 ± 0.00002	
^{106}Ru	On Site	96	0.0076 ± 0.0069	-0.0095 ± 0.0078	0.0009 ± 0.0008	30
	100 Areas	12	0.0032 ± 0.0036	-0.0039 ± 0.0054	0.0000 ± 0.0015	
	200 Areas	36	0.0076 ± 0.0069	-0.0043 ± 0.0061	0.0014 ± 0.0012	
	300 Area	12	0.0062 ± 0.0071	-0.0095 ± 0.0078	-0.0003 ± 0.0027	
	400 Area	12	0.0062 ± 0.0043	-0.0036 ± 0.0061	0.0006 ± 0.0014	
	Perimeter	72	0.0100 ± 0.0110	-0.0120 ± 0.0120	0.0001 ± 0.0012	
	Nearby Communities	60	0.0100 ± 0.0099	-0.0100 ± 0.0110	0.0006 ± 0.0011	
	Distant Communities	60	0.0138 ± 0.0100	-0.0117 ± 0.0165	0.0011 ± 0.0016	
^{129}I	On Site	4	0.0005000 ± 0.0001000	0.0002300 ± 0.0000340	0.0003700 ± 0.0001200	70
	200 Areas	4	0.0005000 ± 0.0001000	0.0002330 ± 0.0000340	0.0003700 ± 0.0001200	
	Perimeter	8	0.0000180 ± 0.0000030	0.0000050 ± 0.0000008	0.0000090 ± 0.0000030	
	Distant Communities	4	0.0000010 ± 0.0000002	0.0000003 ± 0.0000001	0.0000006 ± 0.0000003	
^{131}I	On Site	180	0.0058 ± 0.0058	-0.0068 ± 0.0541	0.0001 ± 0.0003	400
	100 Areas	51	0.0055 ± 0.0073	-0.0041 ± 0.0054	0.0001 ± 0.0006	
	200 Areas	77	0.0039 ± 0.0062	-0.0046 ± 0.0055	-0.0002 ± 0.0005	
	300 Area	26	0.0058 ± 0.0058	-0.0037 ± 0.0040	0.0008 ± 0.0008	

TABLE C.5. (Airborne Radionuclide Concentrations contd)

Radionuclide	Composite Group[b]	No. of Samples	Concentration pCi/m^3[a] (10^{-12} µCi/mL) Maximum			Minimum			Average			Concentration Guide pCi/m^3[c]
	400 Area	26	0.0052	±	0.0052	-0.0068	±	0.0541	-0.0003	±	0.0009	
	Perimeter	129	0.0067	±	0.0054	-0.0106	±	0.0116	0.0001	±	0.0004	
	Nearby Communities	26	0.0040	±	0.0040	-0.0110	±	0.0062	-0.0013	±	0.0012	
	Distant Communities	50	0.0054	±	0.0054	0.0035	±	0.0038	0.0004	±	0.0005	
^{137}Cs	On Site	96	0.0005	±	0.0006	-0.0010	±	0.0016	0.0001	±	0.0001	400
	100 Areas	12	0.0005	±	0.0006	-0.0006	±	0.0004	0.0001	±	0.0002	
	200 Areas	36	0.0011	±	0.0011	-0.0007	±	0.0013	0.0001	±	0.0001	
	300 Area	12	0.0004	±	0.0007	-0.0006	±	0.0008	0.0000	±	0.0002	
	400 Area	12	0.0005	±	0.0006	-0.0004	±	0.0008	0.0001	±	0.0002	
	Perimeter	72	0.0016	±	0.0011	-0.0014	±	0.0012	0.0001	±	0.0001	
	Nearby Communities	60	0.0013	±	0.0025	-0.0020	±	0.0016	0.0000	±	0.0002	
	Distant Communities	48	0.0008	±	0.0012	0.0012	±	0.0015	0.0000	±	0.0001	
U(total)[d]	On Site	24	0.002800	±	0.000085	0.000024	±	0.000007	0.000299	±	0.000244	0.1
	100 Areas	4	0.000110	±	0.000016	0.000029	±	0.000008	0.000053	±	0.000038	
	200 Areas	8	0.000092	±	0.000017	0.000024	±	0.000007	0.000048	±	0.000016	
	300 Area	4	0.001300	±	0.000067	0.000246	±	0.000019	0.000559	±	0.000495	
	Perimeter	8	0.000270	±	0.000030	0.000039	±	0.000011	0.000105	±	0.000062	
	Distant Communities	8	0.000150	±	0.000024	0.000028	±	0.000009	0.000067	±	0.000029	
^{238}Pu	On Site	32	0.0000009	±	0.0000028	-0.0000018	±	0.0000033	-0.0000002	±	0.0000002	0.03
	100 Areas	4	0.0000005	±	0.0000012	-0.0000011	±	0.0000029	-0.0000002	±	0.0000006	
	200 Areas	12	0.0000003	±	0.0000012	-0.0000018	±	0.0000033	-0.0000004	±	0.0000004	
	300 Area	4	0.0000003	±	0.0000035	-0.0000002	±	0.0000010	0.0000000	±	0.0000002	
	400 Area	4	0.0000009	±	0.0000028	-0.0000001	±	0.0000009	0.0000003	±	0.0000004	
	Perimeter	24	0.0000029	±	0.0000033	-0.0000008	±	0.0000008	0.0000000	±	0.0000003	
	Nearby Communities	20	0.0000007	±	0.0000019	-0.0000017	±	0.0000016	-0.0000003	±	0.0000003	
	Distant Communities	16	0.0000021	±	0.0000020	-0.0000041	±	0.0000054	-0.0000001	±	0.0000006	
^{239}Pu	On Site	32	0.0000036	±	0.0000028	-0.0000018	±	0.0000033	0.0000006	±	0.0000004	0.02
	100 Areas	4	0.0000028	±	0.0000027	-0.0000002	±	0.0000006	0.0000011	±	0.0000014	
	200 Areas	12	0.0000022	±	0.0000021	-0.0000020	±	0.0000033	0.0000004	±	0.0000007	
	300 Area	4	0.0000010	±	0.0000013	0.0000051	±	0.0000011	0.0000008	±	0.0000002	
	400 Area	4	0.0000013	±	0.0000020	-0.0000002	±	0.0000005	0.0000003	±	0.0000007	
	Perimeter	24	0.0000005	±	0.0000011	-0.0000029	±	0.0000025	-0.0000002	±	0.0000003	
	Nearby Communities	20	0.0000025	±	0.0000039	-0.0000014	±	0.0000019	0.0000001	±	0.0000005	
	Distant Communities	16	0.0000010	±	0.0000020	-0.0000015	±	0.0000034	0.0000000	±	0.0000003	
Beta	On Site	615	0.0900	±	0.0029	0.0006	±	0.0007	0.0200	±	0.0010	
	100 Areas	103	0.0900	±	0.0029	0.0006	±	0.0007	0.0200	±	0.0032	
	200 Areas	204	0.0700	±	0.0028	0.0063	±	0.0010	0.0200	±	0.0015	
	300 Area	78	0.0490	±	0.0022	0.0044	±	0.0006	0.0200	±	0.0024	
	400 Area	102	0.0490	±	0.0022	0.0079	±	0.0011	0.0200	±	0.0018	
	Perimeter	361	0.0770	±	0.0026	-0.0022	±	0.0002	0.0190	±	0.0013	
	Nearby Communities	228	0.0810	±	0.0030	0.0049	±	0.0006	0.0200	±	0.0017	
	Distant Communities	157	0.0770	±	0.0030	0.0047	±	0.0009	0.0190	±	0.0020	
Alpha	On Site	485	0.00340	±	0.00067	-0.00023	±	0.00016	0.00037	±	0.00003	
	100 Areas	25	0.00150	±	0.00047	-0.00015	±	0.00019	0.00030	±	0.00014	
	200 Areas	204	0.00170	±	0.00054	-0.00023	±	0.00014	0.00033	±	0.00004	
	300 Area	52	0.00170	±	0.00050	-0.00010	±	0.00028	0.00051	±	0.00011	
	400 Area	102	0.00120	±	0.00043	-0.00020	±	0.00019	0.00036	±	0.00006	
	Perimeter	256	0.00180	±	0.00048	-0.00009	±	0.00020	0.00042	±	0.00004	
	Nearby Communities	51	0.00150	±	0.00051	-0.00011	±	0.00016	0.00044	±	0.00010	
	Distant Communities	51	0.00150	±	0.00047	-0.00011	±	0.00019	0.00028	±	0.00008	

(a) Maximum and minimum single sample result ±2 sigma counting error. Averages of all samples ±2 standard errors of calculated mean. Most entries have been rounded to two significant figures; however, an equal number of digits has been maintained for each radionuclide set to make visual comparisons easier.
(b) On site, perimeter, nearby communities, and distant sampling locations are identified in Figure 4.1 and Table C.3.
(c) From draft DOE Derived Concentration Guide (see Appendix B).
(d) Summation of ^{234}U, ^{235}U, and ^{238}U.

TABLE C.6. Radionuclide Concentrations Measured in Columbia River Water at Priest Rapids Dam in 1988

Radionuclide[b]	No. of Samples	Concentration (pCi/L)[a] Maximum	Minimum	Average	Drinking Water Standard[c]
Composite System					
Gross Alpha	12	0.85 ± 0.81	-0.07 ± 0.20	0.31 ± 0.17	15
Gross Beta	12	2.31 ± 1.00	0.06 ± 1.00	0.96 ± 0.40	50
^{3}H	12	89 ± 6	56 ± 4	70 ± 6	20,000
^{89}Sr	12	0.184 ± 0.084	-0.044 ± 0.072	0.019 ± 0.038	20
^{90}Sr	12	0.15 ± 0.03	0.05 ± 0.03	0.10 ± 0.02	8
^{234}U	12	0.27 ± 0.06	0.11 ± 0.03	0.20 ± 0.03	---[d]
^{235}U	12	0.014 ± 0.013	-0.003 ± 0.008	0.006 ± 0.003	---
^{238}U	12	0.21 ± 0.04	0.11 ± 0.03	0.17 ± 0.02	---
U-Total	12	0.48 ± 0.07	0.23 ± 0.05	0.37 ± 0.04	---
Continuous System					
^{60}Co P	20	0.0018 ± 0.0019	-0.0012 ± 0.0024	0.0006 ± 0.0003	100
D	20	0.0042 ± 0.0041	-0.0027 ± 0.0042	0.0009 ± 0.0011	
^{129}I D	4	0.000045 ± 0.000005	0.000006 ± 0.000001	0.000017 ± 0.000019	1
^{131}I P	11	0.0026 ± 0.0037	-0.0011 ± 0.0043	0.0008 ± 0.0008	3
D	11	0.0038 ± 0.0073	-0.0068 ± 0.0114	-0.0007 ± 0.0023	---
^{137}Cs P	20	0.004 ± 0.0024	0.0002 ± 0.0014	0.0018 ± 0.0005	200
D	20	0.0067 ± 0.0040	-0.0019 ± 0.0044	0.0028 ± 0.0011	---
$^{239,240}Pu$ P	4	0.00010 ± 0.00008	0.000002 ± 0.000007	0.00006 ± 0.00005	---
D	4	0.00010 ± 0.00016	0.00002 ± 0.00005	0.00006 ± 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 B.2, Appendix B).
(d) Dashes indicate no concentration guides provided in DWS.

TABLE C.7. Radionuclide Concentrations Measured in Columbia River Water at the 300 Area in 1988

Radionuclide[b]	No. of Samples	Concentration (pCi/L)[a] Maximum	Minimum	Average	Drinking Water Standard[c]
Composite System					
Gross Alpha	4	0.76 ± 0.45	0.38 ± 0.42	0.52 ± 0.17	15
Gross Beta	4	1.55 ± 1.24	0.37 ± 1.21	1.02 ± 0.54	50
^{3}H	3	170 ± 6	128 ± 6	148 ± 24	20,000
^{89}Sr	4	0.110 ± 0.107	-0.073 ± 0.133	0.016 ± 0.079	20
^{90}Sr	4	0.14 ± 0.04	0.09 ± 0.03	0.12 ± 0.02	8
^{234}U	4	0.33 ± 0.05	0.21 ± 0.05	0.27 ± 0.05	---[d]
^{235}U	4	0.009 ± 0.013	0.002 ± 0.008	0.006 ± 0.003	---
^{238}U	4	0.24 ± 0.05	0.18 ± 0.05	0.20 ± 0.02	---
U-Total	4	0.58 ± 0.07	0.41 ± 0.07	0.48 ± 0.07	---
Continuous System					
^{60}Co P	23	0.0023 ± 0.0012	-0.0003 ± 0.0009	0.0010 ± 0.0003	100
D	23	0.0063 ± 0.0045	-0.0003 ± 0.0032	0.0026 ± 0.0007	
^{129}I D	4	0.00011 ± 0.00001	0.000054 ± 0.000006	0.00009 ± 0.00003	1
^{131}I P	14	0.0020 ± 0.0030	-0.0015 ± 0.0032	0.0002 ± 0.0006	3
D	14	0.0114 ± 0.0055	-0.0020 ± 0.0078	0.0015 ± 0.0021	
^{137}Cs P	23	0.0037 ± 0.0028	-0.0002 ± 0.0007	0.0014 ± 0.0005	200
D	23	0.0066 ± 0.0028	0.0000 ± 0.0014	0.0035 ± 0.0007	---
$^{239,240}Pu$ P	4	0.00005 ± 0.00004	0.00001 ± 0.00001	0.00003 ± 0.00002	---
D	4	0.00003 ± 0.00005	-0.000003 ± 0.0	0.00001 ± 0.00001	---

(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 B.2, Appendix B).
(d) Dashes indicate no concentration guides provided in DWS.

TABLE C.8. Radionuclide Concentrations Measured in Columbia River Water at the Richland Pumphouse in 1988

Radionuclide[b]	No. of Samples	Concentration (pCi/L)[a] Maximum	Minimum	Average	Drinking Water Standard[c]
Composite System					
Gross Alpha	12	0.76 ± 0.42	-0.04 ± 0.23	0.29 ± 0.13	15
Gross Beta	12	1.62 ± 1.23	-0.02 ± 0.89	0.87 ± 0.29	50
^{3}H	12	160 ± 7	98 ± 5	132 ± 10	20,000
^{89}Sr	12	0.098 ± 0.083	-0.072 ± 0.068	0.002 ± 0.028	20
^{90}Sr	12	0.17 ± 0.03	0.08 ± 0.03	0.12 ± 0.02	8
^{234}U	12	0.28 ± 0.05	0.04 ± 0.02	0.22 ± 0.04	---[d]
^{235}U	12	0.044 ± 0.020	-0.005 ± 0.000	0.009 ± 0.007	---
^{238}U	12	0.25 ± 0.05	0.07 ± 0.03	0.18 ± 0.03	---
U-Total	12	0.57 ± 0.07	0.11 ± 0.04	0.41 ± 0.07	---
Continuous System					
^{60}Co P	23	0.0059 ± 0.0038	0.0002 ± 0.0013	0.0014 ± 0.0005	100
D	23	0.0113 ± -0.0071	-0.0010 ± 0.0036	0.0029 ± 0.0011	
^{129}I D	4	0.00014 ± 0.00002	0.000069 ± 0.000007	0.00010 ± 0.00003	1
^{131}I P	12	0.0022 ± 0.0025	-0.0011 ± 0.0034	0.0005 ± 0.0006	3
D	12	0.0101 ± 0.0164	-0.0116 ± 0.0205	0.0011 ± 0.0033	---
^{137}Cs P	23	0.0057 ± 0.0017	-0.0004 ± 0.0014	0.0019 ± 0.0005	200
D	23	0.0130 ± 0.0059	-0.0012 ± 0.0034	0.0031 ± 0.0014	---
^{239}Pu P	4	0.00013 ± 0.00006	0.00002 ± 0.00001	0.00007 ± 0.00005	---
D	4	0.00005 ± 0.00011	-0.000005 ± 0.000057	0.00003 ± 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 B.2, Appendix B).
(d) Dashes indicate no concentration guides provided in DWS.

TABLE C.9. Radionuclide Concentrations in Columbia River Sediment in 1988

Location	Radionuclide	No. of Samples	Concentration (pCi/L)[a] Maximum	Minimum	Average
Priest Rapids Dam	^{60}Co	4	0.014 ± 0.018	-0.012 ± 0.012	0.003 ± 0.012
	^{90}Sr	4	0.072 ± 0.006	0.0048 ± 0.0037	0.026 ± 0.031
	^{134}Cs	3	0.0098 ± 0.018	-0.0021 ± 0.011	0.0049 ± 0.0072
	^{137}Cs	4	0.28 ± 0.03	0.24 ± 0.02	0.26 ± 0.02
	^{235}U[b]	4	0.097 ± 0.15	0.007 ± 0.12	0.063 ± 0.042
	^{238}U[b]	4	0.79 ± 0.38	0.67 ± 0.36	0.73 ± 0.05
	^{238}Pu	4	0.00026 ± 0.00017	0.00004 ± 0.00006	0.00015 ± 0.00009
	$^{239,240}Pu$	4	0.0028 ± 0.0007	0.0015 ± 0.0003	0.0023 ± 0.0006
McNary Dam	^{60}Cu	4	0.36 ± 0.03	0.15 ± 0.03	0.27 ± 0.11
	^{90}Sr	4	0.058 ± 0.006	0.036 ± 0.005	0.046 ± 0.009
	^{134}Cs	3	0.057 ± 0.021	0.030 ± 0.014	0.044 ± 0.016
	^{137}CS	4	0.79 ± 0.05	0.63 ± 0.04	0.69 ± 0.07
	^{235}U[b]	4	0.22 ± 0.14	-0.09 ± 0.16	0.05 ± 0.13
	^{238}U[b]	4	0.89 ± 0.49	0.63 ± 0.31	0.78 ± 0.12
	^{238}Pu	4	0.00059 ± 0.00028	0.00020 ± 0.00020	0.00043 ± 0.00018
	$^{239,240}Pu$	4	0.011 ± 0.001	0.009 ± 0.001	0.010 ± 0.001

(a) Maximum and minimum values ±2 sigma counting error. Average ±2 standard error of the calculated mean.
(b) Uranium-235 and ^{238}U by Low-Energy Photon Detector (LEPD) method.

TABLE C.10. Columbia River Water Quality Data for 1988

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	8.5	7.4	NA	12	8.3	7.3	NA	6.5-8.5
Fecal coliform	#/100 mL	12	130	2	2[c]	12	70	2	7[c]	100
Total coliform	#/100 mL	12	1600	2	48[c]	12	240	9	70[c]	
Biological oxygen demand	mg/L	12	5.2	0.7	2.1 ± 0.8	12	2.5	0.7	1.7 ± 0.4	
Nitrate	mg/L	12	0.23	0.05	0.14 ± 0.03	12	1.1	0.06	0.3 ± 0.2	
USGS Sampling Program[d]										
Temperature[e]	°C	365	19.6	1.8	11.3	365	20.0	1.4	11.6	20 (maximum)
Dissolved oxygen	mg/L	6	13.4	8.8	11.5 ± 1.4	4	13.2	10.3	11.7 ± 1.5	8 (minimum)
Turbidity	NTU	6	1.8	0.4	1.0 ± 0.4	3	1.5	0.6	1.0 ± 0.6	5 + background
pH	pH units	6	8.8	8.0	NA	4	8.7	7.9	NA	6.5 - 8.5
Fecal coliform	#/100 mL	6	3	<1	2[c]	4	8	<1	7[c]	100
Suspended solids, 105°C	mg/L	NR				3	4	<1	<2.7 ± 1.8	
Dissolved solids, 180°C	mg/L	6	88	71	81 ± 6	3	91	74	83 ± 10	
Specific conductance	µmhos/cm	6	162	123	140 ± 15	4	156	122	139 ± 17	
Hardness, as $CaCO_3$	mg/L	6	77	58	68 ± 7	3	76	62	71 ± 9	
Phosphorus, total	mg/L	6	0.03	0.02	0.023 ± 0.004	3	0.03	0.02	0.023 ± 0.007	
Chromium, dissolved	µg/L	3	<1	<1	<1	3	<1	<1	<1	
Nitrogen, Kjeldahl	mg/L	6	0.5	<0.2	<0.28 ± 0.11	3	0.3	<0.2	0.27 ± 0.07	
Total organic carbon	mg/L	4	2.8	1.4	2.1 ± 0.7	4	3.1	1.3	2.2 ± 0.8	
Iron, dissolved	µg/L	3	65	9	28 ± 37	3	8	4	5.3 ± 2.7	
Ammonia, dissolved (as N)	mg/L	5	0.05	<0.01	<0.02 ± 0.02	3	0.04	<0.01	<0.03 ± 0.02	

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

TABLE C.11. Radionuclide Concentrations in Onsite Ponds in 1988

Location	Radionuclide	No. of Samples	Concentration, pCi/L[a] Maximum	Minimum	Average
West Lake	Gross Alpha	3	259 ± 15	182 ± 13	226 ± 46
	Gross Beta	3	295 ± 47	234 ± 42	267 ± 36
	^{3}H	3	650 ± 150	370 ± 170	480 ± 170
	^{90}Sr	3	2.6 ± 0.2	2.1 ± 0.1	2.4 ± 0.3
	^{137}Cs	3	2.3 ± 2.1	-0.2 ± 1.6	0.8 ± 1.5
	^{234}U	3	175 ± 4	106 ± 3	145 ± 41
	^{235}U	3	6.3 ± 0.8	4.0 ± 0.6	5.3 ± 1.3
	^{238}U	3	165 ± 4	100 ± 3	137 ± 39
	U-Tot	3	346 ± 6	210 ± 4	287 ± 81
B Pond	Gross Alpha	4	0.7 ± 0.4	0.1 ± 0.3	0.4 ± 0.2
	Gross Beta	4	32 ± 4	0.9 ± 1.1	9.5 ± 14.9
	^{3}H	4	169 ± 162	-65 ± 162	78 ± 102
	^{90}Sr	4	1.6 ± 0.1	0.4 ± 0.08	1.1 ± 0.6
	^{137}Cs	4	1.4 ± 1.8	-0.3 ± 2.1	0.7 ± 0.8
FFTF Pond	Gross Alpha	2	0.07 ± 0.25	-0.16 ± 0.15	-0.04 ± 0.23
	Gross Beta	2	21 ± 4	16 ± 3	19 ± 5
	^{3}H	2	5,550 ± 280	5,200 ± 260	5,380 ± 350
	^{137}Cs	2	1.0 ± 2.0	-0.2 ± 0.6	0.4 ± 1.2
	^{22}Na	2	0.2 ± 1.7	-0.2 ± 2.0	0.01 ± 0.34

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

TABLE C.12. Radionuclide Concentrations Measured in Offsite Water in 1988

Location	Radionuclide	No. of Samples	Concentration (pCi/L)[a] Maximum	Minimum	Average	Drinking Water Standard
Well Water						
Webber Ranch	Gross Alpha	1			0.03 ± 0.22	15
	Gross Beta	1			11.5 ± 2.58	50
	^{3}H	1			-162 ± 158	20,000
	^{129}I	1			0.000023 ± 0.000018	1
	^{234}U	1			0.011 ± 0.016	---
	^{235}U	1			0.0001 ± 0.0044	---
	^{238}U	1			0.006 ± 0.012	---
	U-Total	1			0.017 ± 0.020	---
Ringold Hatchery	Gross Alpha	1			0.14 ± 0.25	15
	Gross Beta	1			8.6 ± 2.2	50
	^{3}H	1			13 ± 124	20,000
	^{234}U	1			-0.0001 ± 0.018	---
	^{235}U	1			-0.0052 ± 0.0000	---
	^{238}U	1			-0.002 ± 0.011	---
	U-Total	1			-0.007 ± 0.021	---
W-15	Gross Alpha	5	7.9 ± 1.2	4.8 ± 0.9	6.8 ± 1.1	15
	Gross Beta	5	8.1 ± 2.3	5.3 ± 2.0	6.5 ± 1.1	50
	^{3}H	5	225 ± 159	-22 ± 163	117 ± 82	20,000
	^{129}I	1			0.000033 ± 0.00005	1
	^{234}U	5	4.2 ± 0.2	3.8 ± 0.2	4.0 ± 0.2	---
	^{235}U	5	0.16 ± 0.04	0.10 ± 0.03	0.12 ± 0.02	---
	^{238}U	5	3.5 ± 0.2	3.1 ± 0.2	3.4 ± 0.2	---
	U-Total	5	7.8 ± 0.3	7.2 ± 0.2	7.5 ± 0.3	---
White Bluffs Water Assn	Gross Alpha	5	30.9 ± 2.3	0.5 ± 0.3	13.8 ± 9.8	15
	Gross Beta	5	13.3 ± 2.9	0.5 ± 1.1	5.1 ± 4.3	50
	^{3}H	5	377 ± 161	80.0 ± 161	223 ± 164	20,000
	^{129}I	1			0.000096 ± 0.000014	1
	^{234}U	5	15.6 ± 0.4	0.3 ± 0.1	9.0 ± 5.7	---
	^{235}U	5	0.55 ± 0.07	0.003 ± 0.004	0.31 ± 0.21	---
	^{238}U	5	14.5 ± 0.3	0.21 ± 0.04	8.3 ± 5.4	---
	U-Total	5	30.6 ± 0.5	0.5 ± 0.1	17.6 ± 11.3	---
Alexander	Gross Alpha	5	44.9 ± 2.8	0.02 ± 0.22	18.0 ± 21.3	15
	Gross Beta	5	20.2 ± 3.8	10.8 ± 2.7	14.5 ± 3.2	50
	^{3}H	5	350 ± 161	-76.2 ± 153	150 ± 183	20,000
	^{129}I	1			0.000008 ± 0.000002	1
	^{234}U	5	28.7 ± 0.5	-0.04 ± 0.06	10.6 ± 12.7	---
	^{235}U	5	0.72 ± 0.08	-0.03 ± 0.00	0.25 ± 0.31	---
	^{238}U	5	18.1 ± 0.4	-0.03 ± 0.04	6.7 ± 7.9	---
	U-Total	5	47.5 ± 0.6	-0.1 ± 0.1	17.5 ± 20.9	---
Irrigation Water						
Riverview Canal	^{60}Co	3	0.43 ± 0.82	-0.08 ± 1.04	0.25 ± 0.33	100
	^{90}Sr	3	0.20 ± 0.04	0.14 ± 0.04	0.16 ± 0.04	8
	^{137}Cs	3	0.03 ± 1.11	-0.53 ± 0.81	-0.26 ± 0.33	200

(a) Maximum and minimum values ± 2 sigma counting error. Averages ± 2 standard error of the calculated mean.
--- No concentration guides provided in DWS.

TABLE C.13. Radionuclide Concentrations in Milk Samples in 1988 (pCi/L)[a]

Location[b]	^{3}H No. of Samples	^{3}H Maximum	^{3}H Average
Wahluke East Area Composite	13	230 ± 130	77 ± 55
Sagemoor Area Composite	13	250 ± 120	110 ± 63
Riverview Area[c]	8	170 ± 130	41 ± 52
Benton City Area	13	340 ± 160	56 ± 84
Sunnyside Area	13	300 ± 120	85 ± 53
Moses Lake Area	10	370 ± 140	150 ± 89

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 ± 0.3	0.8 ± 0.4	2	0.010 ± 0.002	0.010 ± 0.001
Sagemoor Area Composite	4	1.2 ± 0.3	0.8 ± 0.3	2	0.017 ± 0.002	0.012 ± 0.010
Riverview Area[c]	2	0.8 ± 0.3	0.8 ± 0.2	2	0.014 ± 0.002	0.014 ± 0.001
Benton City Area	4	1.4 ± 0.4	0.8 ± 0.3	2	0.020 ± 0.002	0.011 ± 0.018
Sunnyside Area	4	1.0 ± 0.4	0.7 ± 0.3	2	0.008 ± 0.001	0.006 ± 0.006
Moses Lake Area	3	1.3 ± 0.4	1.1 ± 0.3	2	0.0004 ± 0.0001	0.0004 ± 0.0001

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	0.10 ± 0.19	-0.01 ± 0.07	13	2.6 ± 4.1	0.7 ± 1.1
Sagemoor Area Composite	26	0.24 ± 0.23	0.01 ± 0.06	26	7.8 ± 3.7	1.2 ± 1.1
Riverview Area[c]	6	0.12 ± 0.20	-0.01 ± 0.10	8	8.6 ± 4.4	1.3 ± 3.1
Benton City Area	13	0.20 ± 0.21	0.06 ± 0.08	13	5.0 ± 6.4	0.5 ± 1.5
Sunnyside Area	26	0.22 ± 0.26	-0.01 ± 0.07	26	3.9 ± 3.3	0.5 ± 0.8
Moses Lake Area	10	0.11 ± 0.15	-0.01 ± 0.07	10	2.7 ± 3.8	0.8 ± 1.3

(a) Maximum values ±2 sigma counting error. Averages ±2 standard error of the calculated mean.
(b) Refer to Figure 4.28.
(c) Irrigation water obtained from the Columbia River downstream of Hanford.

TABLE C.14. Radionuclide Concentrations in Leafy Vegetables in 1988

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
Riverview Area[c]	3	0.013 ± 0.004	0.006 ± 0.007	3	-0.001 ± 0.001	-0.002 ± 0.006
Sunnyside Area	3	0.001 ± 0.002	0.001 ± 0.001	3	-0.001 ± 0.001	-0.001 ± 0.008

(a) Maximum concentrations ±2 sigma counting error. Averages ±2 standard error of the calculated mean.
(b) Refer to Figure 4.28.
(c) Irrigated with Columbia River water.

TABLE C.15. Radionuclide Concentrations in Vegetables in 1988

Type/Location[b]	^{90}Sr, pCi/g, wet weight[a]			^{137}Cs, pCi/g, wet weight[a]			$^{239,240}Pu$, pCi/g wet weight		
	No. of Samples	Maximum	Average	No. of Samples	Maximum	Average	No. of Samples	Maximum	Average
Carrots									
Riverview Area[c]	3	0.012 ± 0.003	0.010 ± 0.003	3	0.005 ± 0.005	0.002 ± 0.005	NS	—	—
Potatoes									
Riverview Area[c]	3	0.005 ± 0.002	0.005 ± 0.001	3	0.002 ± 0.008	0.001 ± 0.006	NS	—	—
Sagemoor Area	3	0.007 ± 0.003	0.005 ± 0.003	3	0.007 ± 0.008	0.002 ± 0.008	3	0.0001 ± 0.0001	0.0001 ± 0.0001
Wahluke East Area	3	0.005 ± 0.003	0.002 ± 0.004	3	0.003 ± 0.006	-0.001 ± 0.006	NS	—	—
Sunnyside Area	3	0.008 ± 0.003	0.005 ± 0.003	3	-0.004 ± 0.009	-0.004 ± 0.006	3	0.0001 ± 0.0001	0.0001 ± 0.0001

(a) Maximum values ±2 sigma counting error. Averages ±2 standard error of the calculated mean.
(b) Refer to Figure 4.28.
(c) Irrigated with Columbia River water.
NS No Sample.

TABLE C.16. Radionuclide Concentrations in Fruit in 1988

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
Apples						
Riverview Area[c]	3	0.001 ± 0.002	-0.001 ± 0.002	3	0.010 ± 0.008	0.004 ± 0.011
Sagemoor Area	3	0.001 ± 0.001	0.001 ± 0.001	3	0.004 ± 0.009	0.002 ± 0.006
Cold Creek Area	3	-0.001 ± 0.002	-0.001 ± 0.001	3	-0.001 ± 0.009	-0.003 ± 0.005
Sunnyside Area	3	0.001 ± 0.002	0.001 ± 0.001	3	0.005 ± 0.010	0.001 ± 0.008
Wahluke Area	3	0.001 ± 0.002	0.001 ± 0.002	3	0.002 ± 0.010	-0.004 ± 0.010
Cherries						
Sagemoor Area	3	0.004 ± 0.002	0.003 ± 0.002	3	-0.002 ± 0.006	-0.002 ± 0.003
Sunnyside Area	3	0.002 ± 0.002	0.001 ± 0.001	3	0.003 ± 0.007	-0.001 ± 0.006
Grapes						
Riverview Area[c]	3	0.001 ± 0.002	0.001 ± 0.001	3	0.005 ± 0.006	0.002 ± 0.005
Sagemoor Area	3	0.002 ± 0.002	0.002 ± 0.002	3	0.005 ± 0.007	-0.002 ± 0.009
Cold Creek Area	3	0.003 ± 0.003	0.002 ± 0.003	3	0.003 ± 0.006	0.001 ± 0.005
Sunnyside Area	3	0.001 ± 0.002	0.001 ± 0.001	3	0.008 ± 0.007	0.002 ± 0.008
Melons						
Riverview Area[c]	3	0.001 ± 0.002	0.001 ± 0.002	3	0.004 ± 0.005	0.001 ± 0.006

Type/ Location[b]	^{3}H, pCi/L, water[a]			$^{239,240}Pu$, pCi/g, wet weight		
	No. of Samples	Maximum	Average	No. of Samples	Maximum	Average
Apples						
Riverview Area[c]	3	160 ± 110	140 ± 70	NS	---	---
Sagemoor Area	3	200 ± 110	180 ± 77	3	-0.0001 ± 0.0	-0.0001 ± 0.0001
Cold Creek Area	3	410 ± 170	270 ± 260	NS	---	---
Sunnyside Area	3	270 ± 140	170 ± 140	3	0.0002 ± 0.0002	-0.0001 ± 0.0002
Wahluke Area	3	200 ± 140	160 ± 100	NS	---	---
Cherries						
Sagemoor Area	3	190 ± 160	180 ± 90	NS	---	---
Sunnyside Area	3	99 ± 160	230 ± 130	NS	---	---
Grapes						
Riverview Area [c]	3	280 ± 170	21 ± 380	NS	---	---
Sagemoor Area	3	130 ± 170	-310 ± 560	NS	---	---
Cold Creek Area	3	390 ± 170	120 ± 290	NS	---	---
Sunnyside Area	3	320 ± 170	43 ± 320	NS	---	---
Melons						
Riverview Area[c]	3	160 ± 110	110 ± 100	NS	---	---

(a) Maximum values ±2 sigma counting error. Averages ±2 standard error of the calculated mean.
(b) Refer to Figure 4.28.
(c) Irrigated with Columbia River water.

TABLE C.17. Iodine-129 Concentrations in Special Samples of Fruits and Vegetables

Type/ Location	No. of Samples	pCi/g Wet Weight [a] Maximum	Average
Apples			
Sagemore	3	0.007 ± 0.031	-0.002 ± 0.013
Sunnyside	3	0.028 ± 0.038	0.001 ± 0.029
Peaches			
Sagemore	3	0.010 ± 0.015	-0.001 ± 0.015
Sunnyside	3	0.010 ± 0.017	-0.012 ± 0.029
Potatoes			
Sagemore	3	0.001 ± 0.058	-0.029 ± 0.031
Sunnyside	3	0.007 ± 0.066	-0.001 ± 0.014
Leafy Vegetables			
Sagemore	NS	---	---
Sunnyside	3	0.001 ± 0.014	-0.008 ± 0.008

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

TABLE C.18. Radionuclide Concentrations in Local Wine in 1988

Location[b]	No. of Samples	^{3}H, pCi/L[a] Maximum	^{3}H, pCi/L[a] Average	^{137}Cs, pCi/L[a] Maximum	^{137}Cs, pCi/L[a] Average
Columbia Basin					
White Wine	3	480 ± 115	290 ± 200	2.7 ± 4.4	2.4 ± 0.4
Red Wine	3	380 ± 110	220 ± 170	5.2 ± 3.4	2.3 ± 3.2
Yakima Valley					
White Wine	3	110 ± 95	81 ± 35	1.0 ± 4.3	-1.1 ± 3.9
Red Wine	3	500 ± 110	260 ± 260	3.3 ± 5.6	0.5 ± 4.5

(a) Maximum values ±2 sigma counting error. Averages ±2 standard error of the calculated mean.
(b) Refer to Figure 4.28.

TABLE C.19. Radionuclide Concentrations in Wheat and Alfalfa in 1988

Type/ Location[b]	^{90}Sr, pCi/g, dry weight[a] No. of Samples	Maximum	Average	^{137}Cs, pCi/g, dry weight[a] No. of Samples	Maximum	Average	$^{239,240}Pu$, pCi/g, dry weight[a] No. of Samples	Maximum	Average
Wheat									
Wahluke East Area	3	0.010 ± 0.002	0.009 ± 0.002	3	0.006 ± 0.010	0.003 ± 0.008	NS	—	—
Sagemoor Area	3	0.014 ± 0.003	0.012 ± 0.003	3	0.010 ± 0.011	0.004 ± 0.010	3	-0.0001 ± 0.0001	0.0001 ± 0.0006
Riverview Area[c]	3	0.015 ± 0.004	0.012 ± 0.004	3	0.003 ± 0.011	0.001 ± 0.008	NS	—	—
Moses Lake Area	3	0.009 ± 0.002	0.008 ± 0.002	3	0.002 ± 0.010	0.001 ± 0.007	NS	—	—
Sunnyside	3	0.004 ± 0.003	0.004 ± 0.002	3	0.001 ± 0.010	-0.005 ± 0.011	3	0.0001 ± 0.0001	0.0001 ± 0.0001
Alfalfa									
Wahluke East Area	3	0.24 ± 0.01	0.15 ± 0.01	3	0.006 ± 0.014	0.003 ± 0.009	NS	—	—
Sagemoor Area	3	0.21 ± 0.01	0.17 ± 0.06	3	0.021 ± 0.037	0.009 ± 0.024	NS	—	—
Riverview Area[c]	3	0.27 ± 0.01	0.25 ± 0.03	3	0.013 ± 0.016	0.010 ± 0.009	NS	—	—
Benton City Area	3	0.16 ± 0.03	0.15 ± 0.02	3	0.019 ± 0.024	0.008 ± 0.015	NS	—	—
Sunnyside Area	3	0.079 ± 0.006	0.076 ± 0.007	3	0.026 ± 0.012	0.011 ± 0.019	NS	—	—
Moses Lake Area	3	0.24 ± 0.01	0.20 ± 0.04	3	0.014 ± 0.016	0.010 ± 0.010	NS	—	—

(a) Maximum values ±2 sigma counting error. Averages ±2 standard error of the calculated mean.
(b) Refer to Figure 4.28.
(c) Irrigated with Columbia River water.
NS No Sample

TABLE C.20. Radionuclide Concentrations in Beef, Chicken, and Eggs in 1988

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						
Riverview Area	1	---	0.003 ± 0.003	1	---	-0.003 ± 0.005
Sagemoor Area	1	---	-0.001 ± 0.001	1	---	0.001 ± 0.007
Sunnyside Area	1	---	0.001 ± 0.003	1	---	0.004 ± 0.007
Chicken						
Sagemoor Area	2	0.002 ± 0.003	0.001 ± 0.003	2	0.005 ± 0.001	0.004 ± 0.010
Sunnyside	2	0.001 ± 0.002	0.001 ± 0.002	2	0.004 ± 0.002	-0.001 ± 0.020
Eggs						
Sagemoor Area	2	0.003 ± 0.003	0.002 ± 0.003	2	0.004 ± 0.007	0.001 ± 0.008
Sunnyside	2	0.002 ± 0.001	0.002 ± 0.002	2	0.007 ± 0.007	0.003 ± 0.010

(a) Maximum values ±2 sigma counting error. Averages ±2 standard error of the calculated mean or ±2 sigma counting error if single sample.
(b) Refer to Figure 4.28.

TABLE C.21. Concentrations of Cesium-137 in Deer Muscle and Plutonium-239,240 in Deer Liver in 1988

Location	Type	^{137}Cs, pCi/g, wet weight[a]			$^{239,240}Pu$, pCi/g, wet weight[a]		
		No. of Samples	Maximum	Average	No. of Samples	Maximum	Average
Random (road kills)	Muscle	3	0.010 ± 0.007	0.008 ± 0.003	NS	—[b]	—
	Liver	NS	—	—	3	0.00011 ± 0.00013	0.00002 ± 0.00009

(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 C.22. Radionuclide Concentrations in Columbia River Fish in 1988

Type/Location[b]	^{60}Co, pCi/g, wet weight[a]			^{90}Sr, pCi/g, wet weight[a]			^{137}Cs, pCi/g, wet weight[a]		
	No. of Samples	Maximum	Average	No. of Samples	Maximum	Average	No. of Samples	Maximum	Average
Whitefish Muscle									
Upstream of Site Boundary	5	0.011 ± 0.023	0.005 ± 0.006	5	0.003 ± 0.003	0.001 ± 0.001	5	0.014 ± 0.021	0.008 ± 0.010
100-D Area Vicinity	10	0.035 ± 0.026	0.016 ± 0.012	10	0.005 ± 0.006	0.001 ± 0.001	10	0.039 ± 0.022	0.023 ± 0.010
Whitefish Carcass									
Upstream of Site Boundary	NS	–	–	5	0.054 ± 0.007	0.031 ± 0.016	NS	–	–
100-D Area Vicinity	NS	–	–	10	0.064 ± 0.005	0.026 ± 0.009	NS	–	–
Bass Muscle									
100-F Sloughs	5	0.047 ± 0.033	0.009 ± 0.022	5	0.003 ± 0.003	0.002 ± 0.001	5	0.089 ± 0.046	0.053 ± 0.028
Bass Carcass									
100-F Sloughs	NS	–	–	5	0.059 ± 0.008	0.040 ± 0.015	NS	–	–
Salmon Muscle									
Priest Rapids Dam	5	0.015 ± 0.015	-0.007 ± 0.019	5	0.001 ± 0.002	0.001 ± 0.001	5	0.048 ± 0.021	0.023 ± 0.018
White Bluffs	5	0.010 ± 0.025	0.002 ± 0.013	5	0.002 ± 0.002	-0.001 ± 0.002	5	0.031 ± 0.017	0.017 ± 0.016

(a) Maximum values ±2 sigma counting error. Averages ±2 standard error of the calculated mean.
(b) Refer to Figure 4.32.
NS No sample.

TABLE C.23. Radionuclide Concentrations in Muscle Tissue of Upland Gamebirds in 1988

Type/ Location[b]	^{60}Co, pCi/g, wet weight[a]			^{137}Cs, pCi/g, wet weight[a]		
	No. of Samples	Maximum	Average	No. of Samples	Maximum	Average
Pheasant						
100 Areas	5	0.015 ± 0.024	0.003 ± 0.016	5	0.035 ± 0.021	0.016 ± 0.018

(a) Maximum values ±2 sigma counting error. Averages ±2 standard error of the calculated mean.
(b) Refer to Figure 4.32.

TABLE C.24. Radionuclide Concentrations in Muscle Tissue of Mallard Ducks in 1988

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
100-N Area	4	0.006 ± 0.005	0.001 ± 0.003	4	0.03 ± 0.03	0.01 ± 0.02
200 Area B Pond				14	4.1 ± 0.1	0.96 ± 0.68
200 Area West Lake	4	0.010 ± 0.004	0.005 ± 0.004	4	0.62 ± 0.07	0.31 ± 0.30
300 Area Trench				4	0.44 ± 0.03	0.28 ± 0.19

(a) Maximum and minimum values ±2 sigma counting error. Average ±2 standard error of the calculated mean.
(b) Refer to Figure 4.32.

TABLE C.25. Radionuclide Concentrations in Bone, Muscle, and Liver Tissue of Rabbits in 1988

Type/Location[b]	^{90}Sr (Bone), pCi/g, wet weight[a]			^{137}Cs (Muscle), pCi/g, wet weight[a]			$^{239,240}Pu$ (Liver), pCi/g, wet weight[a]		
	No. of Samples	Maximum	Average	No. of Samples	Maximum	Average	No. of Samples	Maximum	Average
Cottontail									
100-N Area	2	180 ± 3	110 ± 200	2	0.079 ± 0.092	0.072 ± 0.053	2	6.7 ± 0.1	3.4 ± 8.4
Jack Rabbit									
200-W Area	1	—	2.6 ± 0.2	1	—	0.021 ± 0.034	1	—	0.003 ± 0.002
200-E Area	3	19 ± 1	12 ± 11	3	0.032 ± 0.015	0.027 ± 0.015	3	0.001 ± 0.001	0.001 ± 0.001

(a) Maximum values ± 2 sigma counting error. Averages ±2 standard error of the calculated mean or ±2 sigma counting error if single sample.
(b) Refer to Figure 4.32.

TABLE C.26. Strontium-90 (^{90}Sr) Concentrations in Soil

Location	Map Location[b]	pCi/g (dry weight)[a] 1983	1984	1985	1986	1987	1988
ON SITE							
1 Mile NE of 100-N Area	1	0.70 ± 0.023	0.29 ± 0.017	0.28 ± 0.058	0.24 ± 0.01	—[c]	0.11 ± 0.01
1 Mile E of 100-N Area	2	0.85 ± 0.026	0.22 ± 0.010	0.44 ± 0.091	0.22 ± 0.01	0.31 ± 0.01	0.22 ± 0.01
100 Area Fire Station	3	1.7 ± 0.033	0.45 ± 0.020	0.57 ± 0.11	0.34 ± 0.01	0.33 ± 0.01	0.28 ± 0.02
200-East NC	4	2.7 ± 0.047	0.20 ± 0.19	1.2 ± 0.23	0.61 ± 0.01	1.1 ± 0.1	0.77 ± 0.02
E of 200-East	5	0.78 ± 0.033	0.73 ± 0.48	0.90 ± 0.18	0.39 ± 0.01	0.34 ± 0.02	0.57 ± 0.02
200-East SE	6	1.3 ± 0.028	0.44 ± 0.060	0.20 ± 0.042	0.27 ± 0.01	0.24 ± 0.02	0.59 ± 0.02
SW of BC Cribs	7	0.79 ± 0.033	0.12 ± 0.050	0.39 ± 0.079	0.11 ± 0.01	0.02 ± 0.01	0.04 ± 0.01
S of 200-East	8	0.38 ± 0.020	0.50 ± 0.11	0.14 ± 0.030	0.54 ± 0.01	0.11 ± 0.01	0.23 ± 0.01
E of 200-West	9	2.6 ± 0.048	0.33 ± 0.020	0.61 ± 0.12	0.56 ± 0.01	0.38 ± 0.02	0.71 ± 0.27
2 Miles S of 200-West	10	0.28 ± 0.015	0.14 ± 0.020	0.37 ± 0.078	0.23 ± 0.02	—	0.14 ± 0.01
NE of FFTF	11	0.52 ± 0.020	0.18 ± 0.021	0.17 ± 0.039	—	0.09 ± 0.01	0.09 ± 0.01
SE of FFTF	12	0.54 ± 0.019	0.032 ± 0.054	0.20 ± 0.042	0.44 ± 0.01	—	0.07 ± 0.01
N of 300 Area	13	0.73 ± 0.023	0.58 ± 0.029	0.32 ± 0.068	0.18 ± 0.02	0.24 ± 0.01	0.13 ± 0.01
Hanford Townsite	14	1.9 ± 0.048	0.31 ± 0.029	0.25 ± 0.052	—	0.29 ± 0.01	0.13 ± 0.01
Wye Barricade	15	0.81 ± 0.026	0.31 ± 0.040	0.31 ± 0.062	—	0.18 ± 0.01	0.14 ± 0.01
ONSITE AVERAGE		1.1 ± 0.40	0.32 ± 0.10	0.42 ± 0.15	0.31 ± 0.11	0.31 ± 0.16	0.31 ± 0.13
OFF SITE							
Riverview	16	0.90 ± 0.044	0.039 ± 0.012	0.074 ± 0.019	0.06 ± 0.01	0.19 ± 0.01	0.23 ± 0.01
Byers Landing	17	0.30 ± 0.020	0.064 ± 0.008	0.18 ± 0.016	0.17 ± 0.01	0.08 ± 0.01	0.10 ± 0.01
Sagemoor	18	0.28 ± 0.017	0.25 ± 0.046	0.081 ± 0.019	0.11 ± 0.02	0.04 ± 0.01	0.20 ± 0.01
Taylor Flats No. 2	19	0.23 ± 0.039	0.042 ± 0.008	0.046 ± 0.013	0.36 ± 0.02	0.10 ± 0.01	0.06 ± 0.01
W End Fir Road	20	1.20 ± 0.031	0.14 ± 0.015	0.091 ± 0.022	0.12 ± 0.02	0.05 ± 0.01	0.08 ± 0.01
Ringold	21	1.80 ± 0.032	0.24 ± 0.014	0.20 ± 0.042	0.26 ± 0.02	0.21 ± 0.01	0.26 ± 0.01
Berg Ranch	22	0.92 ± 0.023	0.20 ± 0.019	0.15 ± 0.033	0.20 ± 0.01	0.20 ± 0.01	0.10 ± 0.01
Wahluke Slope No. 2[d]	23	0.65 ± 0.023	0.16 ± 0.017	0.21 ± 0.046	0.10 ± 0.01	0.07 ± 0.01	0.09 ± 0.01
Vernita Bridge[d]	24	0.52 ± 0.017	0.17 ± 0.015	0.31 ± 0.064	0.09 ± 0.01	—	0.07 ± 0.01
Yakima Barricade[d]	25	0.59 ± 0.023	0.13 ± 0.017	0.54 ± 0.109	—	0.06 ± 0.01	0.07 ± 0.01
Rattlesnake Springs[d]	26	0.89 ± 0.033	0.075 ± 0.009	0.33 ± 0.069	0.18 ± 0.01	0.12 ± 0.01	0.04 ± 0.01
ALE[d]	27	1.60 ± 0.032	0.36 ± 0.039	0.61 ± 0.12	—	0.40 ± 0.03	0.34 ± 0.01
Prosser Barricade[d]	28	1.10 ± 0.027	0.36 ± 0.020	0.45 ± 0.092	0.17 ± 0.01	—	0.11 ± 0.01
S of 300 Area[d]	29	1.4 ± 0.039	0.35 ± 0.015	0.51 ± 0.10	0.31 ± 0.01	—	0.27 ± 0.01
Benton City	30	0.42 ± 0.018	0.36 ± 0.031	0.12 ± 0.027	0.25 ± 0.01	0.24 ± 0.01	0.43 ± 0.02
Sunnyside	31	1.60 ± 0.040	0.31 ± 0.029	0.26 ± 0.055	0.05 ± 0.01	0.25 ± 0.02	0.26 ± 0.06
Walla Walla	32			0.31 ± 0.015	0.14 ± 0.08	0.02 ± 0.01	0.04 ± 0.01
McNary Dam	33			0.29 ± 0.019	0.18 ± 0.08	0.07 ± 0.06	0.13 ± 0.01
Moses Lake	34				0.08 ± 0.01	0.06 ± 0.02	0.08 ± 0.01
Washtucna	35				0.40 ± 0.02	0.12 ± 0.12	0.25 ± 0.01
Connell	36				0.32 ± 0.02	0.12 ± 0.11	0.09 ± 0.01
Othello	37				0.27 ± 0.02	0.15 ± 0.08	0.04 ± 0.01
Yakima	38				0.04 ± 0.01	0.06 ± 0.04	0.09 ± 0.01
OFFSITE AVERAGE		1.0 ± 0.29	0.20 ± 0.059	0.26 ± 0.080	0.18 ± 0.05	0.12 ± 0.03	0.16 ± 0.04

(a) Individual results ±2 sigma counting error. Averages ±2 standard error of the calculated mean.
(b) Locations are identified in Figure 4.39.
(c) Locations sampled every other year indicated by dashed line.
(d) Perimeter location on Site near Site boundary.

TABLE C.27. Cesium-137 (^{137}Cs) Concentrations in Soil

Location	Map Location[b]	nCi/g (dry weight)[a] 1983	1984	1985	1986	1987	1988
ON SITE							
1 Mile NE of 100-N Area	1	0.48 ± 0.04	0.70 ± 0.05	0.76 ± 0.065	0.81 ± 0.05	—[c]	0.80 ± 0.05
1 Mile E of 100-N Area	2	0.77 ± 0.05	0.67 ± 0.04	0.62 ± 0.057	0.55 ± 0.04	1.1 ± 0.1	0.74 ± 0.05
100 Area Fire Station	3	1.40 ± 0.07	0.98 ± 0.06	1.2 ± 0.082	1.6 ± 0.1	1.3 ± 0.1	1.2 ± 0.1
200-East NC	4	28 ± 0.33	21 ± 0.23	23 ± 1.4	9.6 ± 0.2	16 ± 0.1	26. ± 0.1
E of 200-East	5	1.30 ± 0.07	1.4 ± 0.06	3.0 ± 0.20	1.4 ± 0.1	0.69 ± 0.04	1.8 ± 0.1
200-East SE	6	0.16 ± 0.03	0.54 ± 0.04	0.55 ± 0.048	0.37 ± 0.03	0.61 ± 0.04	1.6 ± 0.1
SW of BC Cribs	7	0.31 ± 0.03	0.06 ± 0.02	0.14 ± 0.022	0.12 ± 0.02	0.01 ± 0.02	0.04 ± 0.02
S of 200-East	8	0.15 ± 0.03	0.14 ± 0.02	0.56 ± 0.053	0.71 ± 0.04	0.13 ± 0.03	0.58 ± 0.04
E of 200-West	9	5.70 ± 0.15	0.59 ± 0.04	2.0 ± 0.069	3.1 ± 0.1	1.3 ± 0.1	5.4 ± 1.7
2 Miles S of 200 West	10	0.07 ± 0.02	0.17 ± 0.03	0.30 ± 0.030	0.50 ± 0.04	—	0.49 ± 0.04
NE of FFTF	11	0.18 ± 0.03	0.12 ± 0.02	0.080 ± 0.028	—	0.33 ± 0.03	0.24 ± 0.03
SE of FFTF	12	0.20 ± 0.04	0.08 ± 0.02	0.083 ± 0.022	0.04 ± 0.02	—	0.12 ± 0.02
N of 300 Area	13	0.53 ± 0.04	0.43 ± 0.04	0.46 ± 0.052	0.54 ± 0.45	1.2 ± 0.1	0.51 ± 0.04
Hanford Townsite	14	1.00 ± 0.07	0.91 ± 0.05	1.1 ± 0.086	—	1.1 ± 0.1	0.88 ± 0.06
Wye Barricade	15	0.84 ± 0.05	0.68 ± 0.04	13 ± 0.098	—	0.59 ± 0.04	0.56 ± 0.04
ONSITE AVERAGE		2.8 ± 3.7	1.9 ± 2.8	2.3 ± 3.0	1.5 ± 1.4	2.0 ± 2.6	2.9 ± 3.2
OFF SITE							
Riverview	16	1.2 ± 0.07	0.077 ± 0.021	0.21 ± 0.026	0.17 ± 0.04	0.86 ± 0.05	1.3 ± 0.1
Byers Landing	17	0.59 ± 0.05	0.20 ± 0.03	0.19 ± 0.035	0.50 ± 0.04	0.23 ± 0.03	0.52 ± 0.03
Sagemoor	18	0.14 ± 0.03	1.0 ± 0.06	0.10 ± 0.023	0.32 ± 0.04	0.12 ± 0.02	1.0 ± 0.1
Taylor Flats No. 2	19	2.2 ± 0.07	0.084 ± 0.031	0.085 ± 0.028	1.2 ± 0.1	0.60 ± 0.06	0.39 ± 0.04
W End Fir Road	20	0.25 ± 0.03	0.12 ± 0.03	0.14 ± 0.025	0.25 ± 0.03	0.23 ± 0.04	0.28 ± 0.03
Ringold	21	1.6 ± 0.08	0.44 ± 0.044	1.1 ± 0.046	0.40 ± 0.04	1.0 ± 0.1	1.8 ± 0.06
Berg Ranch	22	0.61 ± 0.05	0.49 ± 0.046	0.58 ± 0.052	0.60 ± 0.05	0.31 ± 0.04	0.35 ± 0.03
Wahluke Slope No. 2[d]	23	0.25 ± 0.03	0.29 ± 0.03	0.47 ± 0.047	0.30 ± 0.03	0.16 ± 0.03	0.22 ± 0.03
Vernita Bridge[d]	24	0.27 ± 0.03	0.46 ± 0.037	0.20 ± 0.03	—	—	0.19 ± 0.04
Yakima Barricade[d]	25	0.70 ± 0.033	0.10 ± 0.028	1.1 ± 0.066	—	0.08 ± 0.02	0.08 ± 0.02
Rattlesnake Springs[d]	26	0.52 ± 0.05	0.14 ± 0.03	0.46 ± 0.037	0.37 ± 0.04	0.32 ± 0.04	0.08 ± 0.02
ALE[d]	27	1.5 ± 0.07	0.55 ± 0.04	1.6 ± 0.069	—	1.1 ± 0.1	1.0 ± 0.1
Prosser Barricade[d]	28	0.77 ± 0.05	0.15 ± 0.03	0.73 ± 0.045	0.32 ± 0.03	—	0.33 ± 0.03
S of 300 Area[d]	29	1.1 ± 0.06	1.1 ± 0.06	0.88 ± 0.072	0.68 ± 0.04	—	0.77 ± 0.04
Benton City	30	0.54 ± 0.05	0.53 ± 0.04	0.87 ± 0.064	0.79 ± 0.05	0.65 ± 0.04	0.91 ± 0.06
Sunnyside	31	1.1 ± 0.06	1.5 ± 0.071	0.29 ± 0.036	0.09 ± 0.03	0.29 ± 0.04	1.0 ± 0.3
Walla Walla	32			0.29 ± 0.024	0.25 ± 0.03	0.07 ± 0.02	0.23 ± 0.03
McNary Dam	33			0.52 ± 0.040	0.28 ± 0.03	0.30 ± 0.47	0.48 ± 0.04
Moses Lake	34				0.24 ± 0.03	0.16 ± 0.09	0.38 ± 0.04
Washtucna	35				1.2 ± 0.1	0.38 ± 0.17	0.97 ± 0.06
Connell	36				1.7 ± 0.1	0.35 ± 0.61	0.46 ± 0.04
Othello	37				0.26 ± 0.2	0.76 ± 0.42	0.22 ± 0.03
Yakima	38				0.11 ± 0.1	0.16 ± 0.06	0.11 ± 0.02
OFFSITE AVERAGE		0.85 ± 0.28	0.44 ± 0.21	0.56 ± 0.19	0.80 ± 0.68	0.38 ± 0.12	0.59 ± 0.18

(a) Individual results ±2 sigma counting error. Averages ±2 standard error of the calculated mean.
(b) Locations are identified in Figure 4.39.
(c) Locations sampled every other year indicated by dashed line.
(d) Perimeter location on Site near Site boundary.

TABLE C.28. Plutonium-239,240 ($^{239,240}Pu$) Concentrations in Soil

Location	Map Location[b]	1983	1984	1985	1986	1987	1988
		pCi/g dry weight[a]					
ON SITE							
1 Mile NE of 100-N Area	1	0.012 ± 0.0030	0.015 ± 0.0020	0.016 ± 0.0016	0.015 ± 0.001	—[c]	0.011 ± 0.001
1 Mile E of 100-N Area	2	0.0069 ± 0.0014	0.016 ± 0.0027	0.013 ± 0.0011	0.012 ± 0.001	0.023 ± 0.002	0.019 ± 0.002
100 Area Fire Station	3	0.0022 ± 0.0015	0.021 ± 0.0017	0.024 ± 0.0016	0.030 ± 0.002	0.017 ± 0.001	0.027 ± 0.002
200-East NC	4	0.051 ± 0.0065	0.033 ± 0.0040	0.030 ± 0.0019	0.015 ± 0.002	0.031 ± 0.002	0.066 ± 0.003
E of 200-East	5	0.011 ± 0.002	0.012 ± 0.0015	0.026 ± 0.0017	0.011 ± 0.001	0.009 ± 0.001	0.017 ± 0.001
200-East SE	6	0.028 ± 0.0050	0.0091 ± 0.0017	0.022 ± 0.0016	0.008 ± 0.001	0.012 ± 0.001	0.036 ± 0.002
SW of BC Cribs	7	0.0076 ± 0.0012	0.0034 ± 0.0019	0.024 ± 0.0022	0.004 ± 0.001	0.001 ± 0.001	0.001 ± 0.001
S of 200-East	8	0.0088 ± 0.0017	0.0056 ± 0.0031	0.0041 ± 0.0014	0.007 ± 0.001	0.003 ± 0.001	0.013 ± 0.001
E of 200-West	9	0.83 ± 0.027	0.074 ± 0.0040	0.33 ± 0.0069	0.34 ± 0.001	0.17 ± 0.01	0.67 ± 0.12
2 Miles S of 200-West	10	0.0006 ± 0.00095	0.0036 ± 0.0019	0.0094 ± 0.0011	0.013 ± 0.001	—	0.015 ± 0.001
NE of FFTF	11	0.0029 ± 0.0007	0.0021 ± 0.0007	0.0025 ± 0.0005	—	0.006 ± 0.001	0.005 ± 0.001
SE of FFTF	12	0.0042 ± 0.0018	0.0067 ± 0.0011	0.0021 ± 0.0005	0.001 ± 0.001	—	0.003 ± 0.001
N of 300 Area	13	0.013 ± 0.002	0.0064 ± 0.0029	0.010 ± 0.0011	0.008 ± 0.001	0.014 ± 0.001	0.011 ± 0.001
Hanford Townsite	14	0.021 ± 0.004	0.016 ± 0.0030	0.0059 ± 0.0009	—	0.019 ± 0.002	0.021 ± 0.002
Wye Barricade	15	0.017 ± 0.0022	0.014 ± 0.0020	0.017 ± 0.0015	—	0.011 ± 0.001	0.008 ± 0.001
ONSITE AVERAGE		0.068 ± 0.11	0.016 ± 0.0090	0.035 ± 0.042	0.038 ± 0.005	0.026 ± 0.027	0.10 ± 0.11
OFF SITE							
Riverview	16	0.021 ± 0.005	0.0018 ± 0.0016	0.0052 ± 0.0098	0.003 ± 0.001	0.015 ± 0.001	0.022 ± 0.002
Byers Landing	17	0.012 ± 0.002	0.0066 ± 0.0040	0.0027 ± 0.0006	0.008 ± 0.001	0.003 ± 0.001	0.009 ± 0.001
Sagemoor	18	0.0079 ± 0.0015	0.019 ± 0.0021	0.0018 ± 0.0005	0.006 ± 0.001	0.002 ± 0.001	0.020 ± 0.002
Taylor Flats No. 2	19	0.031 ± 0.005	0.0014 ± 0.0005	0.0008 ± 0.0003	0.021 ± 0.003	0.019 ± 0.002	0.004 ± 0.001
W End Fir Road	20	0.0059 ± 0.0017	0.0022 ± 0.0015	0.0017 ± 0.0005	0.004 ± 0.001	0.003 ± 0.001	0.004 ± 0.001
Ringold	21	0.028 ± 0.005	0.0075 ± 0.0012	0.017 ± 0.0016	0.006 ± 0.001	0.017 ± 0.002	0.033 ± 0.002
Berg Ranch	22	0.014 ± 0.003	0.0097 ± 0.0015	0.011 ± 0.0011	0.012 ± 0.002	0.006 ± 0.001	0.008 ± 0.001
Wahluke Slope No. 2[d]	23	0.010 ± 0.002	0.0061 ± 0.0029	0.0087 ± 0.0015	0.006 ± 0.001	0.003 ± 0.001	0.007 ± 0.001
Vernita Bridge[d]	24	0.015 ± 0.0026	0.0060 ± 0.0024	0.0095 ± 0.0010	0.003 ± 0.001	—	0.003 ± 0.001
Yakima Barricade[d]	25	0.014 ± 0.002	0.0016 ± 0.0011	0.022 ± 0.0015	—	0.002 ± 0.001	0.003 ± 0.001
Rattlesnake Springs[d]	26	0.026 ± 0.0049	0.0032 ± 0.0016	0.0085 ± 0.0009	0.006 ± 0.001	0.006 ± 0.001	0.003 ± 0.001
ALE[d]	27	0.031 ± 0.005	0.0091 ± 0.0014	0.034 ± 0.0021	—	0.024 ± 0.002	0.026 ± 0.002
Prosser Barricade[d]	28	0.020 ± 0.004	0.0039 ± 0.0016	0.019 ± 0.0019	0.008 ± 0.001	—	0.006 ± 0.001
S of 300 Area[d]	29	0.022 ± 0.0013	0.022 ± 0.0023	0.018 ± 0.0015	0.015 ± 0.001	—	0.017 ± 0.001
Benton City	30	0.015 ± 0.0017	0.0099 ± 0.0015	0.019 ± 0.0020	0.016 ± 0.001	0.014 ± 0.001	0.014 ± 0.002
Sunnyside	31	0.026 ± 0.005	0.025 ± 0.0026	0.015 ± 0.0016	0.002 ± 0.001	0.006 ± 0.001	0.023 ± 0.006
Walla Walla	32			0.013 ± 0.0012	0.005 ± 0.001	0.002 ± 0.002	0.003 ± 0.001
McNary Dam	33			0.015 ± 0.0023	0.007 ± 0.001	0.006 ± 0.008	0.009 ± 0.001
Moses Lake	34				0.016 ± 0.001	0.002 ± 0.001	0.008 ± 0.001
Washtucna	35				0.024 ± 0.002	0.006 ± 0.003	0.016 ± 0.001
Connell	36				0.027 ± 0.002	0.007 ± 0.011	0.008 ± 0.001
Othello	37				0.004 ± 0.001	0.013 ± 0.011	0.004 ± 0.001
Yakima	38				0.002 ± 0.001	0.003 ± 0.003	0.003 ± 0.001
OFFSITE AVERAGE		0.019 ± 0.004	0.0084 ± 0.0037	0.012 ± 0.0046	0.009 ± 0.003	0.007 ± 0.002	0.011 ± 0.004

(a) Individual results ±2 sigma counting error. Averages ±2 standard error of the calculated mean.
(b) Locations are identified in Figure 4.39.
(c) Locations sampled every other year indicated by dashed line.
(d) Perimeter location on Site near Site boundary.

TABLE C.29. Uranium Concentrations in Soil

Location	Map Location[d]	Total Uranium[a] pCi/g (dry weight)[b] 1983	1984	1985	1986	1987	U-238[c] pCi/g (dry weight)[b] 1988
ON SITE							
1 Mile NE of 100-N	1	0.39 ± 0.109	0.42 ± 0.11	0.49 ± 0.16	0.19 ± 0.06	—[e]	0.78 ± 0.45
1 Mile E of 100-N	2	0.28 ± 0.077	0.32 ± 0.088	0.40 ± 0.13	0.45 ± 0.13	0.34 ± 0.10	0.71 ± 0.44
100 Area Fire Station	3	0.22 ± 0.061	0.45 ± 0.12	0.44 ± 0.15	0.53 ± 0.15	0.35 ± 0.10	0.88 ± 0.30
200-East NC	4	0.25 ± 0.071	0.36 ± 0.098	0.39 ± 0.13	0.28 ± 0.08	0.23 ± 0.06	0.64 ± 0.50
E of 200-East	5	0.26 ± 0.07	0.32 ± 0.08	0.46 ± 0.15	0.47 ± 0.13	0.31 ± 0.09	1.2 ± 0.3
200-East SE	6	0.20 ± 0.057	0.37 ± 0.070	0.39 ± 0.13	0.03 ± 0.08	0.25 ± 0.07	1.2 ± 0.3
SW of BC Cribs	7	0.28 ± 0.078	1.0 ± 0.15	0.33 ± 0.11	0.32 ± 0.09	0.19 ± 0.05	0.61 ± 0.48
S of 200-East	8	0.18 ± 0.05	0.46 ± 0.22	0.34 ± 0.11	0.32 ± 0.09	0.22 ± 0.06	0.66 ± 0.33
E of 200-West	9	0.53 ± 0.15	0.53 ± 0.29	0.43 ± 0.14	0.48 ± 0.13	0.39 ± 0.11	0.77 ± 0.31
2 Miles S of 200-West	10	0.26 ± 0.074	0.34 ± 0.092	0.47 ± 0.16	0.49 ± 0.14	—	0.65 ± 0.33
NE of FFTF	11	0.25 ± 0.068	0.30 ± 0.082	0.39 ± 0.13	—	0.24 ± 0.07	0.54 ± 0.45
SE of FFTF	12	0.16 ± 0.046	0.27 ± 0.073	0.40 ± 0.13	0.37 ± 0.11	—	0.76 ± 0.32
N of 300 Area	13	0.50 ± 0.14	0.76 ± 0.20	3.9 ± 1.1	0.66 ± 0.19	3.8 ± 1.1	0.90 ± 0.47
Hanford Townsite	14	0.24 ± 0.067	0.34 ± 0.093	0.35 ± 0.12	—	0.42 ± 0.12	0.44 ± 0.46
Wye Barricade	15	0.19 ± 0.053	0.65 ± 0.10	0.29 ± 0.097	—	0.19 ± 0.05	0.45 ± 0.45
ONSITE AVERAGE		0.28 ± 0.061	0.46 ± 0.11	0.82 ± 0.66	0.40 ± 0.08	0.58 ± 0.59	0.74 ± 0.15
OFF SITE							
Riverview	16	0.37 ± 0.10	0.32 ± 0.085	0.44 ± 0.14	0.26 ± 0.07	0.30 ± 0.08	0.90 ± 0.46
Byers Landing	17	0.32 ± 0.09	0.43 ± 0.11	0.39 ± 0.13	0.26 ± 0.07	0.10 ± 0.03	0.90 ± 0.48
Sagemoor	18	0.38 ± 0.11	0.50 ± 0.13	0.58 ± 0.18	0.31 ± 0.08	0.24 ± 0.07	0.63 ± 0.31
Taylor Flats No. 2	19	0.47 ± 0.13	1.0 ± 0.26	1.3 ± 0.36	0.44 ± 0.12	0.97 ± 0.27	0.93 ± 0.55
W End Fir Road	20	0.47 ± 0.13	0.54 ± 0.14	0.73 ± 0.22	0.32 ± 0.09	0.55 ± 0.15	0.86 ± 0.34
Ringold	21	0.37 ± 0.10	0.78 ± 0.21	0.84 ± 0.26	1.1 ± 0.3	0.67 ± 0.19	0.83 ± 0.35
Berg Ranch	22	0.24 ± 0.07	0.41 ± 0.11	0.43 ± 0.14	0.28 ± 0.08	0.38 ± 0.11	0.55 ± 0.46
Wahluke Slope No. 2[f]	23	0.35 ± 0.10	0.43 ± 0.12	0.35 ± 0.12	0.21 ± 0.06	0.17 ± 0.05	0.68 ± 0.49
Vernita Bridge[f]	24	0.37 ± 0.10	0.92 ± 0.26	0.73 ± 0.22	0.34 ± 0.09	—	0.58 ± 0.32
Yakima Barricade[f]	25	0.26 ± 0.071	0.21 ± 0.056	0.35 ± 0.12	—	0.27 ± 0.08	1.0 ± 0.5
Rattlesnake Springs[f]	26	0.25 ± 0.07	0.26 ± 0.069	0.44 ± 0.14	0.26 ± 0.07	0.28 ± 0.08	0.78 ± 0.45
ALE[f]	27	0.28 ± 0.08	0.25 ± 0.067	0.46 ± 0.15	—	0.45 ± 0.13	0.68 ± 0.36
Prosser Barricade[f]	28	0.25 ± 0.07	0.36 ± 0.06	0.80 ± 0.24	0.25 ± 0.07	—	0.81 ± 0.43
S of 300 Area[f]	29	0.31 ± 0.08	1.0 ± 0.29	0.66 ± 0.21	0.56 ± 0.16	—	0.94 ± 0.33
Benton City	30	0.44 ± 0.12	0.91 ± 0.24	0.64 ± 0.20	0.45 ± 0.12	0.39 ± 0.11	1.1 ± 0.4
Sunnyside	31	0.20 ± 0.05	0.26 ± 0.071	0.26 ± 0.090	0.31 ± 0.09	0.29 ± 0.08	0.70 ± 0.39
Walla Walla	32			0.20 ± 0.071	0.35 ± 0.10	0.62 ± 0.17	0.66 ± 0.34
McNary Dam	33			0.15 ± 0.055	0.41 ± 0.12	0.32 ± 0.09	0.59 ± 0.33
Moses Lake	34				0.11 ± 0.03	0.19 ± 0.05	0.42 ± 0.29
Washtucna	35				0.20 ± 0.06	0.24 ± 0.07	0.73 ± 0.39
Connell	36				0.25 ± 0.07	0.32 ± 0.09	0.53 ± 0.30
Othello	37				0.21 ± 0.06	0.24 ± 0.06	0.58 ± 0.30
Yakima	38				0.48 ± 0.14	0.41 ± 0.11	1.0 ± 0.5
OFFSITE AVERAGE		0.32 ± 0.048	0.54 ± 0.15	0.54 ± 0.14	0.35 ± 0.09	0.36 ± 0.07	0.75 ± 0.11

(a) Total uranium leached from sample.
(b) Individual results ±2 sigma counting error. Averages ±2 standard error of the calculated mean.
(c) U-238 by Low Energy Photon Detector (LEPD) method.
(d) Locations are identified in Figure 4.39.
(e) Locations sampled every other year indicated by dashed line.
(f) Perimeter location on Site near Site boundary.

TABLE C.30. Strontium-90 (^{90}Sr) Concentrations in Vegetation

Location	Map Location[b]	pCi/g (dry weight)[a] 1983	1984	1985	1986	1987	1988
ON SITE							
1 Mile NE of 100-N Area	1	0.11 ± 0.017	0.069 ± 0.007	0.078 ± 0.072	NS	—[c]	0.050 ± 0.007
1 Mile E of 100-N Area	2	0.29 ± 0.018	0.12 ± 0.012	0.012 ± 0.0012	0.14 ± 0.01	0.038 ± 0.008	0.049 ± 0.005
100-Area Fire Station	3	0.37 ± 0.020	0.11 ± 0.011	0.17 ± 0.017	0.14 ± 0.01	0.010 ± 0.005	0.041 ± 0.005
200-East NC	4	0.63 ± 0.024	0.39 ± 0.020	0.41 ± 0.018	0.38 ± 0.01	0.13 ± 0.01	0.096 ± 0.007
E of 200-East	5	0.91 ± 0.030	0.20 ± 0.030	0.25 ± 0.019	0.18 ± 0.01	0.24 ± 0.02	0.12 ± 0.01
200-East SE	6	0.91 ± 0.031	0.20 ± 0.013	0.53 ± 0.018	8.2 ± 0.1	0.086 ± 0.010	0.066 ± 0.006
SW of BC Cribs	7	0.34 ± 0.016	0.11 ± 0.030	0.41 ± 0.016	NS	0.071 ± 0.009	0.092 ± 0.007
S of 200-East	8	0.53 ± 0.017	1.1 ± 0.066	0.44 ± 0.022	0.14 ± 0.01	0.089 ± 0.010	0.14 ± 0.01
E of 200-West	9	0.47 ± 0.022	0.13 ± 0.020	1.1 ± 0.026	0.13 ± 0.01	0.10 ± 0.01	0.078 ± 0.008
2 Miles S of 200-West	10	0.34 ± 0.016	0.19 ± 0.007	0.89 ± 0.035	0.14 ± 0.01	—	0.046 ± 0.006
NE of FFTF	11	1.2 ± 0.037	0.022 ± 0.006	0.28 ± 0.015	—	0.025 ± 0.005	0.014 ± 0.004
SE of FFTF	12	1.7 ± 0.040	0.088 ± 0.009	0.28 ± 0.019	NS	—	0.016 ± 0.005
N of 300 Area	13	0.93 ± 0.029	0.023 ± 0.004	0.13 ± 0.016	0.26 ± 0.01	0.021 ± 0.004	0.008 ± 0.003
Hanford Townsite	14	0.29 ± 0.015	0.044 ± 0.006	0.18 ± 0.013	—	0.087 ± 0.009	0.081 ± 0.006
Wye Barricade	15	0.16 ± 0.012	0.016 ± 0.007	0.15 ± 0.012	—	0.012 ± 0.004	0.034 ± 0.005
ONSITE AVERAGE		0.61 ± 0.22	0.19 ± 0.14	0.36 ± 0.16	1.1 ± 1.8	0.075 ± 0.004	0.062 ± 0.020
OFF SITE							
Riverview	16	1.1 ± 0.033	0.015 ± 0.010	0.069 ± 0.085	0.039 ± 0.004	0.018 ± 0.005	0.014 ± 0.005
Byers Landing	17	0.12 ± 0.006	0.018 ± 0.008	0.057 ± 0.089	0.074 ± 0.006	0.007 ± 0.005	0.052 ± 0.006
Sagemoor	18	0.006 ± 0.017	0.067 ± 0.012	0.097 ± 0.011	NS	0.046 ± 0.008	0.010 ± 0.005
Taylor Flats No. 2	19	0.037 ± 0.024	0.063 ± 0.010	0.10 ± 0.010	0.054 ± 0.006	0.064 ± 0.010	0.047 ± 0.006
W End Fir Road	20	0.086 ± 0.020	0.047 ± 0.016	0.076 ± 0.088	0.062 ± 0.005	0.040 ± 0.007	0.013 ± 0.005
Ringold	21	0.65 ± 0.026	0.051 ± 0.010	0.066 ± 0.0081	0.059 ± 0.005	0.012 ± 0.005	0.048 ± 0.007
Berg Ranch	22	0.023 ± 0.027	0.092 ± 0.026	0.050 ± 0.079	NS	0.036 ± 0.009	0.043 ± 0.006
Wahluke Slope No. 2[d]	23	0.018 ± 0.016	0.046 ± 0.013	0.15 ± 0.012	NS	0.038 ± 0.008	0.046 ± 0.005
Vernita Bridge[d]	24	0.10 ± 0.011	0.073 ± 0.011	0.21 ± 0.011	NS	—	0.034 ± 0.005
Yakima Barricade[d]	25	0.04 ± 0.008	0.022 ± 0.003	0.21 ± 0.011	—	0.034 ± 0.007	0.021 ± 0.003
Rattlesnake Springs[d]	26	0.69 ± 0.026	0.087 ± 0.011	1.7 ± 0.033	0.14 ± 0.01	0.073 ± 0.009	0.016 ± 0.004
ALE[d]	27	0.017 ± 0.023	0.082 ± 0.007	0.095 ± 0.090	—	0.036 ± 0.006	0.017 ± 0.005
Prosser Barricade[d]	28	0.021 ± 0.022	0.12 ± 0.009	NS	0.084 ± 0.07	—	0.067 ± 0.006
S of 300 Area[d]	29	0.05 ± 0.011	0.047 ± 0.005	0.091 ± 0.014	0.10 ± 0.01	—	0.036 ± 0.005
Benton City	30	0.12 ± 0.013	0.055 ± 0.016	0.30 ± 0.013	0.14 ± 0.01	0.045 ± 0.009	0.025 ± 0.004
Sunnyside	31	0.18 ± 0.016	0.037 ± 0.008	0.061 ± 0.075	0.044 ± 0.00	0.061 ± 0.008	0.067 ± 0.006
Walla Walla	32					0.039 ± 0.008	0.031 ± 0.005
McNary Dam	33					0.007 ± 0.003	0.065 ± 0.006
Moses Lake	34					0.023 ± 0.008	0.020 ± 0.005
Washtucna	35					0.091 ± 0.011	0.052 ± 0.006
Connell	36					0.024 ± 0.005	0.018 ± 0.004
Othello	37					0.053 ± 0.007	0.046 ± 0.006
Yakima	38					0.024 ± 0.006	0.019 ± 0.005
OFFSITE AVERAGE		0.20 ± 0.16	0.057 ± 0.015	0.22 ± 0.21	0.080 ± 0.023	0.038 ± 0.010	0.035 ± 0.008

(a) Individual results ±2 sigma counting error. Averages ±2 standard error of the calculated mean.
(b) Locations are identified in Figure 4.39.
(c) Locations sampled every other year indicated by dashed line.
(d) Perimeter location on Site near Site boundary.
NS No sample.

TABLE C.31. Cesium-137 (^{137}Cs) Concentrations in Vegetation

Location	Map Location[b]	pCi/g dry weight[a] 1983	1984	1985	1986	1987	1988
ON SITE							
1 Mile NE of 100-N Area	1	0.003 ± 0.012	0.0097 ± 0.014	0.015 ± 0.011	0.027 ± 0.017	—[c]	0.009 ± 0.14
1 Mile E of 100-N Area	2	0.026 ± 0.008	0.0032 ± 0.013	0.003 ± 0.025	0.007 ± 0.022	0.21 ± 0.03	0.024 ± 0.015
100-Area Fire Station	3	0.015 ± 0.008	0.015 ± 0.012	0.016 ± 0.014	0.034 ± 0.0177	0.11 ± 0.02	0.018 ± 0.014
200-East NC	4	0.18 ± 0.014	0.24 ± 0.020	0.36 ± 0.042	0.20 ± 0.03	0.32 ± 0.03	0.25 ± 0.02
E of 200-East	5	0.069 ± 0.010	0.069 ± 0.013	0.12 ± 0.030	0.11 ± 0.03	0.11 ± 0.02	0.057 ± 0.016
200-East SE	6	0.053 ± 0.009	0.079 ± 0.017	0.078 ± 0.020	0.10 ± 0.02	0.11 ± 0.02	0.022 ± 0.014
SW of BC Cribs	7	0.0085 ± 0.0055	0.018 ± 0.013	0.038 ± 0.016	0.011 ± 0.017	0.052 ± 0.018	-0.005 ± 0.015
S of 200-East	8	0.019 ± 0.007	0.022 ± 0.011	0.068 ± 0.015	0.029 ± 0.017	0.035 ± 0.020	0.004 ± 0.020
E of 200-West	9	-0.03 ± 0.009	0.055 ± 0.016	0.052 ± 0.017	0.032 ± 0.020	0.054 ± 0.019	0.034 ± 0.016
2 Miles S of 200-West	10	0.025 ± 0.009	0.011 ± 0.012	0.019 ± 0.023	0.029 ± 0.020	—	0.011 ± 0.018
NE of FFTF	11	-0.02 ± 0.008	0.0064 ± 0.11	0.048 ± 0.020	—	0.056 ± 0.023	0.001 ± 0.016
SE of FFTF	12	0.03 ± 0.009	-0.0095 ± 0.015	0.032 ± 0.018	0.017 ± 0.012	—	0.011 ± 0.016
N of 300 Area	13	0.010 ± 0.006	0.011 ± 0.009	0.024 ± 0.016	0.17 ± 0.51	0.053 ± 0.016	0.003 ± 0.013
Hanford Townsite	14	0.011 ± 0.011	0.010 ± 0.020	0.038 ± 0.022	—	0.097 ± 0.022	0.024 ± 0.013
Wye Barricade	15	-0.01 ± 0.016	0.0037 ± 0.011	0.035 ± 0.015	—	0.053 ± 0.020	0.022 ± 0.012
ONSITE AVERAGE		0.035 ± 0.023	0.034 ± 0.033	0.062 ± 0.045	0.071 ± 0.051	0.10 ± 0.05	0.033 ± 0.033
OFF SITE							
Riverview	16	-0.021 ± 0.007	-0.0001 ± 0.014	-0.0054 ± 0.011	1.1 ± 0.1	0.049 ± 0.016	0.003 ± 0.011
Byers Landing	17	-0.013 ± 0.011	0.024 ± 0.012	0.017 ± 0.011	1.9 ± 0.1	0.049 ± 0.023	0.015 ± 0.015
Sagemoor	18	0.012 ± 0.012	0.003 ± 0.012	0.013 ± 0.014	1.2 ± 0.1	0.035 ± 0.017	0.007 ± 0.017
Taylor Flats No. 2	19	0.025 ± 0.012	0.016 ± 0.013	0.011 ± 0.022	1.7 ± 0.1	0.030 ± 0.015	0.017 ± 0.013
W End Flr Road	20	-0.021 ± 0.010	0.095 ± 0.021	0.022 ± 0.021	1.2 ± 0.1	0.012 ± 0.013	0.013 ± 0.017
Ringold	21	-0.020 ± 0.008	-0.0008 ± 0.013	0.0083 ± 0.013	1.5 ± 0.1	0.031 ± 0.014	0.025 ± 0.014
Berg Ranch	22	-0.014 ± 0.009	0.027 ± 0.011	0.0073 ± 0.014	0.009 ± 0.013	0.11 ± 0.03	0.008 ± 0.016
Wahluke Slope No. 2[d]	23	-0.02 ± 0.008	-0.0012 ± 0.012	0.023 ± 0.013	0.026 ± 0.024	0.075 ± 0.025	0.026 ± 0.017
Vernita Bridge[d]	24	0.014 ± 0.010	0.005 ± 0.010	0.0061 ± 0.015	0.009 ± 0.022	—	0.021 ± 0.014
Yakima Barricade[d]	25	0.012 ± 0.010	0.00 ± 0.013	0.0027 ± 0.015	—	0.018 ± 0.013	-0.006 ± 0.020
Rattlesnake Springs[d]	26	0.004 ± 0.009	0.0054 ± 0.013	0.016 ± 0.014	0.81 ± 0.05	0.047 ± 0.017	0.009 ± 0.013
ALE[d]	27	0.0093 ± 0.0095	-0.0006 ± 0.012	0.022 ± 0.013	—	0.049 ± 0.020	-0.006 ± 0.015
Prosser Barricade[d]	28	0.011 ± 0.008	0.012 ± 0.012	NS	0.004 ± 0.025	—	0.031 ± 0.018
S of 300 Area[d]	29	0.005 ± 0.012	0.0032 ± 0.013	0.013 ± 0.020	0.018 ± 0.023	—	0.014 ± 0.017
Benton City	30	0.022 ± 0.007	0.0041 ± 0.011	0.093 ± 0.021	1.4 ± 0.1	0.002 ± 0.016	0.008 ± 0.020
Sunnyside	31	0.006 ± 0.009	0.018 ± 0.012	0.018 ± 0.015	0.34 ± 0.03	0.004 ± 0.023	0.026 ± 0.012
Walla Walla	32				0.006 ± 0.020	0.029 ± 0.015	0.016 ± 0.020
McNary Dam	33				0.014 ± 0.019	0.042 ± 0.020	0.011 ± 0.014
Moses Lake	34				0.85 ± 0.05	0.079 ± 0.023	-0.001 ± 0.016
Washtucna	35				0.98 ± 0.05	0.023 ± 0.018	0.002 ± 0.016
Connell	36				0.027 ± 0.017	0.029 ± 0.014	0.007 ± 0.018
Othello	37				0.002 ± 0.019	0.012 ± 0.017	-0.001 ± 0.017
Yakima	38				0.21 ± 0.03	0.011 ± 0.015	0.012 ± 0.017
OFFSITE AVERAGE		0.014 ± 0.0041	0.0078 ± 0.0055	0.018 ± 0.012	0.64 ± 0.29	0.039 ± 0.012	0.011 ± 0.005

(a) Individual results ±2 sigma counting error. Averages ±2 standard error of the calculated mean.
(b) Locations are identified in Figure 4.39.
(c) Locations sampled every other year indicated by dashed line.
(d) Perimeter location on Site near Site boundary.
NS No sample.

TABLE C.32. Plutonium-239,240 ($^{239,240}Pu$) Concentrations in Vegetation

Location	Map Location[b]	pCi/dry weight[a] 1993	1994	1995	1996	1997	1998
ON SITE							
1 Mile NE of 100-N	1	0.00000 ± 0.00000	0.0005 ± 0.00015	0.00013 ± 0.00015	NS	—[c]	0.00030 ± 0.00025
1 Mile E of 100-N	2	0.00022 ± 0.00045	0.00012 ± 0.00030	0.00036 ± 0.00020	0.00048 ± 0.00026	0.00061 ± 0.00027	0.0014 ± 0.0005
100 Area Fire Station	3	0.032 ± 0.0020	0.00012 ± 0.00025	0.00032 ± 0.00018	0.00041 ± 0.00029	0.00064 ± 0.00032	0.00024 ± 0.00022
200-East NC	4	0.00028 ± 0.00039	0.00042 ± 0.00022	0.00067 ± 0.00026	0.00070 ± 0.00042	0.0021 ± 0.0005	0.00053 ± 0.00038
E of 200-East	5	0.00066 ± 0.00046	0.00074 ± 0.00066	0.0075 ± 0.0011	0.0010 ± 0.0003	0.0010 ± 0.0003	0.00054 ± 0.00037
200-East SE	6	0.00046 ± 0.00061	0.00093 ± 0.00066	0.0018 ± 0.00043	0.0021 ± 0.0005	0.0012 ± 0.0004	0.00040 ± 0.00037
SW of BC Cribs	7	0.00016 ± 0.00018	0.00054 ± 0.00061	0.00096 ± 0.00032	NS	0.00077 ± 0.00033	0.0011 ± 0.0005
S of 200-East	8	0.00020 ± 0.00025	0.00044 ± 0.00037	0.0025 ± 0.00051	0.0017 ± 0.0004	0.00062 ± 0.00032	0.0017 ± 0.0006
E of 200-West	9	0.0044 ± 0.0010	0.0065 ± 0.0018	0.0060 ± 0.00083	0.0044 ± 0.0012	0.0082 ± 0.0015	0.0032 ± 0.0010
2 Miles S of 200-West	10	0.0021 ± 0.00084	0.0001 ± 0.00020	0.00059 ± 0.00028	0.00094 ± 0.00036	—	0.00039 ± 0.00025
NE of FFTF	11	0.00022 ± 0.00026	0.00036 ± 0.00039	0.00047 ± 0.00023	—	0.00012 ± 0.00012	0.00006 ± 0.00015
SE of FFTF	12	0.00070 ± 0.00069	0.00083 ± 0.00063	0.00049 ± 0.00030	NS	—	0.00016 ± 0.00024
N of 300 Area	13	0.00046 ± 0.00034	0.0022 ± 0.0011	0.00026 ± 0.00014	0.00053 ± 0.00025	0.00021 ± 0.00019	0.00012 ± 0.00016
Hanford Townsite	14	0.0007 ± 0.0010	0.00055 ± 0.00035	0.00042 ± 0.00022	—	0.00016 ± 0.00013	0.00040 ± 0.00023
Wye Barricade	15	0.00026 ± 0.00024	0.00078 ± 0.00088	0.0012 ± 0.00038	—	0.00018 ± 0.00014	0.00009 ± 0.00014
ONSITE AVERAGE		0.0028 ± 0.0042	0.0010 ± 0.00085	0.0016 ± 0.0012	0.0014 ± 0.0009	0.0013 ± 0.0013	0.00071 ± 0.00045
OFF SITE							
Riverview	16	0.00220 ± 0.00086	-0.00013 ± 0.00017	0.00075 ± 0.00039	0.00029 ± 0.00028	0.00010 ± 0.00011	0.00023 ± 0.00020
Byers Landing	17	0.00040 ± 0.00038	0.00010 ± 0.00010	0.00015 ± 0.00013	0.00029 ± 0.00024	0.00037 ± 0.00023	0.00022 ± 0.00019
Sagemoor	18	0.00020 ± 0.00060	0.00012 ± 0.00014	0.00022 ± 0.00017	NS	0.00005 ± 0.00008	0.00027 ± 0.00028
Taylor Flats No. 2	19	0.00056 ± 0.00036	-0.00010 ± 0.00010	0.00036 ± 0.00028	0.00015 ± 0.00015	0.00028 ± 0.00018	0.00026 ± 0.00021
W End Fir Road	20	0.00021 ± 0.00029	0.00039 ± 0.00046	0.00019 ± 0.00015	0.00007 ± 0.00015	0.00004 ± 0.00018	0.00009 ± 0.00011
Ringold	21	0.00000 ± 0.00000	-0.00007 ± 0.00030	0.00019 ± 0.00017	0.00033 ± 0.00031	0.00001 ± 0.00001	0.00017 ± 0.00027
Berg Ranch	22	0.00050 ± 0.00030	0.00080 ± 0.00059	0.00058 ± 0.00031	NS	0.00023 ± 0.00018	0.00012 ± 0.00016
Wahluke Slope No. 2[d]	23	0.00001 ± 0.00002	0.00017 ± 0.00028	0.00026 ± 0.00021	NS	0.00020 ± 0.00016	0.00019 ± 0.00017
Vernita Bridge[d]	24	0.00008 ± 0.00030	0.00035 ± 0.00025	0.00017 ± 0.00028	NS	—	0.00021 ± 0.00019
Yakima Barricade[d]	25	0.00038 ± 0.00029	0.00027 ± 0.00044	0.00056 ± 0.00022	—	0.00017 ± 0.00018	0.00043 ± 0.00026
Rattlesnake Springs[d]	26	0.00083 ± 0.00096	0.00022 ± 0.00022	0.00040 ± 0.00021	0.00013 ± 0.00012	0.00037 ± 0.00022	0.00047 ± 0.00034
ALE[d]	27	0.00033 ± 0.00028	0.00074 ± 0.00063	0.00054 ± 0.00025	—	0.00020 ± 0.00014	0.00031 ± 0.00024
Prosser Barricade[d]	28	0.00034 ± 0.00034	0.00017 ± 0.00031	NS	0.00071 ± 0.00027	—	0.00043 ± 0.00036
S of 300 Area[d]	29	0.00014 ± 0.00021	0.00036 ± 0.00067	0.00045 ± 0.00021	0.0026 ± 0.00027	—	0.00007 ± 0.00017
Benton City	30	0.00070 ± 0.00050	-0.00015 ± 0.00025	0.0019 ± 0.00048	0.0013 ± 0.00016	0.00005 ± 0.00011	0.00014 ± 0.00015
Sunnyside	31	0.00031 ± 0.00029	0.00031 ± 0.00025	0.00017 ± 0.00014	0.0006 ± 0.00011	0.00015 ± 0.00017	0.00083 ± 0.00034
Walla Walla	32					0.00008 ± 0.00002	0.00030 ± 0.00022
McNary Dam	33					0.00011 ± 0.00014	0.00048 ± 0.00031
Moses Lake	34					0.00024 ± 0.00020	0.00027 ± 0.00030
Washtucna	35					0.00005 ± 0.00008	0.00020 ± 0.00021
Connell	36					0.00007 ± 0.00009	0.00027 ± 0.00025
Othello	37					0.00015 ± 0.00016	-0.00001 ± 0.00000
Yakima	38					0.00010 ± 0.00013	0.00005 ± 0.00013
OFFSITE AVERAGE		0.00045 ± 0.00028	0.00022 ± 0.00017	0.00046 ± 0.00023	0.00047 ± 0.00049	0.00015 ± 0.00006	0.00026 ± 0.00009

(a) Individual results ±2 sigma counting error. Averages ±2 standard error of the calculated mean.
(b) Locations are identified in Figure 4.39.
(c) Locations sampled every other year indicated by dashed line.
(d) Perimeter location on Site near Site boundary.
NS No sample.

TABLE C.33. Uranium Concentrations in Vegetation in 1988

Location	Map Location[b]	pCi/g (dry weight)[a] 1983	1984	1985	1986	1987	1988
ON SITE							
1 Mile NE of 100-N Area	1	0.006 ± 0.003	0.007 ± 0.0034	0.0076 ± 0.0056	NS	—[c]	0.005 ± 0.002
1 Mile E of 100-N Area	2	0.007 ± 0.003	0.0061 ± 0.0030	0.013 ± 0.0074	0.0060 ± 0.0017	0.014 ± 0.004	0.004 ± 0.001
100-Area Fire Station	3	0.007 ± 0.003	0.0067 ± 0.0033	0.016 ± 0.0078	0.0054 ± 0.0016	0.008 ± 0.002	0.001 ± 0.001
200-East NC	4	0.007 ± 0.004	0.0092 ± 0.0037	0.015 ± 0.0076	0.011 ± 0.003	0.014 ± 0.004	0.007 ± 0.002
E of 200-East	5	0.008 ± 0.003	0.0066 ± 0.0042	0.011 ± 0.0064	0.0046 ± 0.0013	0.029 ± 0.08	-0.001 ± 0.001
200-East SE	6	0.007 ± 0.003	0.0052 ± 0.0040	0.016 ± 0.0080	0.013 ± 0.004	0.016 ± 0.04	0.003 ± 0.001
SW of BC Cribs	7	0.005 ± 0.003	0.017 ± 0.0077	0.014 ± 0.0077	NS	0.007 ± 0.002	0.003 ± 0.001
S of 200-East	8	0.009 ± 0.004	0.011 ± 0.0054	0.035 ± 0.014	0.0072 ± 0.0021	0.025 ± 0.007	0.001 ± 0.001
E of 200-West	9	0.011 ± 0.004	0.016 ± 0.0065	0.022 ± 0.0096	0.016 ± 0.005	—	0.001 ± 0.001
2 Miles S of 200-West	10	0.007 ± 0.003	0.015 ± 0.0058	0.0096 ± 0.0063	0.0060 ± 0.0017	0.025 ± 0.007	0.007 ± 0.002
NE of FFTF	11	0.005 ± 0.003	0.014 ± 0.005	0.0081 ± 0.0054	—	0.015 ± 0.004	0.006 ± 0.002
SE of FFTF	12	0.01 ± 0.004	0.0050 ± 0.0027	0.022 ± 0.0098	NS	—	0.002 ± 0.001
N of 300 Area	13	0.018 ± 0.006	0.012 ± 0.0046	0.082 ± 0.027	0.018 ± 0.005	0.016 ± 0.004	0.019 ± 0.006
Hanford Townsite	14	0.011 ± 0.048	0.0032 ± 0.0022	0.015 ± 0.0080	—	0.010 ± 0.003	0.004 ± 0.001
Wye Barricade	15	0.0077 ± 0.0035	0.0045 ± 0.0036	0.021 ± 0.0095	—	0.007 ± 0.002	0.005 ± 0.002
ONSITE AVERAGE		0.0083 ± 0.0018	0.0093 ± 0.0026	0.021 ± 0.0099	0.0097 ± 0.0030	0.002 ± 0.004	0.005 ± 0.002
OFF SITE							
Riverview	16	0.014 ± 0.005	0.021 ± 0.0076	0.0099 ± 0.0060	0.015 ± 0.004	0.018 ± 0.005	0.009 ± 0.003
Byers Landing	17	0.015 ± 0.006	0.022 ± 0.0078	0.19 ± 0.058	0.021 ± 0.006	0.020 ± 0.006	0.020 ± 0.006
Sagemoor	18	0.013 ± 0.005	0.012 ± 0.0050	0.019 ± 0.0086	NS	0.012 ± 0.003	0.006 ± 0.002
Taylor Flats No. 2	19	0.016 ± 0.006	0.011 ± 0.0044	0.022 ± 0.0096	0.016 ± 0.005	0.031 ± 0.009	0.012 ± 0.004
W End Fir Road	20	0.02 ± 0.007	0.036 ± 0.012	0.038 ± 0.014	0.0092 ± 0.0027	0.023 ± 0.006	0.022 ± 0.007
Ringold	21	0.027 ± 0.009	0.025 ± 0.0085	0.041 ± 0.015	0.011 ± 0.003	0.049 ± 0.014	0.021 ± 0.006
Berg Ranch	22	0.012 ± 0.005	0.017 ± 0.0066	0.0097 ± 0.0063	NS	0.014 ± 0.004	0.006 ± 0.002
Wahluke Slope No. 2[d]	23	0.011 ± 0.005	0.0088 ± 0.0039	0.015 ± 0.0079	NS	0.018 ± 0.005	0.011 ± 0.003
Vernita Bridge[d]	24	0.013 ± 0.005	0.011 ± 0.0045	0.020 ± 0.0090	NS	—	0.004 ± 0.001
Yakima Barricade[d]	25	0.0078 ± 0.0035	0.0037 ± 0.0020	0.020 ± 0.0090	—	0.009 ± 0.001	0.005 ± 0.002
Rattlesnake Springs[d]	26	0.012 ± 0.005	0.0042 ± 0.0022	0.013 ± 0.0068	0.0097 ± 0.0028	0.012 ± 0.003	0.001 ± 0.001
ALE[d]	27	0.0055 ± 0.0029	0.0057 ± 0.0025	0.0075 ± 0.0054	—	0.016 ± 0.004	0.001 ± 0.001
Prosser Barricade[d]	28	0.011 ± 0.005	0.0042 ± 0.0023	NS	0.0097 ± 0.0028	—	0.008 ± 0.003
S of 300 Area[d]	29	0.0118 ± 0.0056	0.014 ± 0.0053	0.036 ± 0.014	0.014 ± 0.004	—	0.011 ± 0.003
Benton City	30	0.015 ± 0.006	0.014 ± 0.0056	0.013 ± 0.0074	0.021 ± 0.006	0.018 ± 0.005	0.007 ± 0.002
Sunnyside	31	0.009 ± 0.004	0.0013 ± 0.0014	0.0086 ± 0.0057	0.0060 ± 0.0017	0.014 ± 0.004	0.005 ± 0.002
Walla Walla	32					0.016 ± 0.004	0.016 ± 0.005
McNary Dam	33					0.014 ± 0.004	0.010 ± 0.003
Moses Lake	34					0.016 ± 0.004	0.007 ± 0.002
Washtucna	35					0.015 ± 0.004	0.004 ± 0.001
Connell	36					0.014 ± 0.004	0.007 ± 0.002
Othello	37					0.013 ± 0.004	0.001 ± 0.001
Yakima	38					0.011 ± 0.003	0.007 ± 0.002
OFFSITE AVERAGE		0.013 ± 0.0028	0.013 ± 0.0049	0.041 ± 0.041	0.013 ± 0.003	0.018 ± 0.004	0.009 ± 0.003

(a) Individual results ±2 sigma analytical error. Averages ±2 standard error of the calculated mean.
(b) Locations are identified in Figure 4.39.
(c) Locations sampled every other year indicated by dashed line.
(d) Perimeter location on Site near Site boundary.
NS No sample.

TABLE C.34. Environmental Dosimeter Measurements - Perimeter and Community Locations

Location	Map Location[b]	No. of Samples	Dose Rate, mrem/yr[a] Maximum	Minimum	Average[c,d]
PERIMETER STATIONS					
Prosser Barricade	1	13	108	77	89 ± 5
ALE	2	13	110	77	89 ± 6
Rattlesnake Springs	3	13	112	65	92 ± 7
Yakima Barricade	4	13	115	74	91 ± 6
Vernita Bridge	5	12	108	76	90 ± 6
Wahluke Slope No. 2	6	12	113	53	87 ± 9
Berg Ranch	7	13	125	81	93 ± 7
Sagehill	8	13	112	72	86 ± 6
Ringold	9	13	121	78	93 ± 7
Fir Road	10	13	99	77	86 ± 3
Pettett	11	13	95	71	84 ± 4
Sagemoor	12	13	125	66	86 ± 7
Byers Landing	13	13	99	62	86 ± 6
RRC No. 64	14	13	125	71	84 ± 8
Horn Rapids Rd., Mi. 12	15	13	104	74	86 ± 5
Horn Rapids, Substation	16	13	101	68	83 ± 5
Perimeter Average					88 ± 2
NEARBY COMMUNITIES					
Benton City	17	12	85	64	73 ± 4
Othello	18	13	102	57	74 ± 7
Connell	19	13	115	62	82 ± 8
Pasco	20	13	89	54	77 ± 5
Richland	21	13	110	57	77 ± 7
Eltopia	22	13	102	51	72 ± 9
Prosser	23	12	137	65	81 ± 11
Mattawa	24	12	122	60	76 ± 9
Kennewick	25	13	130	56	85 ± 10
Nearby Average					78 ± 1
DISTANT COMMUNITIES					
Walla Walla	26	14	119	68	85 ± 7
McNary	27	13	116	66	86 ± 8
Sunnyside	28	13	91	59	76 ± 5
Moses Lake	29	14	84	56	72 ± 4
Washtucna	30	14	88	59	78 ± 5
Yakima	31	13	83	60	72 ± 5
Distant Average					78 ± 2

(a) Monthly integrated readings in mR were converted to annual dose equivalent rates.
(b) Locations are identified in Figure 4.42.
(c) Averages ±2 times the standard error of the calculated mean.
(d) The grand averages shown have 2 times the standard error based on means, thus n is small.

TABLE C.35. Immersion Dose Rates Measured in the Columbia River in 1988

Location[b]	Number of Measurements	Dose Rate, mrem/h[a] Maximum	Minimum	Average[c]
Richland Pumphouse	3	0.005	0.004	0.005 ± 0.0008
Coyote Rapids	3	0.007	0.005	0.006 ± 0.0013

(a) Quarterly integrated readings in mR were converted to hourly dose equivalent rates.
(b) Locations are identified in Figure 4.44.
(c) Averages ±2 times the standard error of calculated mean.

TABLE C.36. Environmental Dosimeter Measurements at Publicly Accessible Onsite Locations in 1988

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	12	0.032	0.024	0.029 ± 0.0014
Below 100-N Main Stack	2	12	0.034	0.015	0.020 ± 0.0027
Upstream Tip 100-N Berm	3	12	0.032	0.016	0.021 ± 0.0023
Downstream 100-N Outfall	4	12	0.042	0.012	0.028 ± 0.0049
3705 West Fence	5	13	0.012	0.008	0.010 ± 0.0006
400 East Fence	6	13	0.013	0.006	0.009 ± 0.001

(a) Monthly integrated readings in mR were converted to hourly dose equivalent rates.
(b) Locations are identified in Figure 4.45.
(c) Averages ±2 times the standard error of the calculated mean.

TABLE C.37. Environmental Dosimeter Measurements Along the Hanford Reach of the Columbia River in 1988

Location	Map Location[b]	No. of Measurements	Dose Rate, mrem/h[a] Maximum	Minimum	Average[c]
Upriver 100-B Area	1	4	0.009	0.009	0.009 ± 0.001
Below 100-B Retention Basin	2	4	0.016	0.015	0.016 ± 0.0002
Above 100-K Boat Ramp	3	4	0.010	0.009	0.009 ± 0.0003
Downriver from 100-D Area	4	4	0.012	0.010	0.011 ± 0.0005
Downriver Opposite 100-D Area	5	4	0.009	0.008	0.008 ± 0.0003
Lower End Locke Island	6	4	0.010	0.009	0.009 ± 0.0005
White Bluffs Slough	7	4	0.014	0.013	0.014 ± 0.0004
White Bluffs Ferry Landing	8	4	0.010	0.009	0.009 ± 0.0005
Below 100-F Area	9	4	0.009	0.008	0.009 ± 0.0003
100-F Floodplain	10	4	0.014	0.013	0.014 ± 0.0003
Hanford Powerline Crossing	11	4	0.011	0.009	0.010 ± 0.0006
Hanford Ferry Landing	12	4	0.009	0.008	0.008 ± 0.0004
Hanford Peninsula	13	3	0.014	0.012	0.013 ± 0.0007
Hanford Railroad Track	14	4	0.013	0.012	0.012 ± 0.0004
Savage Island Slough	15	4	0.012	0.011	0.012 ± 0.0004
Ringold Island	16	3	0.010	0.009	0.010 ± 0.0009
Powerline Crossing	17	4	0.011	0.010	0.010 ± 0.0003
North End Wooded Island	18	4	0.010	0.008	0.009 ± 0.0005
South End Wooded Island	19	4	0.011	0.010	0.010 ± 0.0003
Island Near 300 Area	20	4	0.012	0.011	0.012 ± 0.0006
Below Bateman Island	21	3	0.011	0.011	0.011 ± 0.0002

(a) Quarterly integrated readings in mR were converted to hourly dose equivalent rates.
(b) Locations are identified in Figure 4.44.
(c) Averages ±2 times the standard error of the calculated mean.

TABLE C.38. Onsite External Penetrating Dose Measurements in 1988

Location	Map Location[b]	No. of Measurements	Dose Rate, mrem/h[a] Maximum	Minimum	Average[c]
100 Areas					
100-K	1	12	0.010	0.008	0.009 ± 0.0004
100-N	2	12	0.013	0.009	0.011 ± 0.0006
100-D	3	12	0.011	0.009	0.010 ± 0.0004
100 Area Fire Station	4	12	0.011	0.008	0.009 ± 0.0005
200 Areas					
N of 200-East	5	13	0.013	0.007	0.010 ± 0.0008
E of 200-East	6	13	0.014	0.009	0.010 ± 0.0008
200-E SE	7	13	0.012	0.007	0.010 ± 0.0008
GTE Building	8	13	0.012	0.008	0.009 ± 0.0008
SW of BC Cribs	9	13	0.013	0.007	0.010 ± 0.0009
S of 200-East	10	12	0.014	0.008	0.010 ± 0.0009
300 Area					
300 Pond	11	13	0.014	0.007	0.010 ± 0.0009
3614 A Building	12	13	0.013	0.005	0.010 ± 0.0010
300 S Gate	13	13	0.012	0.006	0.009 ± 0.0007
300 SW Gate	14	13	0.012	0.007	0.010 ± 0.0008
3705 West Fence	15	13	0.012	0.008	0.010 ± 0.0006
400 Area					
400-East	16	13	0.013	0.006	0.009 ± 0.0010
400-West	17	13	0.012	0.007	0.010 ± 0.0008
400-South	18	13	0.012	0.007	0.009 ± 0.0008
400-North	19	13	0.012	0.007	0.009 ± 0.0008
FFTF North	20	13	0.013	0.008	0.009 ± 0.0007
FFTF Southeast	21	13	0.012	0.007	0.010 ± 0.0007
600 Area					
Rt. 11A, Mi. 9	22	13	0.013	0.007	0.010 ± 0.0008
Hanford Townsite	23	13	0.013	0.008	0.010 ± 0.0007
Wye Barricade	24	12	0.012	0.007	0.009 ± 0.0009
Army Loop Camp	25	13	0.013	0.008	0.010 ± 0.0008

(a) Monthly integrated reading in mR were converted to hourly dose equivalent rates.
(b) Locations are identified in Figure 4.46.
(c) Averages ±2 times the standard error of the mean.

TABLE C.39. Environmental Dosimeter Intercomparison[a]

Source	Exposure	WPPSS		OSHD[b]		DSHS		PNL[c]	
^{137}Cs	15.0 mR	18.4	(0.6)	12.5	(0.4)	16.3	(1.1)	14.1	(1.8)
				13.8	(0.2)			14.7	(2.3)
	53.5	56.6	(1.7)	36.1	(1.0)	58.3	(2.8)	55.3	(4.4)
				44.6	(0.6)			53.4	(2.9)
	95.0	97.8	(2.2)	66.0	(3.0)	100.6	(7.0)	96.2	(8.3)
				79.5	(3.3)			97.7	(5.3)
	200.0	204.9	(4.6)	152.0	(7.0)	206.7	(12.5)	213.0	(17.4)
				168.0	(8.0)			202.9	(13.1)
^{60}Co	30.0	31.9	(1.0)	19.1	(2.1)	32.7	(1.3)	34.8	(3.2)
				21.5	(1.0)			27.4	(3.6)
	55.0	55.0	(1.6)	39.3	(3.0)	61.0	(3.8)	59.8	(4.3)
				41.3	(0.8)			52.8	(4.7)
	107.0	104.4	(2.2)	76.2	(6.3)	117.8	(7.4)	114.9	(12.4)
				82.0	(5.0)			112.6	(16.4)
	220.0	211.2	(4.2)	162.0	(16.0)	252.4	(30.4)	236.3	(14.4)
				168.0	(2.0)			217.8	(38.3)
^{226}Ra	25.0	31.1	(0.8)	22.8	(1.1)	35.3	(3.8)	33.8	(3.7)
				20.1	(0.6)			28.9	(3.8)
	56.3	66.0	(1.9)	50.2	(2.8)	84.9	(2.8)	79.3	(7.5)
				46.5	(3.0)			59.8	(10.5)
	126.0	131.3	(4.0)	83.0	(8.0)	173.0	(4.9)	160.0	(11.2)
				94.0	(1.0)			122.6	(4.8)
	244.0	292.7	(7.1)	240.0	(17.0)	388.2	(12.9)	388.9	(31.6)
				191.0	(8.0)			266.6	(58.5)
#46	Env.	28.4	(1.0)	13.8	(0.8)	23.0	(1.8)	22.5	(3.1)
				16.8	(0.5)			24.0	(3.1)

(a) Average result shown with two standard deviations in parenthesis.
WPPSS = Washington Public Power Supply System
OSHD = Oregon State Health Division
DSHS = Washington State Division of Social and Health Services
PNL = Pacific Northwest Laboratory

(b) The results for two types of dosimeters are listed. The first entry is for a TLD-700 dosimeter. The second entry is for a TLD-200 dosimeter.

(c) The results for two types of dosimeters are listed. The first entry is for a TLD-700 dosimeter. The second entry is for a TLD-400 dosimeter.

TABLE C.40. Maximum, Minimum, and Average Tritium (^3H) Concentrations in Ground-Water Samples in 1988

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum			Minimum			Average		
1-B3-1	2	3,670	±	253	3,620	±	296	3,650	±	25
1-B3-2P	1	509	±	203	---	±	---	509	±	---
1-B3-2Q	1	796	±	214	---	±	---	796	±	---
1-B4-1	2	49,700	±	737	21,000	±	583	35,400	±	14,400
1-B4-2	2	2,670	±	267	2,280	±	263	2,480	±	195
1-B4-3	2	19,400	±	484	12,400	±	465	15,900	±	3,500
1-B4-4	2	2,280	±	259	2,130	±	219	2,210	±	75
1-B5-1	2	1,560	±	239	1,470	±	202	1,520	±	45
1-D2-5	4	33,500	±	499	30,600	±	663	32,000	±	657
1-D5-12	2	16,000	±	506	10,800	±	428	13,400	±	2,600
1-D8-3	2	4,440	±	310	3,990	±	212	4,220	±	225
1-F5-1	2	561	±	210	61	±	193	311	±	250
1-F5-3	2	926	±	222	611	±	212	769	±	158
1-F5-4	4	13,500	±	479	9,700	±	412	11,400	±	799
1-F5-6	2	1,130	±	227	1,110	±	227	1,120	±	10
1-F7-1	4	637	±	211	505	±	225	556	±	30
1-F8-1	11	9,530	±	412	6,030	±	299	6,880	±	335
1-F8-2	4	2,300	±	260	1,620	±	253	1,950	±	139
1-H3-1	4	5,110	±	285	3,590	±	247	4,290	±	344
1-H4-3	7	3,290	±	285	1,140	±	235	2,670	±	276
1-H4-4	7	1,760	±	248	1,420	±	240	1,630	±	48
1-H4-5	4	5,550	±	344	2,150	±	212	3,250	±	777
1-H4-6	4	4,900	±	278	2,320	±	269	3,990	±	570
1-H4-7	4	7,820	±	360	3,450	±	296	4,880	±	993
1-H4-9	4	3,730	±	313	2,170	±	264	2,930	±	327
1-H4-10	4	3,280	±	244	2,370	±	264	2,710	±	206
1-H4-11	4	2,210	±	266	1,020	±	193	1,360	±	286
1-H4-14	4	1,150	±	236	859	±	189	991	±	76
1-H4-16	4	764	±	182	489	±	169	635	±	56
1-H4-17	4	3,530	±	246	3,020	±	285	3,400	±	125
1-H4-18	4	1,550	±	243	573	±	218	1,100	±	205
1-K-11	2	537	±	212	471	±	208	504	±	33
1-K-19	6	4,640	±	325	2,840	±	281	3,570	±	290
1-K-20	2	1,380	±	238	1,060	±	226	1,220	±	160
1-K-22	3	862	±	221	700	±	216	792	±	48
1-K-27	2	2,740	±	274	1,850	±	249	2,300	±	445
1-K-28	2	3,290	±	286	3,050	±	239	3,170	±	120
1-K-29	2	17,000	±	521	10,800	±	371	13,900	±	3,100
1-K-30	2	1,220,000	±	2,900	1,180,000	±	3,500	1,200,000	±	20,000
1-N-2	5	91,400	±	995	83,500	±	1,110	87,300	±	1,390
1-N-3	4	43,200	±	797	31,900	±	598	39,400	±	2,550
1-N-4	5	86,600	±	1,130	73,400	±	1,010	80,300	±	2,480

TABLE C.40. (Tritium contd)

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum			Minimum			Average		
1-N-5	3	33,200	±	701	25,900	±	609	28,900	±	2,210
1-N-6	3	129,000	±	1,310	59,000	±	932	90,800	±	20,500
1-N-14	5	121,000	±	1,310	36,600	±	648	93,700	±	15,000
1-N-15	2	55,300	±	908	44,000	±	567	49,700	±	5,650
1-N-16	2	190	±	199	-159	±	187	16	±	175
1-N-18	4	26,500	±	632	12,500	±	392	20,300	±	2,910
1-N-19	3	3,690	±	308	1,690	±	251	2,400	±	645
1-N-20	2	1,370	±	248	1,090	±	235	1,230	±	140
1-N-21	5	1,490	±	240	494	±	167	1,140	±	207
1-N-22	1	656	±	213	---	±	---	656	±	---
1-N-23	3	3,060	±	282	1,940	±	252	2,520	±	324
1-N-24	1	404	±	207	---	±	---	404	±	---
1-N-25	4	374	±	166	57	±	195	224	±	67
1-N-27	5	187,000	±	1,420	48,100	±	823	116,000	±	25,500
1-N-28	4	141,000	±	1,360	48,200	±	834	80,900	±	20,700
1-N-29	4	77,000	±	901	38,500	±	656	59,400	±	8,350
1-N-30	2	92,400	±	1,140	89,600	±	1,130	91,000	±	1,400
1-N-31	6	443,000	±	2,150	52,500	±	865	147,000	±	61,900
1-N-32	4	119,000	±	1,260	58,300	±	923	85,500	±	13,400
1-N-33	7	113,000	±	1,220	57,900	±	916	74,600	±	7,050
1-N-36	5	171,000	±	1,500	58,500	±	805	95,500	±	19,900
1-N-37	2	81,500	±	935	66,100	±	990	73,800	±	7,700
1-N-39	4	113,000	±	1,290	48,600	±	843	68,700	±	15,000
1-N-41	3	121,000	±	1,110	53,300	±	767	86,700	±	19,500
1-N-42	3	127,000	±	1,140	65,400	±	844	97,400	±	17,800
1-N-45	7	459,000	±	2,210	30,900	±	696	235,000	±	66,300
1-N-49	3	152,000	±	1,480	113,000	±	1,090	130,000	±	11,500
1-N-50	2	133,000	±	1,390	124,000	±	1,150	129,000	±	4,500
1-N-51	2	96,600	±	1,190	92,900	±	1,150	94,800	±	1,850
1-N-52	6	96,800	±	1,020	62,600	±	802	75,700	±	4,810
1-N-58	2	74	±	189	56	±	153	65	±	9
1-N-59	2	210	±	194	149	±	156	180	±	31
1-N-60	2	227	±	159	207	±	192	217	±	10
1-N-61	2	356	±	196	15	±	153	186	±	171
1-N-67	1	84,900	±	963	---	±	---	84,900	±	---
1-N-69	1	90,700	±	999	---	±	---	90,700	±	---
1-N-70	2	102,000	±	1,050	91,800	±	1,100	96,900	±	5,100
2-E13-5	4	13	±	187	-324	±	185	-152	±	69
2-E13-8	2	-29	±	196	-42	±	194	-35	±	6
2-E13-14	2	390	±	211	78	±	201	234	±	156
2-E13-19	2	218	±	203	98	±	201	158	±	60
2-E16-2	12	17,300	±	510	737	±	250	3,250	±	1,310
2-E17-1	1	8,050,000	±	9,120	---	±	---	8,050,000	±	---
2-E17-2	12	112,000	±	1,090	22,300	±	592	44,100	±	6,680
2-E17-5	13	4,210,000	±	6,580	187,000	±	1,420	1,510,000	±	400,000
2-E17-6	5	8,240	±	334	69	±	164	3,440	±	1,630
2-E17-8	4	5,830,000	±	7,760	2,780,000	±	6,240	4,530,000	±	642,000
2-E17-9	6	4,750,000	±	7,050	3,760,000	±	7,340	4,220,000	±	157,000

TABLE C.40. (Tritium contd)

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum	Minimum	Average
2-E17-12	12	1,930,000 ± 5,280	952,000 ± 3,540	1,500,000 ± 78,600
2-E17-13	12	2,430,000 ± 5,910	291,000 ± 2,000	1,050,000 ± 214,000
2-E17-14	1	217,000 ± 1,530	— ± —	217,000 ± —
2-E17-16	2	36,200 ± 643	35,200 ± 629	35,700 ± 500
2-E17-17	1	630,000 ± 2,590	— ± —	630,000 ± —
2-E17-18	1	86,600 ± 978	— ± —	86,600 ± —
2-E18-1	1	-287 ± 224	— ± —	-287 ± —
2-E18-2	2	391 ± 238	-216 ± 226	88 ± 304
2-E18-3	1	-341 ± 224	— ± —	-341 ± —
2-E18-4	1	847 ± 258	— ± —	847 ± —
2-E23-1	2	1,260,000 ± 4,080	135,000 ± 1,390	698,000 ± 563,000
2-E24-1	11	7,810,000 ± 9,190	1,920,000 ± 4,500	4,350,000 ± 548,000
2-E24-2	4	4,630,000 ± 6,900	1,990,000 ± 5,110	3,010,000 ± 583,000
2-E24-4	4	10,800 ± 432	8,430 ± 341	9,790 ± 494
2-E24-7	2	1,950,000 ± 5,030	418,000 ± 2,450	1,180,000 ± 766,000
2-E24-8	4	4,820,000 ± 7,200	7,570 ± 332	1,210,000 ± 1,200,000
2-E24-11	4	8,070,000 ± 9,140	2,250,000 ± 5,470	4,990,000 ± 1,210,000
2-E24-12	8	2,360,000 ± 5,060	53,600 ± 770	366,000 ± 285,000
2-E24-13	2	6,390 ± 361	6,120 ± 352	6,260 ± 135
2-E25-2	2	6,210 ± 340	5,940 ± 350	6,080 ± 135
2-E25-3	2	5,510 ± 339	4,340 ± 315	4,930 ± 585
2-E25-6	11	17,900 ± 465	4,590 ± 320	7,130 ± 1,110
2-E25-9	4	3,580 ± 253	3,030 ± 305	3,230 ± 123
2-E25-11	12	777,000 ± 3,210	425,000 ± 2,330	568,000 ± 28,300
2-E25-17	12	468,000 ± 2,480	163,000 ± 1,310	294,000 ± 29,300
2-E25-18	4	552,000 ± 2,450	93,900 ± 1,010	263,000 ± 102,000
2-E25-19	4	4,750,000 ± 7,190	596,000 ± 2,790	2,950,000 ± 967,000
2-E25-20	4	1,280,000 ± 4,110	745,000 ± 2,840	1,030,000 ± 110,000
2-E25-21	4	8,680 ± 347	2,590 ± 281	4,980 ± 1,350
2-E25-22	6	8,460 ± 344	5,070 ± 335	6,530 ± 644
2-E25-23	4	603 ± 216	36 ± 221	355 ± 118
2-E25-24	4	1,040 ± 220	130 ± 225	486 ± 207
2-E25-25	4	558 ± 178	-153 ± 224	290 ± 160
2-E25-26	2	3,120 ± 284	2,380 ± 283	2,750 ± 370
2-E25-27	2	3,770 ± 318	3,120 ± 284	3,450 ± 325
2-E25-28	2	1,690 ± 245	1,490 ± 260	1,590 ± 100
2-E25-29	2	104,000 ± 1,060	70,000 ± 986	87,000 ± 17,000
2-E25-30	2	2,160 ± 179	1,380 ± 266	1,770 ± 390
2-E25-31	4	28,100 ± 651	20,700 ± 401	23,200 ± 1,680
2-E25-32	2	1,150 ± 252	865 ± 235	1,010 ± 143
2-E25-33	3	47,300 ± 727	23,900 ± 428	31,800 ± 7,750
2-E26-1	2	16,700 ± 523	15,200 ± 414	16,000 ± 750
2-E26-2	4	2,980 ± 293	2,340 ± 266	2,650 ± 166
2-E26-3	2	4,650 ± 325	4,140 ± 304	4,400 ± 255
2-E26-4	4	42,800 ± 806	17,800 ± 526	28,400 ± 5,440
2-E26-6	4	4,130 ± 307	2,310 ± 279	3,390 ± 401
2-E26-8[c]	2	1 ± 191	-288 ± 184	-143 ± 145
2-E27-1	2	1,470 ± 241	1,140 ± 173	1,310 ± 165

TABLE C.40. (Tritium contd)

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum			Minimum			Average		
2-E27-5	2	5,990	±	279	4,350	±	315	5,170	±	820
2-E27-8	2	10,500	±	430	9,380	±	345	9,940	±	560
2-E27-9	2	10,800	±	434	8,780	±	334	9,790	±	1,010
2-E27-10	2	9,080	±	409	6,360	±	298	7,720	±	1,360
2-E28-1	2	7,390	±	304	7,120	±	373	7,260	±	135
2-E28-5	1	2,180	±	265	---	±	---	2,180	±	---
2-E28-7	2	7,940	±	381	7,280	±	377	7,610	±	330
2-E28-12	12	277,000	±	1,740	97,900	±	1,160	137,000	±	13,400
2-E28-13	4	7,860	±	385	5,890	±	302	7,100	±	427
2-E28-18	11	165,000	±	1,320	8,410	±	337	40,700	±	14,200
2-E28-21	12	114,000	±	1,110	9,590	±	362	30,400	±	8,960
2-E28-23	7	8,170	±	390	6,120	±	304	7,360	±	233
2-E28-26	2	126,000	±	1,150	32,800	±	691	79,400	±	46,600
2-E28-27	2	137,000	±	1,200	65,300	±	951	101,000	±	35,900
2-E32-1	2	14,400	±	405	9,390	±	412	11,900	±	2,510
2-E32-2	2	64,100	±	828	36,300	±	724	50,200	±	13,900
2-E32-3	2	247,000	±	1,610	62,300	±	937	155,000	±	92,400
2-E32-4	2	1,890	±	206	1,850	±	265	1,870	±	20
2-E33-1A	2	5,230	±	326	4,500	±	323	4,870	±	365
2-E33-3	2	5,230	±	326	2,570	±	275	3,900	±	1,330
2-E33-5	2	5,040	±	324	4,910	±	330	4,980	±	65
2-E33-7	2	10,900	±	434	7,770	±	388	9,340	±	1,570
2-E33-8	2	4,990	±	330	3,080	±	221	4,040	±	955
2-E33-9	3	4,580	±	316	3,450	±	304	4,030	±	326
2-E33-10	2	4,430	±	254	4,310	±	317	4,370	±	60
2-E33-12[c]	2	640	±	219	431	±	214	536	±	105
2-E33-14	2	295	±	206	171	±	201	233	±	62
2-E33-18	2	5,470	±	331	4,920	±	326	5,200	±	275
2-E33-20	2	5,070	±	330	4,980	±	329	5,030	±	45
2-E33-21	2	2,280	±	268	2,080	±	258	2,180	±	100
2-E33-24	2	16,100	±	517	13,400	±	391	14,800	±	1,350
2-E33-27	1	4,700	±	325	---	±	---	4,700	±	---
2-E33-28	2	2,680	±	263	2,000	±	205	2,340	±	340
2-E33-29	2	7,150	±	376	6,510	±	302	6,830	±	320
2-E33-30	3	5,770	±	330	4,870	±	270	5,300	±	261
2-E34-1	4	1,900	±	270	1,460	±	234	1,640	±	100
2-E34-2	2	2,100	±	272	2,090	±	214	2,100	±	5
2-E34-3	2	9,080	±	409	8,780	±	338	8,930	±	150
2-E34-5	2	617	±	233	302	±	163	460	±	158
2-E34-6	2	476	±	228	412	±	167	444	±	32
2-W6-1	2	59,700	±	902	59,600	±	947	59,700	±	50
2-W6-2	1	15,200	±	503	---	±	---	15,200	±	---
2-W7-1	1	175	±	221	---	±	---	175	±	---
2-W7-2	1	397	±	227	---	±	---	397	±	---
2-W7-3	2	63	±	157	41	±	215	52	±	11
2-W7-4	3	850	±	240	319	±	164	530	±	163
2-W7-5	2	886	±	241	278	±	162	582	±	304

TABLE C.40. (Tritium contd)

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum			Minimum			Average		
2-W7-6	1	1,050	±	245	---	±	---	1,050	±	---
2-W8-1	2	364	±	225	137	±	157	251	±	114
2-W9-1	2	144	±	158	-123	±	225	11	±	134
2-W10-1	2	54,800	±	902	53,700	±	769	54,300	±	550
2-W10-3	2	118,000	±	1,320	107,000	±	1,080	113,000	±	5,500
2-W10-4	2	88,500	±	1,150	76,300	±	1,000	82,400	±	6,100
2-W10-5	2	9,810	±	419	9,310	±	410	9,560	±	250
2-W10-8	2	3,240	±	286	2,730	±	282	2,990	±	255
2-W10-9	2	65,000	±	982	59,000	±	905	62,000	±	3,000
2-W10-13	1	382	±	226	---	±	---	382	±	---
2-W10-14	1	-88	±	211	---	±	---	-88	±	---
2-W11-3	2	560	±	233	242	±	205	401	±	159
2-W11-9	1	2,740	±	277	---	±	---	2,740	±	---
2-W12-1	2	6,730	±	367	5,650	±	343	6,190	±	540
2-W14-2	2	80,300	±	1,100	51,200	±	842	65,800	±	14,600
2-W14-5	2	6,280	±	362	1,780	±	238	4,030	±	2,250
2-W14-6	4	11,400	±	447	5,560	±	290	8,350	±	1,210
2-W14-10	2	1,700	±	246	1,090	±	187	1,400	±	305
2-W15-2	2	1,190	±	238	103	±	202	647	±	544
2-W15-4	2	202,000	±	1,630	155,000	±	1,500	179,000	±	23,500
2-W15-7	2	2,040	±	270	976	±	230	1,510	±	532
2-W15-10	2	7,110	±	377	4,840	±	264	5,980	±	1,140
2-W15-11	2	18,100	±	454	14,700	±	498	16,400	±	1,700
2-W15-15	2	680	±	247	465	±	168	573	±	108
2-W15-16	2	98	±	156	-14	±	230	42	±	56
2-W15-17	1	-136	±	211	---	±	---	-136	±	---
2-W15-18	1	472	±	230	---	±	---	472	±	---
2-W18-3	2	372	±	226	253	±	200	313	±	60
2-W18-15	4	484	±	201	101	±	157	224	±	88
2-W18-17	3	102	±	197	-98	±	159	34	±	66
2-W18-20	3	521	±	211	-58	±	129	202	±	170
2-W18-21	1	360	±	227	---	±	---	360	±	---
2-W18-22	1	9	±	214	---	±	---	9	±	---
2-W18-23	1	17	±	214	---	±	---	17	±	---
2-W18-24	1	52	±	230	---	±	---	52	±	---
2-W19-2	4	75,100	±	898	51,100	±	847	62,900	±	5,400
2-W19-3	7	817	±	215	334	±	210	495	±	64
2-W19-5	2	826	±	224	369	±	205	598	±	229
2-W19-9	4	562	±	217	60	±	200	253	±	117
2-W19-11	1	680	±	221	---	±	---	680	±	---
2-W19-12	2	310	±	225	282	±	209	296	±	14
2-W19-13	4	593	±	216	54	±	194	223	±	127
2-W19-14	4	212	±	197	114	±	164	154	±	21
2-W19-15	4	1,080	±	234	947	±	167	1,010	±	27
2-W19-16	3	395	±	147	124	±	201	286	±	83
2-W19-17	3	373	±	238	26	±	199	192	±	100
2-W19-18	4	3,860	±	305	854	±	186	1,710	±	721
2-W19-19	15	1,910	±	260	1,060	±	239	1,600	±	52
2-W19-20	12	3,130	±	286	1,350	±	248	1,820	±	143

TABLE C.40. (Tritium contd)

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum			Minimum			Average		
2-W19-21	3	115	±	165	-18	±	134	64	±	42
2-W19-23	11	1,130	±	244	456	±	221	763	±	66
2-W19-24	11	2,550	±	232	943	±	269	1,920	±	125
2-W19-25	10	2,110	±	221	1,350	±	248	1,730	±	81
2-W19-26	7	1,520	±	206	424	±	258	1,210	±	140
2-W19-27	4	227	±	196	65	±	156	142	±	33
2-W21-1	2	90,400	±	1,140	82,100	±	1,060	86,300	±	4,150
2-W22-1	3	1,900	±	192	792	±	224	1,260	±	332
2-W22-2	4	14,900	±	425	6,700	±	361	10,500	±	1,830
2-W22-7	2	364,000	±	2,290	335,000	±	2,100	350,000	±	14,500
2-W22-9	2	7,560,000	±	12,600	6,880,000	±	9,480	7,220,000	±	340,000
2-W22-10	2	121,000	±	1,320	93,700	±	1,150	107,000	±	13,700
2-W22-12	2	25,200	±	631	20,100	±	546	22,700	±	2,550
2-W22-20	2	200,000	±	1,710	193,000	±	1,610	197,000	±	3,500
2-W22-22	4	1,810	±	247	-127	±	129	1,150	±	434
2-W22-26	2	132,000	±	1,320	86,500	±	1,130	109,000	±	22,800
2-W23-1	2	435	±	228	231	±	201	333	±	102
2-W23-4	7	5,450,000	±	8,780	496,000	±	2,560	1,690,000	±	650,000
2-W23-8	1	178,000	±	1,550	---	±	---	178,000	±	---
2-W23-9	11	1,470,000	±	4,530	1,280,000	±	3,660	1,380,000	±	17,600
2-W23-10	3	687,000	±	2,710	579,000	±	2,440	636,000	±	31,300
2-W23-11	4	1,240	±	199	341	±	235	816	±	184
2-W26-3	2	121	±	205	-86	±	213	17	±	104
2-W26-6	2	1,450	±	257	-48	±	199	701	±	749
2-W27-1	3	5,760	±	297	342	±	146	2,800	±	1,580
3-1-1	4	437	±	244	-114	±	158	184	±	119
3-1-2	4	1,690	±	244	388	±	166	808	±	297
3-1-3	4	308	±	151	81	±	203	166	±	51
3-1-5	4	110	±	195	-273	±	223	-70	±	86
3-1-6	4	397	±	202	49	±	198	222	±	79
3-1-7	4	205	±	206	119	±	158	154	±	20
3-1-8	4	129	±	159	-100	±	191	27	±	47
3-1-9	4	-8	±	187	-51	±	193	-26	±	10
3-1-10	4	319	±	163	52	±	200	189	±	68
3-1-11	4	110	±	200	-125	±	191	-9	±	58
3-1-12	4	202	±	204	-48	±	199	109	±	56
3-1-13	4	1,040	±	229	328	±	163	734	±	167
3-1-14	4	466	±	169	-67	±	197	190	±	109
3-1-15	4	6,480	±	362	-40	±	198	4,210	±	1,480
3-1-16A	4	840	±	227	21	±	160	437	±	173
3-1-16B	4	251	±	209	-1	±	159	135	±	66
3-1-16C	4	93	±	197	-72	±	150	-10	±	39
3-1-16D	3	400	±	212	-145	±	194	98	±	160
3-1-17A	4	189	±	201	-145	±	225	26	±	73
3-1-17B	4	64	±	155	-134	±	157	-6	±	47
3-1-17C	4	37	±	195	-80	±	150	-36	±	27
3-1-18B	3	586	±	216	-101	±	151	151	±	218
3-1-18C	4	426	±	210	-159	±	148	71	±	125

TABLE C.40. (Tritium contd)

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum			Minimum			Average		
3-1-19	4	255	±	163	-322	±	222	49	±	127
3-2-1	4	531	±	211	124	±	156	245	±	96
3-2-2	4	579	±	210	-43	±	158	149	±	145
3-2-3	4	358	±	203	16	±	201	128	±	78
3-3-3	4	478	±	215	298	±	211	376	±	39
3-3-6	3	787	±	218	153	±	205	521	±	190
3-3-7	4	2,340	±	260	1,100	±	187	1,750	±	322
3-3-9	4	580	±	215	132	±	199	345	±	105
3-3-10	4	520	±	212	200	±	141	391	±	68
3-3-11	4	2,060	±	197	1,850	±	258	1,980	±	46
3-3-12	4	3,530	±	233	1,680	±	203	2,590	±	393
3-4-1	3	537	±	207	280	±	161	420	±	75
3-4-7	4	1,610	±	198	1,200	±	191	1,460	±	91
3-4-9	4	1,140	±	229	363	±	165	696	±	162
3-4-10	4	1,370	±	235	403	±	166	886	±	198
3-4-11	4	445	±	216	-136	±	192	217	±	127
3-5-1	4	292	±	201	-73	±	198	70	±	79
3-6-1	5	191	±	197	-239	±	192	-91	±	75
3-8-1	4	112	±	198	2	±	152	56	±	31
3-8-2	4	210	±	202	-45	±	153	67	±	55
3-8-3	5	496	±	168	195	±	161	348	±	61
3-8-4	4	80	±	154	-241	±	185	-48	±	68
4-S1-7B	3	57,800	±	938	55,100	±	775	56,300	±	794
4-S1-7C	4	76,200	±	1,030	75,000	±	1,040	75,700	±	296
4-S1-8A	4	82,900	±	1,100	72,300	±	988	78,600	±	2,570
4-S1-8B	4	83,700	±	1,110	77,200	±	1,030	81,000	±	1,410
4-S1-8C	4	6,730	±	367	5,600	±	340	6,120	±	269
4-S0-7	4	53,800	±	896	31,400	±	671	39,500	±	5,000
4-S0-8	3	52,300	±	758	4,770	±	327	28,400	±	13,700
6-S36-E13A	1	107	±	135	---	±	---	107	±	---
6-S32-E13A	1	477	±	148	---	±	---	477	±	---
6-S32-E13B	1	228	±	141	---	±	---	228	±	---
6-S31-E13	1	187	±	139	---	±	---	187	±	---
6-S31-1	1	-14	±	131	---	±	---	-14	±	---
6-S31-1P[c]	2	231	±	200	-87	±	129	72	±	159
6-S30-E15A	3	167	±	166	115	±	164	134	±	16
6-S29-E12	5	14	±	132	-174	±	194	-84	±	30
6-S28-E0	4	165	±	167	-167	±	127	-59	±	78
6-S27-E14	12	130	±	166	-306	±	210	-46	±	42
6-S24-19	2	-55	±	132	-343	±	189	-199	±	144
6-S19-E13	4	7,510	±	326	6,720	±	252	7,060	±	171
6-S19-11	2	-59	±	133	-197	±	194	-128	±	69
6-S18-51	2	-70	±	195	-71	±	196	-71	±	0
6-S14-20A	2	-164	±	127	-294	±	190	-229	±	65
6-S12-3	4	187	±	168	-72	±	129	38	±	60
6-S12-29	4	45	±	153	-193	±	126	-65	±	57

TABLE C.40. (Tritium contd)

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum			Minimum			Average		
6-S11-E12A	1	3,380	±	297	---	±	---	3,380	±	---
6-S11-E12AP[c]	2	-105	±	132	-172	±	194	-138	±	34
6-S8-19	4	100	±	165	-120	±	157	-17	±	47
6-S6-E14A[c]	1	-260	±	190	---	±	---	-260	±	---
6-S6-E4B	4	26,800	±	637	25,500	±	543	26,100	±	278
6-S6-E4D	5	39,000	±	658	31,400	±	774	37,300	±	1,470
6-S3-E12	4	6,460	±	308	5,700	±	271	6,030	±	172
6-S3-25	2	-59	±	198	-66	±	184	-63	±	4
6-1-18	4	48,100	±	726	43,700	±	787	46,100	±	902
6-2-3	4	108,000	±	1,080	104,000	±	1,060	105,000	±	1,000
6-2-7	1	13,300	±	470	---	±	---	13,300	±	---
6-2-33A	4	77	±	231	-171	±	156	-37	±	57
6-3-45	2	137	±	203	113	±	190	125	±	12
6-8-17	4	156,000	±	1,320	150,000	±	1,260	154,000	±	1,310
6-8-25	4	40,300	±	679	34,400	±	622	36,300	±	1,340
6-8-32	4	20	±	187	-117	±	187	-45	±	28
6-10-E12	4	20,400	±	559	17,000	±	527	18,500	±	776
6-10-54A	4	129	±	202	-444	±	207	-62	±	131
6-13-64	4	242	±	206	-535	±	205	-95	±	162
6-14-E6T	1	51,800	±	865	---	±	---	51,800	±	---
6-14-38	4	-94	±	184	-381	±	217	-240	±	68
6-14-47	1	37	±	161	---	±	---	37	±	---
6-15-15B	2	1	±	185	-5	±	161	-2	±	3
6-15-26	5	72,400	±	1,000	64,500	±	857	67,900	±	1,500
6-17-5	1	29	±	161	---	±	---	29	±	---
6-17-47	4	52	±	223	-146	±	156	-67	±	43
6-17-70	4	160	±	161	-531	±	217	-136	±	145
6-19-43	1	180	±	199	---	±	---	180	±	---
6-19-88	4	140	±	162	-326	±	222	-176	±	107
6-20-E12	4	2,500	±	285	-51	±	164	1,200	±	528
6-20-E12P[c]	2	76	±	163	-172	±	193	-48	±	124
6-20-E5A	4	70,100	±	867	67,400	±	981	68,600	±	670
6-20-E5P	2	-138	±	199	-275	±	151	-206	±	69
6-20-E5Q	2	-49	±	128	-148	±	156	-98	±	50
6-20-E5R	2	-2	±	130	-115	±	157	-59	±	57
6-20-20	4	165,000	±	1,350	151,000	±	1,440	158,000	±	3,040
6-20-39[c]	2	-51	±	184	-66	±	184	-58	±	7
6-20-82	4	183	±	199	-532	±	217	-78	±	165
6-21-6	4	51,100	±	869	37,400	±	727	46,000	±	2,980
6-22-70	4	45	±	157	-136	±	157	-34	±	41
6-24-1P[c]	2	389	±	199	232	±	143	311	±	79
6-24-1Q[c]	2	109	±	139	90	±	188	100	±	9
6-24-1R[c]	2	72	±	187	8	±	130	40	±	32
6-24-1S[c]	2	342	±	197	-86	±	128	128	±	214
6-24-1T	1	14,500	±	484	—	±	—	14,500	±	---
6-24-33	4	255,000	±	1,850	127,000	±	1,380	188,000	±	29,800
6-24-46	1	-3	±	187	---	±	---	-3	±	---
6-25-55	4	6,080	±	354	-198	±	205	1,490	±	1,530
6-25-70	4	969	±	194	721	±	240	865	±	52

TABLE C.40. (Tritium contd)

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum			Minimum			Average		
6-26-15A	4	301,000	±	2,020	269,000	±	1,890	285,000	±	7,050
6-27-8	4	263,000	±	1,700	242,000	±	1,800	255,000	±	4,500
6-28-40[c]	4	90,600	±	992	18,500	±	544	44,100	±	16,000
6-28-40P	1	-102	±	195	---	±	---	-102	±	---
6-28-52A	1	-14	±	198	---	±	---	-14	±	---
6-29-4	4	124,000	±	1,350	113,000	±	1,100	117,000	±	2,390
6-29-78	4	282	±	197	104	±	197	232	±	43
6-31-31	1	8,570	±	346	---	±	---	8,570	±	---
6-31-31P[c]	1	154	±	192	---	±	---	154	±	---
6-32-22	4	226,000	±	1,800	191,000	±	1,590	211,000	±	7,290
6-32-43	4	427,000	±	2,470	240,000	±	1,780	317,000	±	41,100
6-32-62	4	2,190	±	264	1,990	±	284	2,100	±	41
6-32-70B	4	269,000	±	1,980	252,000	±	1,830	260,000	±	3,590
6-32-72	4	146,000	±	1,400	134,000	±	1,320	139,000	±	2,650
6-32-77	4	567	±	237	184	±	193	291	±	92
6-33-42	4	380,000	±	2,360	238,000	±	1,770	304,000	±	30,400
6-33-56	3	92	±	165	-154	±	191	-67	±	79
6-34-39A	1	8,230	±	400	---	±	---	8,230	±	---
6-34-41B	4	52,300	±	885	25,000	±	604	39,100	±	6,100
6-34-42	4	106,000	±	1,240	34,300	±	696	65,800	±	15,300
6-34-51	4	113	±	194	-152	±	156	11	±	57
6-35-9	4	196,000	±	1,440	164,000	±	1,480	183,000	±	6,800
6-35-66	4	1,210,000	±	3,630	1,120,000	±	3,760	1,170,000	±	18,900
6-35-70	4	1,180,000	±	4,120	984,000	±	3,110	1,080,000	±	44,000
6-35-78A	4	178	±	194	-14	±	132	100	±	41
6-36-46P[c]	1	-111	±	182	---	±	---	-111	±	---
6-36-46Q[c]	1	375	±	201	---	±	---	375	±	---
6-36-61B	4	2,360	±	260	78	±	199	972	±	548
6-36-93	2	248	±	184	196	±	198	222	±	26
6-37-E4	1	51,100	±	873	---	±	---	51,100	±	---
6-37-43	1	58,300	±	910	---	±	---	58,300	±	---
6-37-82A	4	292	±	209	-399	±	220	-43	±	141
6-38-15	4	489,000	±	2,630	374,000	±	2,160	451,000	±	26,100
6-38-65	4	419,000	±	2,370	397,000	±	2,390	403,000	±	5,350
6-38-70	3	1,460	±	236	914	±	255	1,180	±	158
6-39-0	1	242,000	±	1,870	---	±	---	242,000	±	---
6-39-39	4	316	±	199	150	±	203	234	±	38
6-39-79	4	226	±	195	-385	±	221	18	±	139
6-40-1	4	246,000	±	1,610	237,000	±	1,840	243,000	±	1,940
6-40-33A	1	367	±	206	---	±	---	367	±	---
6-40-62	4	86,900	±	1,090	76,600	±	1,060	80,100	±	2,330
6-41-1	8	243,000	±	1,790	234,000	±	1,790	238,000	±	1,210
6-41-23	4	135,000	±	1,400	103,000	±	1,190	116,000	±	6,870
6-42-2	1	219,000	±	1,790	---	±	---	219,000	±	---
6-42-12A	4	299,000	±	2,090	292,000	±	1,970	297,000	±	1,550
6-42-40A	5	426	±	216	-371	±	215	34	±	144
6-42-40B	12	2,070	±	257	-39	±	197	342	±	172
6-42-40C[c]	2	2,220	±	259	1,430	±	240	1,830	±	395
6-42-42B	1	77,800	±	1,030	---	±	---	77,800	±	---

TABLE C.40. (Tritium contd)

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum			Minimum			Average		
6-43-3	4	242,000	±	1,790	224,000	±	1,720	235,000	±	3,870
6-43-42J	1	1,200	±	259	---	±	---	1,200	±	---
6-43-43	1	539	±	242	---	±	---	539	±	---
6-43-88	4	88	±	196	-39	±	134	35	±	27
6-44-4	1	128,000	±	1,550	---	±	---	128,000	±	---
6-44-42	1	963	±	254	---	±	---	963	±	---
6-44-64	4	647	±	217	511	±	216	593	±	30
6-45-2	4	220,000	±	1,700	202,000	±	1,720	209,000	±	4,030
6-45-42	12	52,300	±	867	45,600	±	798	48,700	±	598
6-45-69A	4	331	±	223	99	±	201	226	±	57
6-46-4	4	167,000	±	1,560	149,000	±	1,400	156,000	±	3,850
6-46-21B	4	48,300	±	819	46,000	±	714	47,600	±	537
6-47-5	11	221,000	±	1,780	139,000	±	1,390	189,000	±	7,760
6-47-35A	1	-129	±	196	---	±	---	-129	±	---
6-47-46A	4	198	±	216	-132	±	194	72	±	73
6-47-50[c]	4	307	±	206	95	±	200	217	±	52
6-47-60	4	128	±	219	-153	±	193	-32	±	59
6-48-7	4	90	±	159	-383	±	209	-63	±	109
6-48-18	4	-44	±	163	-335	±	210	-170	±	62
6-48-71	4	150	±	193	-49	±	133	39	±	49
6-49-13E	4	55	±	195	-348	±	210	-174	±	93
6-49-28	4	1,610	±	208	1,340	±	241	1,510	±	60
6-49-55A	7	14,800	±	500	7,950	±	376	11,800	±	1,000
6-49-55B	2	170	±	197	27	±	166	98	±	72
6-49-57	4	5,390	±	271	3,000	±	287	4,340	±	503
6-49-79	4	53	±	193	-923	±	205	-249	±	227
6-49-100C	4	751	±	231	-57	±	197	196	±	188
6-50-30	4	362	±	232	-55	±	192	162	±	92
6-50-42	4	4,410	±	315	2,490	±	284	3,890	±	466
6-50-45[c]	2	26	±	193	-184	±	180	-79	±	105
6-50-48B[c]	2	219	±	193	81	±	202	150	±	69
6-50-53	7	5,040	±	337	3,070	±	280	3,820	±	257
6-50-85	4	231	±	200	-356	±	210	-59	±	136
6-51-46	2	-10	±	198	-51	±	213	-30	±	21
6-51-63	4	223	±	228	-276	±	189	-14	±	112
6-51-75	4	4	±	165	-187	±	123	-119	±	44
6-52-19	4	62	±	163	-163	±	204	-64	±	54
6-52-46A[c]	2	3,010	±	285	349	±	225	1,680	±	1,330
6-52-48[c]	2	13	±	199	-209	±	208	-98	±	111
6-53-50[c]	2	119	±	165	-84	±	198	18	±	102
6-53-103[c]	2	71	±	194	-430	±	201	-179	±	251
6-54-34	4	792	±	233	-19	±	164	247	±	184
6-54-45A	4	110	±	191	-14	±	190	54	±	29
6-54-57[c]	2	445	±	208	89	±	159	267	±	178
6-55-40	2	862	±	220	255	±	222	559	±	304
6-55-44	2	266	±	223	181	±	198	224	±	43
6-55-50A	4	552	±	230	-29	±	197	289	±	125
6-55-50C	4	229	±	165	-276	±	188	46	±	116

TABLE C.40. (Tritium contd)

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum			Minimum			Average		
6-55-50D	4	368	±	204	9	±	199	177	±	95
6-55-70	1	-171	±	194	---	±	---	-171	±	---
6-55-76	1	525	±	242	---	±	---	525	±	---
6-55-89	2	-76	±	198	-197	±	180	-137	±	60
6-56-43	4	301	±	202	-136	±	193	49	±	94
6-56-53[c]	2	52	±	163	-29	±	197	11	±	41
6-57-29A	4	890	±	257	522	±	217	652	±	83
6-59-58	4	800	±	222	442	±	244	631	±	86
6-60-57	4	505	±	212	227	±	168	427	±	67
6-60-60	1	7,640	±	383	---	±	---	7,640	±	---
6-61-37	4	679	±	182	-32	±	231	441	±	161
6-61-41	4	250	±	169	-293	±	224	85	±	128
6-61-62	4	9,550	±	415	8,820	±	347	9,130	±	159
6-61-66	4	136	±	166	-134	±	190	-7	±	55
6-63-25A	4	1,670	±	246	-54	±	230	398	±	425
6-63-55	4	694	±	182	436	±	210	586	±	55
6-63-58	4	1,670	±	246	1,440	±	208	1,540	±	55
6-63-90	4	64	±	164	-78	±	195	-21	±	31
6-64-27	1	109	±	200	---	±	---	109	±	---
6-64-62	4	8,610	±	396	8,010	±	333	8,360	±	144
6-65-23	1	54	±	198	---	±	---	54	±	---
6-65-50	4	588	±	174	352	±	170	479	±	50
6-65-59A	4	792	±	219	721	±	179	754	±	15
6-65-72	4	3,230	±	293	2,790	±	216	3,020	±	94
6-65-83	4	1,000	±	228	759	±	184	887	±	53
6-66-58	4	1,050	±	191	385	±	206	627	±	146
6-66-64	4	6,850	±	363	5,870	±	344	6,230	±	215
6-66-103	3	248	±	161	161	±	204	218	±	29
6-67-51	4	649	±	182	417	±	172	529	±	60
6-67-86	4	1,110	±	225	600	±	216	869	±	104
6-67-98	4	60	±	199	-103	±	192	-42	±	37
6-68-105	1	509	±	216	---	±	---	509	±	---
6-69-38	4	105	±	193	-131	±	191	-19	±	50
6-70-68	4	1,850	±	256	1,380	±	180	1,650	±	108
6-71-30	4	109	±	196	-2,390	±	---	-608	±	597
6-71-52	4	1,100	±	234	710	±	181	901	±	84
6-71-77	4	4,320	±	314	1,960	±	209	2,730	±	544
6-72-73	2	1,850	±	264	1,670	±	252	1,760	±	90
6-72-88	4	2,880	±	239	2,240	±	215	2,600	±	155
6-72-92	2	2,390	±	279	2,270	±	264	2,330	±	60
6-73-61	4	183	±	165	-247	±	189	46	±	99
6-74-44	4	165	±	198	-196	±	191	-53	±	77
6-77-36	1	112	±	196	---	±	---	112	±	---
6-77-54	4	125	±	203	-42	±	191	47	±	44
6-80-43P	2	165	±	140	58	±	195	112	±	54
6-80-43Q	2	146	±	140	-17	±	192	64	±	82
6-80-43R	2	88	±	196	55	±	136	72	±	16
6-80-43S	2	178	±	199	15	±	196	96	±	82
6-81-58	7	560	±	204	39	±	161	288	±	75

TABLE C.40. (Tritium contd)

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum			Minimum			Average		
6-83-47	2	968	±	216	765	±	219	867	±	102
6-84-35AO	1	243	±	202	---	±	---	243	±	---
6-87-55	4	62,200	±	930	51,300	±	865	56,500	±	2,670
6-89-35	4	535	±	214	320	±	172	474	±	51
6-90-45	4	2,950	±	285	2,350	±	226	2,730	±	134
6-96-49	4	13,400	±	482	11,800	±	454	12,700	±	350
6-97-43	4	10,200	±	432	9,250	±	349	9,750	±	238
6-97-51A	4	15,000	±	507	14,000	±	462	14,400	±	217
6-101-48B	4	270	±	208	30	±	198	121	±	55
6-ATH	1	75	±	137	---	±	---	75	±	---
6-ORV-1	1	113	±	138	---	±	---	113	±	---
11-34-15B	1	195	±	142	---	±	---	195	±	---
11-37-16	1	168	±	142	---	±	---	168	±	---
11-39-16C	1	297	±	144	---	±	---	297	±	---
11-41-13C	1	23	±	131	---	±	---	23	±	---
30-42-16	1	267	±	146	---	±	---	267	±	---

(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 5.1, 5.2, and 5.3 for well locations.
(c) Wells that sample a confined aquifer or a composite of confined and unconfined aquifers.

TABLE C.41. Maximum, Minimum, and Average Uranium Concentrations in Ground-Water Samples in 1988

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum	Minimum	Average		
1-B3-1	2	2.33	2.26	2.30	±	0.04
1-B4-1	2	1.51	1.15	1.33	±	0.18
1-B4-2	2	1.25	1.08	1.17	±	0.09
1-B4-3	2	1.19	0.64	0.91	±	0.28
1-B4-4	2	0.97	0.91	0.94	±	0.03
1-B5-1	2	1.05	0.59	0.82	±	0.23
1-D2-5	4	2.46	1.77	2.15	±	0.15
1-D5-12	4	2.54	1.47	1.83	±	0.24
1-D8-3	2	0.56	0.54	0.55	±	0.01
1-F5-1	2	0.95	0.52	0.74	±	0.21
1-F5-3	2	0.24	0.20	0.22	±	0.02
1-F5-4	4	7.60	6.17	6.96	±	0.35
1-F5-6	2	0.23	0.10	0.16	±	0.07
1-F7-1	4	6.59	4.50	5.19	±	0.49
1-F8-1	12	414.	19.1	222.0	±	28.3
1-F8-2	4	174.	70.7	117.0	±	22.1
1-H3-1	3	5.48	4.55	5.05	±	0.27
1-H3-2A	4	2.34	1.46	1.90	±	0.23
1-H3-2B	3	2.43	1.76	2.08	±	0.19
1-H3-2C	3	0.95	0.88	0.92	±	0.02
1-H4-3	9	165.9	58.7	89.5	±	11.4
1-H4-4	15	89.6	19.3	64.9	±	5.7
1-H4-5	4	3.43	2.58	2.98	±	0.23
1-H4-6	4	4.13	3.10	3.51	±	0.23
1-H4-7	3	3.84	2.95	3.35	±	0.26
1-H4-8	3	3.44	2.80	3.19	±	0.20
1-H4-9	9	8.89	4.33	6.33	±	0.52
1-H4-10	3	1.73	0.83	1.36	±	0.27
1-H4-11	7	3.27	2.40	2.83	±	0.12
1-H4-12A	8	34.37	1.44	15.20	±	4.45
1-H4-12B	8	8.61	3.65	5.92	±	0.66
1-H4-12C	8	8.40	0.25	1.93	±	0.93
1-H4-13	3	1.45	0.90	1.18	±	0.16
1-H4-14	5	1.76	1.43	1.56	±	0.06
1-H4-15A	3	1.81	1.41	1.58	±	0.12
1-H4-15B	3	2.59	1.53	1.92	±	0.34
1-H4-16	4	1.34	0.08	0.90	±	0.28
1-H4-17	3	2.95	2.30	2.71	±	0.20
1-H4-18	8	2.11	1.34	1.84	±	0.09
1-K-11	2	5.24	4.73	4.99	±	0.25
1-K-19	6	1.17	0.63	0.84	±	0.07
1-K-20	2	1.76	0.94	1.35	±	0.41
1-K-22	3	0.77	0.66	0.73	±	0.04

TABLE C.41. (Uranium contd)

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum	Minimum	Average		
1-K-27	2	3.55	3.37	3.46	±	0.09
1-K-28	2	3.77	3.44	3.61	±	0.16
1-K-29	2	1.78	1.76	1.77	±	0.01
1-K-30	2	2.00	1.89	1.95	±	0.05
1-N-2	5	0.35	0.19	0.25	±	0.03
1-N-3	4	1.33	1.02	1.18	±	0.08
1-N-4	5	0.98	0.25	0.44	±	0.13
1-N-5	3	1.04	0.50	0.72	±	0.16
1-N-6	3	2.98	0.46	1.38	±	0.81
1-N-14	6	0.30	0.04	0.18	±	0.04
1-N-15	2	1.11	0.83	0.97	±	0.14
1-N-16	2	3.66	0.84	2.25	±	1.41
1-N-18	4	2.48	1.14	1.87	±	0.34
1-N-19	3	2.74	1.89	2.26	±	0.25
1-N-20	2	4.92	4.44	4.68	±	0.24
1-N-21	5	5.36	3.87	4.66	±	0.27
1-N-22	1	6.59	---	6.59	±	---
1-N-23	3	8.12	5.98	6.70	±	0.71
1-N-24	1	2.50	---	2.50	±	---
1-N-25	4	3.11	1.52	2.18	±	0.35
1-N-27	5	1.07	0.66	0.86	±	0.09
1-N-28	4	3.84	0.46	1.39	±	0.82
1-N-29	5	0.74	0.32	0.51	±	0.08
1-N-30	2	0.44	0.40	0.42	±	0.02
1-N-31	6	0.70	0.20	0.52	±	0.08
1-N-32	5	1.11	0.48	0.82	±	0.11
1-N-33	8	0.70	0.50	0.58	±	0.02
1-N-36	6	0.59	0.36	0.50	±	0.04
1-N-37	2	0.62	0.55	0.59	±	0.04
1-N-39	4	0.57	0.50	0.54	±	0.02
1-N-41	3	0.50	0.35	0.43	±	0.05
1-N-42	3	0.62	0.38	0.50	±	0.07
1-N-45	7	1.12	0.45	0.64	±	0.09
1-N-49	3	0.65	0.26	0.40	±	0.13
1-N-50	2	0.68	0.46	0.57	±	0.11
1-N-51	2	0.64	0.54	0.59	±	0.05
1-N-52	6	1.67	0.52	0.84	±	0.18
1-N-58	4	2.60	1.34	1.88	±	0.32
1-N-59	2	2.93	0.81	1.87	±	1.06
1-N-60	2	0.54	0.50	0.52	±	0.02
1-N-61	2	0.86	0.57	0.72	±	0.15
1-N-67	1	0.53	---	0.53	±	---
1-N-69	1	0.36	---	0.36	±	---
1-N-70	2	0.53	0.32	0.42	±	0.11

TABLE C.41. (Uranium contd)

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum	Minimum	Average		
2-E13-5	2	1.71	1.61	1.66	±	0.05
2-E13-8	2	2.22	2.10	2.16	±	0.06
2-E13-14	2	1.78	1.75	1.77	±	0.02
2-E13-19	2	3.04	2.38	2.71	±	0.33
2-E17-1	1	2.25	---	2.25	±	---
2-E17-2	4	6.16	3.47	4.60	±	0.59
2-E17-5	12	6.55	3.22	5.55	±	0.26
2-E17-9	5	2.77	1.37	2.35	±	0.25
2-E17-12	12	4.06	2.25	3.22	±	0.19
2-E17-13	12	4.93	2.09	3.53	±	0.22
2-E24-2	2	5.67	2.89	4.28	±	1.39
2-E24-8	2	2.29	1.47	1.88	±	0.41
2-E25-9	4	0.74	0.41	0.55	±	0.07
2-E25-10	2	1.43	1.10	1.26	±	0.16
2-E27-1	2	0.96	0.94	0.95	±	0.01
2-E27-5	2	2.04	1.50	1.77	±	0.27
2-E27-8	3	1.99	1.82	1.92	±	0.05
2-E27-9	2	2.23	2.07	2.15	±	0.08
2-E27-10	2	2.40	1.82	2.11	±	0.29
2-E28-7	4	1.19	0.49	0.92	±	0.16
2-E28-9	4	6.36	3.02	5.48	±	0.82
2-E28-12	1	14.14	---	14.10	±	---
2-E28-13	1	2.41	---	2.41	±	---
2-E28-16	2	7.70	6.45	7.08	±	0.62
2-E28-17	4	8.68	5.60	6.95	±	0.76
2-E28-18	12	40.95	6.34	28.40	±	2.73
2-E28-19	4	10.71	4.56	7.83	±	1.48
2-E28-21	12	33.04	17.22	26.40	±	1.54
2-E28-23	4	19.32	14.35	17.20	±	1.11
2-E28-24	4	0.31	0.13	0.19	±	0.04
2-E28-25	4	13.72	5.36	8.98	±	2.08
2-E28-26	2	37.31	28.50	32.90	±	4.40
2-E28-27	2	3.44	2.51	2.98	±	0.47
2-E32-2	2	3.72	3.01	3.37	±	0.36
2-E32-3	2	15.33	7.75	11.50	±	3.79
2-E32-4	2	5.41	2.46	3.94	±	1.48
2-E33-1A	2	2.20	1.41	1.81	±	0.40
2-E33-3	2	2.19	1.74	1.97	±	0.23
2-E33-5	2	2.25	2.09	2.17	±	0.08
2-E33-7	2	1.86	1.50	1.68	±	0.18
2-E33-8	2	2.44	1.66	2.05	±	0.39
2-E33-9	1	2.23	---	2.23	±	---
2-E33-10	2	1.66	1.43	1.55	±	0.12
2-E33-12[c]	2	0.24	0.10	0.17	±	0.07
2-E33-14	2	1.49	1.15	1.32	±	0.17
2-E33-18	2	1.66	1.63	1.65	±	0.02
2-E33-20	2	2.23	2.16	2.20	±	0.04
2-E33-21	2	1.35	1.29	1.32	±	0.03

TABLE C.41. (Uranium contd)

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum	Minimum	Average		
2-E33-24	2	1.90	1.76	1.83	±	0.07
2-E33-27	1	1.59	---	1.59	±	---
2-E33-28	2	1.76	1.35	1.55	±	0.20
2-E33-29	2	1.86	1.30	1.58	±	0.28
2-E33-30	3	1.99	1.29	1.53	±	0.23
2-E34-2	2	2.41	2.09	2.25	±	0.16
2-E34-3	2	1.74	1.28	1.51	±	0.23
2-E34-5	2	3.10	2.93	3.02	±	0.09
2-E34-6	2	3.00	2.71	2.85	±	0.15
2-W6-2	1	0.89	---	0.89	±	---
2-W7-1	2	0.84	0.42	0.63	±	0.21
2-W7-2	2	0.80	0.62	0.71	±	0.09
2-W7-3	2	1.04	0.54	0.79	±	0.25
2-W7-4	3	1.61	1.45	1.55	±	0.05
2-W7-5	2	1.06	1.04	1.05	±	0.01
2-W7-6	2	4.33	3.17	3.75	±	0.58
2-W8-1	2	0.67	0.60	0.63	±	0.04
2-W9-1	2	1.08	0.78	0.93	±	0.15
2-W10-1	2	2.18	1.84	2.01	±	0.17
2-W10-3	2	14.80	7.38	11.10	±	3.71
2-W10-4	2	0.99	0.74	0.86	±	0.12
2-W10-8	2	1.15	1.04	1.10	±	0.05
2-W10-9	2	2.38	1.94	2.16	±	0.22
2-W10-13	1	0.54	---	0.54	±	---
2-W10-14	1	0.59	---	0.59	±	---
2-W11-3	2	1.29	0.72	1.00	±	0.29
2-W11-9	1	1.08	---	1.08	±	---
2-W14-2	2	1.07	0.95	1.01	±	0.06
2-W14-5	2	0.71	0.48	0.59	±	0.11
2-W14-6	2	0.72	0.63	0.68	±	0.05
2-W15-4	2	4.51	2.70	3.61	±	0.91
2-W15-15	3	3.62	3.23	3.39	±	0.12
2-W15-16	2	1.88	1.86	1.87	±	0.01
2-W15-17	2	0.55	0.45	0.50	±	0.05
2-W15-18	2	0.80	0.52	0.66	±	0.13
2-W18-15	4	44.2	39.1	41.0	±	1.17
2-W18-21	2	22.3	22.1	22.2	±	0.12
2-W18-22	2	0.56	0.38	0.47	±	0.09
2-W18-23	1	0.83	---	0.83	±	---
2-W18-24	1	0.90	---	0.90	±	---
2-W19-2	12	99.4	44.6	77.8	±	4.6
2-W19-3	11	3,605.	1,673.	2,200.	±	174.
2-W19-5	2	7.34	6.70	7.02	±	0.32
2-W19-9	4	1,498.	903.	1,080.	±	141.
2-W19-11	3	2,744.	1,827.	2,270.	±	265.
2-W19-12	2	2.62	2.33	2.47	±	0.14

TABLE C.41. (Uranium contd)

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum	Minimum	Average		
2-W19-13	4	7.21	6.26	6.70	±	0.25
2-W19-14	4	3.21	2.24	2.71	±	0.24
2-W19-15	4	235.2	39.2	127.0	±	43.1
2-W19-16	3	1,078.	486.	780.	±	171.
2-W19-17	3	34.9	14.1	21.6	±	6.7
2-W19-18	12	4,032.	1,806.	2,830.	±	201.
2-W19-19	12	513.	354.	455.	±	12.6
2-W19-20	12	379.	272.	331.	±	8.5
2-W19-21	3	16.2	10.2	13.8	±	1.8
2-W19-23	10	165.	110.	140.	±	5.2
2-W19-24	11	446.	288.	375.	±	14.4
2-W19-25	10	273.	197.	226.	±	7.8
2-W19-26	7	270.	181.	217.	±	13.1
2-W19-27	4	9.73	6.30	7.69	±	0.77
2-W21-1	2	1.47	1.46	1.47	±	0.01
2-W22-1	2	5.15	3.42	4.29	±	0.87
2-W22-2	2	4.57	4.47	4.52	±	0.05
2-W22-7	2	1.48	0.73	1.11	±	0.38
2-W22-9	2	5.36	4.19	4.78	±	0.58
2-W22-10	2	0.09	0.04	0.06	±	0.02
2-W22-12	2	1.04	0.75	0.89	±	0.15
2-W22-20	2	6.90	5.92	6.41	±	0.49
2-W22-22	4	4.36	0.52	1.60	±	0.92
2-W22-26	2	4.71	3.90	4.30	±	0.41
2-W23-1	2	6.28	5.42	5.85	±	0.43
2-W23-2	4	5.97	4.76	5.51	±	0.28
2-W23-4	7	58.7	18.4	37.2	±	5.1
2-W23-8	1	3.26	---	3.26	±	---
2-W23-9	11	20.4	13.8	18.4	±	0.54
2-W23-10	3	43.1	31.4	37.3	±	3.37
2-W23-11	4	20.1	11.8	14.7	±	1.9
2-W27-1	4	9.80	6.22	8.28	±	0.80
3-1-1	4	18.4	11.5	14.4	±	1.48
3-1-2	4	29.9	9.74	17.7	±	4.8
3-1-3	4	75.0	27.9	48.5	±	10.4
3-1-4	4	38.1	12.7	20.8	±	5.9
3-1-5	4	56.8	28.1	42.3	±	6.4
3-1-6	4	19.5	8.4	14.7	±	2.8
3-1-7	6	55.3	28.6	39.7	±	4.7
3-1-8	4	41.0	11.9	24.5	±	7.0
3-1-9	4	0.79	-0.01	0.23	±	0.19
3-1-10	5	20.0	8.49	12.5	±	2.1
3-1-11	34	195.	12.7	59.7	±	8.3
3-1-12	5	63.6	29.6	47.5	±	5.9
3-1-13	5	15.4	5.88	9.91	±	2.07
3-1-14	5	17.3	7.76	12.5	±	1.92
3-1-15	5	6.79	4.81	5.62	±	0.42

TABLE C.41. (Uranium contd)

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum	Minimum	Average		
3-1-16A	5	14.9	8.37	10.90	±	1.18
3-1-16B	5	2.58	0.89	1.92	±	0.35
3-1-16C	5	9.15	0.14	3.44	±	1.57
3-1-16D	3	0.10	0.02	0.04	±	0.03
3-1-17A	35	274.	44.0	115.0	±	9.0
3-1-17B	5	0.90	0.06	0.29	±	0.16
3-1-17C	5	0.17	0.01	0.07	±	0.03
3-1-18A	6	5.20	2.32	3.89	±	0.41
3-1-18B	4	0.36	-0.01	0.12	±	0.08
3-1-18C	4	0.54	-0.01	0.17	±	0.13
3-1-19	33	245.7	17.4	136.0	±	9.2
3-2-1	5	10.90	6.88	8.68	±	0.77
3-2-2	5	31.8	6.6	15.7	±	4.4
3-2-3	4	11.2	7.1	9.1	±	1.0
3-3-3	4	7.15	5.31	6.10	±	0.38
3-3-6	4	11.4	6.6	9.2	±	1.1
3-3-7	5	14.7	6.5	9.9	±	1.3
3-3-9	5	19.9	8.6	13.1	±	2.2
3-3-10	5	27.8	12.7	22.9	±	2.9
3-3-11	4	32.5	16.0	22.8	±	3.5
3-3-12	4	25.6	15.3	21.0	±	2.5
3-4-1	5	13.2	8.5	10.0	±	0.9
3-4-7	5	34.6	24.7	29.8	±	1.8
3-4-9	4	28.6	14.3	22.4	±	3.0
3-4-10	4	30.4	21.7	27.1	±	2.0
3-4-11	5	13.2	6.3	8.9	±	1.2
3-5-1	4	4.3	4.2	4.25	±	0.02
3-6-1	5	6.57	5.56	6.07	±	0.18
3-8-1	5	3.03	2.60	2.88	±	0.08
3-8-2	5	1.92	1.38	1.79	±	0.10
3-8-3	6	4.17	3.07	3.47	±	0.15
3-8-4	4	2.00	1.70	1.88	±	0.06
6-S36-E13A	1	1.86	---	1.86	±	---
6-S32-E13A	1	2.09	---	2.09	±	---
6-S32-E13B	1	1.60	---	1.60	±	---
6-S31-E13	1	1.66	---	1.66	±	---
6-S31-1	1	1.12	---	1.12	±	---
6-S30-E15A	3	1.79	1.52	1.63	±	0.08
6-S29-E12	5	2.52	1.97	2.26	±	0.09
6-S28-E0	4	1.39	0.83	1.23	±	0.13
6-S27-E14	12	4.79	3.25	3.74	±	0.15
6-S24-19	2	0.08	-0.02	0.03	±	0.05
6-S19-E13	4	3.62	2.55	3.18	±	0.23
6-S14-20A	2	0.23	0.14	0.18	±	0.04
6-S12-3	2	3.43	2.93	3.18	±	0.25
6-S6-E4B	4	3.47	2.01	2.63	±	0.31

TABLE C.41. (Uranium contd)

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum	Minimum	Average		
6-S6-E4D	5	3.22	2.58	2.93	±	0.12
6-3-45	2	0.40	0.05	0.22	±	0.17
6-20-E12	4	1.34	0.05	0.93	±	0.30
6-20-20	4	3.12	2.28	2.72	±	0.17
6-32-70B	4	1.74	1.08	1.35	±	0.15
6-32-72	4	0.42	0.06	0.31	±	0.08
6-35-66	4	2.39	1.84	2.13	±	0.14
6-35-70	4	2.95	1.75	2.39	±	0.25
6-35-78A	4	18.1	11.8	14.6	±	1.3
6-38-65	4	2.18	1.54	1.78	±	0.14
6-38-70	11	47.0	39.6	42.4	±	0.7
6-41-1	7	3.74	2.52	3.21	±	0.15
6-42-12A	4	2.66	1.68	2.05	±	0.21
6-42-40A	4	0.58	0.34	0.52	±	0.06
6-45-42	12	1.97	1.32	1.52	±	0.05
6-46-21B	1	1.87	---	1.87	±	---
6-47-5	4	2.26	1.53	2.03	±	0.17
6-47-46A	4	2.75	2.20	2.45	±	0.11
6-47-60	4	2.28	1.79	2.00	±	0.12
6-49-55A	7	3.83	2.47	3.00	±	0.17
6-49-57	4	2.51	1.38	1.74	±	0.26
6-51-63	4	1.32	1.12	1.21	±	0.05
6-55-50A	4	1.55	0.02	0.44	±	0.37
6-55-50C	4	0.97	0.81	0.87	±	0.04
6-55-50D	4	2.53	0.07	1.67	±	0.56
6-55-70	1	0.32	---	0.32	±	---
6-55-89	2	1.26	0.79	1.03	±	0.23
6-59-58	4	0.87	0.71	0.79	±	0.04
6-60-57	4	0.56	0.15	0.35	±	0.10
6-60-60	1	0.53	---	0.53	±	---
6-61-62	4	1.72	1.39	1.55	±	0.08
6-61-66	4	1.92	1.28	1.52	±	0.14
6-63-55	4	1.25	0.79	0.92	±	0.11
6-63-58	4	1.05	0.77	0.89	±	0.07
6-64-62	4	1.63	1.29	1.46	±	0.08
6-65-50	4	6.56	1.15	2.51	±	1.35
6-65-59A	4	0.93	0.66	0.84	±	0.06
6-65-72	4	2.68	1.34	1.84	±	0.29
6-66-58	4	2.04	0.78	1.13	±	0.31
6-66-64	4	1.93	1.17	1.49	±	0.16
6-67-51	4	1.08	0.95	1.03	±	0.03
6-70-68	4	1.26	0.63	0.95	±	0.13
6-71-52	4	1.76	1.64	1.70	±	0.03
6-71-77	4	1.59	1.43	1.49	±	0.04
6-73-61	4	1.61	1.23	1.44	±	0.08
6-81-58	3	2.05	0.73	1.22	±	0.42
6-96-49	4	1.47	0.83	1.10	±	0.15
6-97-51A	4	2.01	1.15	1.45	±	0.19

TABLE C.41. (Uranium contd)

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum	Minimum	Average		
6-ATH	1	9.66	---	9.66	±	---
6-ORV-1	1	-0.01	---	-0.01	±	---
11-37-16	1	0.28	---	0.28	±	---
11-39-16C	1	0.20	---	0.20	±	---
11-41-13C	1	1.37	---	1.37	±	---
30-42-16	1	0.53	---	0.53	±	---

(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 5.1, 5.2, and 5.3 for well locations.
(c) Wells that sample a confined aquifer or a composite of confined and unconfined aquifers.

TABLE C.42. Maximum, Minimum, and Average Iodine-129 (^{129}I) Concentrations in Ground-Water Samples in 1988

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum			Minimum			Average		
1-N-2	1	0.22	±	0.21	---	±	---	0.22	±	---
1-N-14	1	0.20	±	0.16	---	±	---	0.20	±	---
1-N-29	1	-0.39	±	0.31	---	±	---	-0.39	±	---
1-N-33	1	0.23	±	0.31	---	±	---	0.23	±	---
2-E13-8	1	1.30	±	0.17	---	±	---	1.30	±	---
2-E13-14	1	-0.010	±	0.055	---	±	---	-0.010	±	---
2-E13-19	1	0.01	±	0.05	---	±	---	0.01	±	---
2-E16-2	1	0.21	±	0.07	---	±	---	0.21	±	---
2-E17-2	1	1.18	±	0.17	---	±	---	1.18	±	---
2-E17-5	3	15.6	±	1.7	3.21	±	0.37	10.8	±	3.9
2-E17-6	3	-0.001	±	0.050	-0.232	±	3.030	-0.078	±	0.077
2-E17-9	1	20.4	±	4.0	---	±	---	20.4	±	---
2-E17-12	2	2.57	±	0.29	2.23	±	0.27	2.40	±	0.17
2-E17-13	2	2.11	±	0.25	1.51	±	0.19	1.81	±	0.30
2-E17-14	1	11.5	±	3.2	---	±	---	11.5	±	---
2-E17-15	1	12.7	±	4.0	---	±	---	12.7	±	---
2-E17-16	2	4.07	±	2.13	1.78	±	3.63	2.93	±	1.14
2-E17-17	1	14.5	±	3.9	---	±	---	14.5	±	---
2-E17-18	1	2.86	±	1.55	---	±	---	2.86	±	---
2-E23-1	1	1.65	±	0.20	---	±	---	1.65	±	---
2-E24-1	1	26.6	±	2.8	---	±	---	26.6	±	---
2-E24-7	1	2.09	±	0.24	---	±	---	2.09	±	---
2-E24-12	1	1.91	±	0.23	---	±	---	1.91	±	---
2-E24-13	1	2.56	±	0.29	---	±	---	2.56	±	---
2-E25-3	1	1.17	±	0.15	---	±	---	1.17	±	---
2-E25-9	1	0.96	±	0.15	---	±	---	0.96	±	---
2-E25-11	1	0.29	±	0.08	---	±	---	0.29	±	---
2-E25-19	1	0.44	±	0.044	---	±	---	0.44	±	---
2-E25-22	1	0.43	±	0.079	---	±	---	0.43	±	---
2-E25-23	1	0.054	±	0.051	---	±	---	0.054	±	---
2-E25-24	1	0.039	±	0.052	---	±	---	0.039	±	---
2-E26-1	1	0.28	±	0.096	---	±	---	0.28	±	---
2-E26-2	1	1.25	±	0.16	---	±	---	1.25	±	---
2-E26-3	1	1.23	±	0.19	---	±	---	1.23	±	---
2-E26-4	1	1.37	±	0.18	---	±	---	1.37	±	---
2-E27-1	1	1.41	±	0.19	---	±	---	1.41	±	---
2-E27-5	1	1.53	±	0.21	---	±	---	1.53	±	---
2-E28-1	1	1.06	±	0.16	---	±	---	1.06	±	---
2-E28-7	1	1.26	±	0.16	---	±	---	1.26	±	---
2-E33-1A	1	0.70	±	0.11	---	±	---	0.70	±	---
2-E33-5	1	0.84	±	0.14	---	±	---	0.84	±	---
2-E33-7	1	0.37	±	0.08	---	±	---	0.37	±	---
2-E33-8	1	1.48	±	0.19	---	±	---	1.48	±	---
2-E33-18	1	0.95	±	0.13	---	±	---	0.95	±	---
2-E33-20	1	0.69	±	0.11	---	±	---	0.69	±	---

TABLE C.42. (^{129}I contd)

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum			Minimum			Average		
2-E33-21	1	1.38	±	0.18	---	±	---	1.38	±	---
2-E33-24	1	0.99	±	0.14	---	±	---	0.99	±	---
2-W6-1	1	0.003	±	0.12	---	±	---	0.003	±	---
2-W10-1	1	0.010	±	0.057	---	±	---	0.010	±	---
2-W10-3	1	0.17	±	0.06	---	±	---	0.17	±	---
2-W10-4	1	-0.034	±	0.060	---	±	---	-0.034	±	---
2-W10-5	1	0.036	±	0.049	---	±	---	0.036	±	---
2-W10-8	1	-0.020	±	0.050	---	±	---	-0.020	±	---
2-W10-9	1	0.030	±	0.052	---	±	---	0.030	±	---
2-W11-3	1	0.101	±	0.046	---	±	---	0.101	±	---
2-W12-1	1	0.24	±	0.07	---	±	---	0.24	±	---
2-W15-2	1	0.028	±	0.053	---	±	---	0.028	±	---
2-W15-7	1	0.10	±	0.08	---	±	---	0.10	±	---
2-W15-10	1	0.017	±	0.058	---	±	---	0.017	±	---
2-W15-11	1	-0.011	±	0.054	---	±	---	-0.011	±	---
2-W18-3	1	0.028	±	0.048	---	±	---	0.028	±	---
2-W19-3	1	15.5	±	1.7	---	±	---	15.5	±	---
2-W19-9	1	1.54	±	0.21	---	±	---	1.54	±	---
2-W19-15	1	1.29	±	0.17	---	±	---	1.29	±	---
2-W19-16	1	2.25	±	0.27	---	±	---	2.25	±	---
2-W21-1	1	3.37	±	0.19	---	±	---	3.37	±	---
2-W22-7	1	1.63	±	0.22	---	±	---	1.63	±	---
2-W22-9	1	23.9	±	2.4	---	±	---	23.9	±	---
2-W22-10	1	-0.005	±	0.058	---	±	---	-0.005	±	---
2-W22-20	1	0.34	±	0.08	---	±	---	0.34	±	---
2-W23-1	1	0.021	±	0.078	---	±	---	0.021	±	---
2-W23-4	1	-0.013	±	0.053	---	±	---	-0.013	±	---
4-S1-7B	1	0.015	±	0.19	---	±	---	0.015	±	---
4-S1-7C	1	-0.12	±	0.17	---	±	---	-0.12	±	---
4-S1-8A	1	0.024	±	0.33	---	±	---	0.024	±	---
4-S1-8B	1	-0.072	±	0.090	---	±	---	-0.072	±	---
4-S1-8C	1	0.000	±	0.20	---	±	---	0.000	±	---
4-S0-7	1	0.022	±	0.056	---	±	---	0.022	±	---
4-S0-8	1	0.055	±	0.067	---	±	---	0.055	±	---
6-S28-E0	1	0.009	±	0.050	---	±	---	0.009	±	---
6-S12-3	1	0.30	±	0.33	---	±	---	0.30	±	---
6-S8-19	1	-0.16	±	0.33	---	±	---	-0.16	±	---
6-S6-E4B	1	0.17	±	0.33	---	±	---	0.17	±	---
6-S6-E4D	1	0.16	±	0.20	---	±	---	0.16	±	---
6-S3-E12	1	-0.035	±	0.072	---	±	---	-0.035	±	---
6-S3-25	1	0.008	±	0.044	---	±	---	0.007	±	---
6-1-18	1	0.057	±	0.071	---	±	---	0.057	±	---
6-2-3	1	0.11	±	0.34	---	±	---	0.11	±	---
6-2-33A	1	0.096	±	0.36	---	±	---	0.096	±	---

TABLE C.42. (^{129}I contd)

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum			Minimum			Average		
6-3-45	1	-0.005	±	0.056	---	±	---	-0.005	±	---
6-8-17	1	0.53	±	0.35	---	±	---	0.53	±	---
6-8-25	1	0.15	±	0.36	---	±	---	0.15	±	---
6-8-32	1	-0.08	±	0.34	---	±	---	-0.08	±	---
6-10-E12	1	0.005	±	0.32	---	±	---	0.005	±	---
6-13-64	1	0.087	±	0.085	---	±	---	0.087	±	---
6-14-38	1	0.027	±	0.099	---	±	---	0.027	±	---
6-15-15B	1	0.049	±	0.084	---	±	---	0.049	±	---
6-15-26	1	1.59	±	0.36	---	±	---	1.59	±	---
6-17-47	1	-0.14	±	0.21	---	±	---	-0.14	±	---
6-20-E12	1	0.033	±	0.059	---	±	---	0.033	±	---
6-20-E5A	1	0.09	±	0.33	---	±	---	0.09	±	---
6-20-20	1	1.52	±	0.40	---	±	---	1.52	±	---
6-21-6	1	-0.14	±	0.20	---	±	---	-0.14	±	---
6-24-33	1	2.71	±	0.43	---	±	---	2.71	±	---
6-24-46	1	0.050	±	0.058	---	±	---	0.050	±	---
6-25-70	1	-0.09	±	0.35	---	±	---	-0.09	±	---
6-26-15A	1	1.89	±	0.34	---	±	---	1.89	±	---
6-27-8	1	2.27	±	0.45	---	±	---	2.27	±	---
6-28-40	1	0.21	±	0.34	---	±	---	0.21	±	---
6-29-4	1	0.32	±	0.20	---	±	---	0.32	±	---
6-29-78	1	-0.30	±	0.20	---	±	---	-0.30	±	---
6-32-22	1	1.53	±	0.20	---	±	---	1.53	±	---
6-32-43	1	6.69	±	0.79	---	±	---	6.69	±	---
6-32-62	1	0.018	±	0.19	---	±	---	0.018	±	---
6-32-70B	1	3.25	±	0.56	---	±	---	3.25	±	---
6-32-72	1	0.039	±	0.32	---	±	---	0.039	±	---
6-32-77	1	0.068	±	0.20	---	±	---	0.068	±	---
6-34-51	1	0.29	±	0.20	---	±	---	0.29	±	---
6-35-9	1	0.53	±	0.38	---	±	---	0.53	±	---
6-35-66	1	6.56	±	0.84	---	±	---	6.56	±	---
6-35-70	2	87.8	±	5.9	13.0	±	1.3	50.4	±	37.4
6-36-61B	1	0.038	±	0.21	---	±	---	0.038	±	---
6-37-43	1	1.81	±	0.21	---	±	---	1.81	±	---
6-38-15	1	0.43	±	0.10	---	±	---	0.43	±	---
6-38-65	1	3.51	±	0.55	---	±	---	3.51	±	---
6-38-70	1	1.42	±	0.30	---	±	---	1.42	±	---
6-39-39	1	0.079	±	0.19	---	±	---	0.079	±	---
6-39-79	1	-0.55	±	0.34	---	±	---	-0.55	±	---
6-40-62	1	0.27	±	0.22	---	±	---	0.27	±	---
6-41-1	1	0.28	±	0.24	---	±	---	0.28	±	---
6-41-23	1	6.33	±	0.81	---	±	---	6.33	±	---
6-42-12A	1	0.57	±	0.19	---	±	---	0.57	±	---
6-42-40C[c,d]	2	0.15	±	0.01	0.14	±	0.01	0.145	±	0.007
6-43-3	1	0.47	±	0.34	---	±	---	0.47	±	---
6-44-64	1	0.075	±	0.21	---	±	---	0.075	±	---
6-45-2	1	0.39	±	0.31	---	±	---	0.39	±	---

TABLE C.42. (^{129}I contd)

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum			Minimum			Average		
6-45-69A	1	0.11	±	0.21	---	±	---	0.11	±	---
6-46-4	1	0.26	±	0.21	---	±	---	0.26	±	---
6-46-21B	1	0.015	±	0.053	---	±	---	0.015	±	---
6-47-35A	1	0.17	±	0.14	---	±	---	0.17	±	---
6-47-46A	1	-0.33	±	0.33	---	±	---	-0.33	±	---
6-47-50[c,d]	1	0.006	±	0.0003	---	±	---	0.006	±	---
6-47-60	1	-0.031	±	0.059	---	±	---	-0.031	±	---
6-48-7	1	0.12	±	0.31	---	±	---	0.12	±	---
6-48-18	1	-0.023	±	0.22	---	±	---	-0.023	±	---
6-48-71	1	-0.14	±	0.38	---	±	---	-0.14	±	---
6-49-13E	1	-0.008	±	0.05	---	±	---	-0.008	±	---
6-49-28	1	0.03	±	0.05	---	±	---	0.03	±	---
6-49-55A[d]	1	0.071	±	0.002	---	±	---	0.071	±	---
6-49-57	1	0.34	±	0.15	---	±	---	0.34	±	---
6-49-100C	1	-0.045	±	0.051	---	±	---	-0.045	±	---
6-50-42	1	0.32	±	0.21	---	±	---	0.32	±	---
6-50-45[c,d]	1	0.0005	±	0.00004	---	±	---	0.0005	±	---
6-50-48B[c,d]	1	0.0035	±	0.0002	---	±	---	0.0035	±	---
6-50-53	1	0.27	±	0.21	---	±	---	0.27	±	---
6-51-46[d]	1	0.0003	±	0.00002	---	±	---	0.0003	±	---
6-51-63	1	-0.10	±	0.07	---	±	---	-0.10	±	---
6-52-19	1	0.24	±	0.33	---	±	---	0.24	±	---
6-52-46A[c,d]	1	0.0003	±	0.00002	---	±	---	0.0003	±	---
6-52-48[c,d]	1	0.0001	±	0.00001	---	±	---	0.0001	±	---
6-53-50[c,d]	1	0.0006	±	0.00004	---	±	---	0.0006	±	---
6-53-55A	1	-0.055	±	0.096	---	±	---	-0.055	±	---
6-55-50A	1	-0.008	±	0.042	---	±	---	-0.008	±	---
6-55-50C	1	0.028	±	0.045	---	±	---	0.028	±	---
6-55-50D	1	0.073	±	0.041	---	±	---	0.073	±	---
6-56-43	1	0.027	±	0.068	---	±	---	0.027	±	---
6-56-53[c,d]	1	0.0023	±	0.0001	---	±	---	0.0023	±	---
6-59-58	1	0.03	±	1.1	---	±	---	0.03	±	---
6-60-57	1	-0.41	±	0.56	---	±	---	-0.41	±	---
6-61-62	1	0.53	±	0.37	---	±	---	0.53	±	---
6-61-66	1	0.21	±	0.34	---	±	---	0.21	±	---
6-63-58	1	0.31	±	0.32	---	±	---	0.31	±	---
6-64-62	1	0.18	±	0.21	---	±	---	0.18	±	---
6-65-50	1	0.25	±	0.30	---	±	---	0.25	±	---
6-65-59A	1	0.09	±	0.20	---	±	---	0.09	±	---
6-65-72	1	0.007	±	0.044	---	±	---	0.007	±	---
6-66-58	1	0.06	±	0.19	---	±	---	0.06	±	---
6-66-64	1	0.08	±	0.20	---	±	---	0.08	±	---
6-70-68	1	-0.007	±	0.06	---	±	---	-0.007	±	---
6-71-52	1	0.02	±	0.08	---	±	---	0.02	±	---

TABLE C.42. (^{129}I contd)

Well Name[b]	No. of Samples	Concentration (pCi/L)[a] Maximum			Minimum			Average		
6-71-77	1	-0.081	±	0.065	---	±	---	-0.081	±	---
6-72-73	1	-0.009	±	0.071	---	±	---	-0.009	±	---
6-73-61	1	0.03	±	0.38	---	±	---	0.03	±	---

(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 5.1, 5.2, and 5.3 for well locations.
(c) Wells that sample a confined aquifer or a composite of confined and unconfined aquifers.
(d) High sensitivity analysis by mass spectrometry. All other samples analyzed by low-energy photon counting.

TABLE C.43. Maximum, Minimum, and Average Nitrate Concentrations in Ground-Water Samples in 1988

Well Name[b]	No. of Samples	Concentration (ppb)[a] Maximum	Minimum	Average		
1-B3-1	4	28,500	25,000	26,900	±	723
1-B3-2P	1	<2,500	---	<2,500	±	---
1-B3-2Q	1	<2,500	---	<2,500	±	---
1-B4-1	2	11,300	10,100	10,700	±	600
1-B4-2	2	11,300	10,100	10,700	±	600
1-B4-3	2	11,400	10,200	10,800	±	600
1-B4-4	2	10,300	9,490	9,900	±	405
1-B5-1	2	10,900	9,720	10,300	±	590
1-B9-1	2	22,100	21,900	22,000	±	100
1-D2-5	4	87,500	76,800	81,000	±	2,280
1-D5-12	4	109,000	60,400	82,100	±	10,300
1-D8-3	2	41,500	38,700	40,100	±	1,400
1-F5-1	2	9,420	3,290	6,360	±	3,070
1-F5-3	2	<2,500	<2,500	<2,500	±	---
1-F5-4	7	74,400	65,800	70,100	±	1,340
1-F5-6	2	<2,500	<2,500	<2,500	±	---
1-F7-1	7	93,200	85,200	88,500	±	1,100
1-F8-1	13	244,000	160,000	202,000	±	6,700
1-F8-2	4	136,000	100,000	123,000	±	8,060
1-H3-1	3	63,100	59,000	61,500	±	1,280
1-H3-2A	4	19,700	17,100	18,500	±	603
1-H3-2B	3	22,500	17,400	20,700	±	1,640
1-H3-2C	3	3,660	3,210	3,390	±	136
1-H4-3	12	663,000	169,000	330,000	±	48,900
1-H4-4	19	320,000	79,300	238,000	±	16,500
1-H4-5	4	40,800	37,400	38,800	±	824
1-H4-6	4	40,000	38,600	39,100	±	304
1-H4-7	3	36,600	30,300	34,000	±	1,890
1-H4-8	3	39,100	37,100	38,200	±	586
1-H4-9	12	256,000	62,800	142,000	±	20,500
1-H4-10	3	17,000	9,620	14,500	±	2,440
1-H4-11	9	50,400	22,900	29,100	±	2,740
1-H4-12A	10	138,000	15,300	76,700	±	13,500
1-H4-12B	10	101,000	35,300	61,500	±	6,830
1-H4-12C	10	6,500	5,570	6,140	±	96
1-H4-13	3	17,600	14,600	16,200	±	869
1-H4-14	5	21,100	17,000	18,900	±	817
1-H4-15A	3	31,700	24,200	28,300	±	2,200
1-H4-15B	3	28,900	27,000	28,000	±	555
1-H4-16	6	21,400	12,600	17,000	±	1,210
1-H4-17	5	52,400	44,700	48,100	±	1,680
1-H4-18	10	23,000	18,600	21,200	±	420

TABLE C.43. (Nitrate contd)

Well Name[b]	No. of Samples	Concentration (ppb)[a] Maximum	Minimum	Average		
1-K-11	2	49,900	47,900	48,900	±	1,000
1-K-19	6	86,800	41,500	63,900	±	6,480
1-K-20	2	22,200	22,100	22,200	±	50
1-K-22	2	2,880	2,720	2,800	±	80
1-K-27	2	11,100	7,900	9,500	±	1,600
1-K-28	2	20,400	18,300	19,400	±	1,050
1-K-29	2	9,300	8,550	8,930	±	375
1-K-30	2	70,100	66,000	68,100	±	2,050
1-N-2	6	38,700	28,800	34,200	±	1,540
1-N-3	3	28,400	21,200	24,900	±	2,080
1-N-4	6	32,000	23,500	27,200	±	1,320
1-N-5	3	21,500	20,600	20,900	±	300
1-N-6	3	27,600	17,900	23,500	±	2,890
1-N-14	8	39,700	33,200	35,300	±	874
1-N-15	2	27,400	22,800	25,100	±	2,300
1-N-16	2	<2,500	<2,500	<2,500	±	---
1-N-18	4	<2,500	<2,500	<2,500	±	---
1-N-19	2	4,680	4,570	4,630	±	55
1-N-20	2	8,600	7,410	8,010	±	595
1-N-21	4	18,400	8,200	13,000	±	2,280
1-N-22	1	<2,500	---	<2,500	±	---
1-N-23	2	5,680	4,920	5,300	±	380
1-N-24	1	16,900	---	16,900	±	---
1-N-25	4	13,700	4,000	8,780	±	2,510
1-N-27	6	27,700	13,900	19,600	±	1,950
1-N-28	6	27,200	9,870	14,300	±	2,620
1-N-29	7	24,200	11,400	16,900	±	1,970
1-N-30	2	30,100	26,600	28,400	±	1,750
1-N-31	8	35,600	8,600	24,200	±	3,350
1-N-32	6	56,800	29,700	43,500	±	4,680
1-N-33	7	29,600	21,600	26,600	±	1,150
1-N-36	9	26,900	8,700	17,600	±	1,650
1-N-37	2	30,500	24,900	27,700	±	2,800
1-N-39	4	67,100	30,900	46,100	±	7,950
1-N-41	4	64,200	31,900	46,700	±	6,980
1-N-42	4	28,200	21,800	25,700	±	1,390
1-N-45	4	25,600	6,700	15,800	±	3,990
1-N-49	4	55,400	44,800	50,500	±	2,500
1-N-50	2	44,800	39,500	42,200	±	2,650
1-N-51	2	33,900	30,900	32,400	±	1,500
1-N-52	7	26,300	21,700	24,600	±	579
1-N-58	8	3,850	1,490	2,500	±	313
1-N-59	6	2,400	1,730	2,020	±	109
1-N-60	6	2,120	1,570	1,930	±	79
1-N-61	6	2,770	1,090	1,890	±	293
1-N-67	1	38,500	---	38,500	±	---

TABLE C.43. (Nitrate contd)

Well Name[b]	No. of Samples	Concentration (ppb)[a] Maximum	Minimum	Average		
1-N-69	1	29,000	---	29,000	±	---
1-N-70	2	32,700	32,300	32,500	±	200
2-E13-5	6	12,200	9,830	11,300	±	358
2-E13-8	2	21,300	15,700	18,500	±	2,800
2-E13-14	6	16,100	12,900	14,600	±	480
2-E13-19	2	11,500	10,400	11,000	±	550
2-E16-2	14	5,240	<2,500	<2,560	±	225
2-E17-1	3	308,000	202,000	270,000	±	34,100
2-E17-2	12	121,000	51,300	89,400	±	6,520
2-E17-5	16	234,000	114,000	170,000	±	9,190
2-E17-6	9	46,500	<500	<7,910	±	4,910
2-E17-8	4	222,000	80,000	167,000	±	30,700
2-E17-9	8	146,000	112,000	125,000	±	4,600
2-E17-12	14	56,600	37,900	49,300	±	1,740
2-E17-13	12	85,200	40,500	62,800	±	3,390
2-E17-14	3	238,000	195,000	219,000	±	12,700
2-E17-15	3	345,000	203,000	267,000	±	41,600
2-E17-16	4	74,100	7,290	26,500	±	15,900
2-E17-17	3	105,000	80,800	92,400	±	7,000
2-E17-18	3	27,700	8,300	14,800	±	6,430
2-E17-19	1	116,000	---	116,000	±	---
2-E17-20	1	245,000	---	245,000	±	---
2-E18-1	3	10,100	8,400	8,970	±	567
2-E18-2	3	<500	<500	<500	±	---
2-E18-3	2	<500	<500	<500	±	---
2-E18-4	2	<500	<500	<500	±	---
2-E23-1	2	58,900	15,800	37,400	±	21,600
2-E24-1	12	334,000	82,800	181,000	±	24,100
2-E24-2	7	176,000	66,400	117,000	±	17,200
2-E24-4	4	2,750	<2,500	<2,560	±	63
2-E24-7	2	82,600	29,300	56,000	±	26,700
2-E24-8	5	180,000	3,220	39,000	±	35,200
2-E24-11	4	234,000	114,000	159,000	±	28,600
2-E24-12	9	164,000	97,400	121,000	±	7,700
2-E24-13	4	<2,500	<2,500	<2,500	±	---
2-E24-16	1	98,900	---	98,900	±	---
2-E24-17	1	122,000	---	122,000	±	---
2-E24-18	1	82,600	---	82,600	±	---
2-E25-2	2	<2,500	<2,500	<2,500	±	---
2-E25-3	2	<2,500	<2,500	<2,500	±	---
2-E25-6	4	<2,500	<2,500	<2,500	±	---
2-E25-9	4	<2,500	<2,500	<2,500	±	---
2-E25-11	12	57,300	32,000	40,600	±	2,050
2-E25-13	4	129,000	68,200	97,400	±	12,400
2-E25-17	12	27,700	7,490	14,400	±	1,730
2-E25-18	5	41,300	7,920	24,700	±	6,680
2-E25-19	10	168,000	62,700	110,000	±	15,200

TABLE C.43. (Nitrate contd)

Well Name[b]	No. of Samples	Concentration (ppb)[a] Maximum	Minimum	Average		
2-E25-20	6	182,000	144,000	162,000	±	6,400
2-E25-21	7	8,400	<2,500	<5,680	±	808
2-E25-22	7	5,880	2,740	4,370	±	436
2-E25-23	7	1,760	<2,500	<2,050	±	222
2-E25-24	7	3,070	<2,500	<2,310	±	296
2-E25-25	6	811	582	684	±	36
2-E25-26	3	1,500	1,210	1,370	±	85
2-E25-27	2	4,000	1,520	2,760	±	1,240
2-E25-28	3	1,300	812	1,040	±	142
2-E25-29	2	12,300	9,300	10,800	±	1,500
2-E25-30	2	5,140	4,500	4,820	±	320
2-E25-31	4	7,000	5,150	5,850	±	402
2-E25-32	3	800	665	722	±	40
2-E25-33	3	12,900	6,370	10,200	±	1,970
2-E25-34	1	1,100	---	1,100	±	---
2-E25-35	1	9,000	---	9,000	±	---
2-E25-36	1	2,400	---	2,400	±	---
2-E26-1	3	<2,500	<500	<1,830	±	667
2-E26-2	4	<2,500	<2,500	<2,500	±	---
2-E26-3	2	<2,500	<2,500	<2,500	±	---
2-E26-4	4	<2,500	<2,500	<2,500	±	---
2-E26-5	1	1,490	---	1,490	±	--
2-E26-6	4	12,600	<2,500	<5,030	±	2,530
2-E26-8[c]	2	<2,500	<2,500	<2,500	±	---
2-E27-1	2	3,140	2,780	2,960	±	180
2-E27-5	3	11,700	5,050	7,370	±	2,170
2-E27-7	2	<2,500	<2,500	<2,500	±	---
2-E27-8	3	7,430	7,000	7,250	±	128
2-E27-9	2	7,400	7,350	7,380	±	25
2-E27-10	2	3,200	3,020	3,110	±	90
2-E28-1	2	5,900	3,750	4,830	±	1,080
2-E28-5	1	3,100	---	3,100	±	---
2-E28-7	3	8,290	7,100	7,830	±	368
2-E28-13	2	48,700	39,600	44,200	±	4,550
2-E28-18	14	42,900	23,300	37,200	±	1,520
2-E28-21	15	41,700	34,500	37,300	±	570
2-E28-23	6	10,700	8,700	9,650	±	331
2-E28-26	2	52,900	50,100	51,500	±	1,400
2-E28-27	2	20,900	16,300	18,600	±	2,300
2-E32-1	4	10,200	8,360	9,290	±	472
2-E32-2	2	15,200	13,600	14,400	±	800
2-E32-3	2	39,300	34,500	36,900	±	2,400
2-E32-4	2	25,000	24,200	24,600	±	400
2-E33-1A	5	52,300	6,640	38,400	±	8,140
2-E33-3	5	60,800	40,700	48,900	±	4,280
2-E33-5	5	33,700	30,200	31,700	±	777
2-E33-7	2	119,000	103,000	111,000	±	8,000
2-E33-8	3	7,780	7,700	7,730	±	25

TABLE C.43. (Nitrate contd)

Well Name[b]	No. of Samples	Concentration (ppb)[a] Maximum	Minimum	Average		
2-E33-9	3	8,730	7,300	8,000	±	413
2-E33-10	5	44,700	6,590	14,600	±	7,540
2-E33-12[c]	2	<2,500	<2,500	<2,500	±	---
2-E33-14	2	15,700	15,400	15,600	±	150
2-E33-18	3	19,900	13,700	17,100	±	1,810
2-E33-20	4	4,430	2,730	3,660	±	415
2-E33-21	3	3,500	3,140	3,310	±	104
2-E33-24	3	13,500	11,300	12,200	±	666
2-E33-28	2	4,200	3,990	4,100	±	105
2-E33-29	2	8,740	8,300	8,520	±	220
2-E33-30	3	8,300	8,060	8,190	±	70
2-E34-1	2	13,400	12,000	12,700	±	700
2-E34-2	2	16,400	11,800	14,100	±	2,300
2-E34-3	2	5,400	5,160	5,280	±	120
2-E34-5	2	14,800	14,300	14,600	±	250
2-E34-6	2	6,600	<500	<3,550	±	3,050
2-W6-1	2	226,000	224,000	225,000	±	1,000
2-W6-2	1	80,700	---	80,700	±	---
2-W7-1	2	42,600	8,800	25,700	±	16,900
2-W7-2	2	27,300	23,600	25,500	±	1,850
2-W7-3	2	44,400	2,040	23,200	±	21,200
2-W7-4	3	74,300	72,300	73,600	±	651
2-W7-5	2	45,400	42,400	43,900	±	1,500
2-W7-6	2	7,000	5,690	6,350	±	655
2-W8-1	2	29,800	29,400	29,600	±	200
2-W9-1	2	19,100	17,000	18,100	±	1,050
2-W10-1	2	550,000	456,000	503,000	±	47,000
2-W10-3	2	926,000	661,000	794,000	±	133,000
2-W10-4	5	222,000	194,000	210,000	±	4,570
2-W10-5	2	104,000	93,400	98,700	±	5,300
2-W10-8	3	58,900	2,720	31,300	±	16,200
2-W10-9	4	426,000	356,000	387,000	±	15,300
2-W10-13	1	7,940	---	7,940	±	---
2-W10-14	1	20,800	---	20,800	±	---
2-W11-3	2	85,900	82,700	84,300	±	1,600
2-W11-7	2	215,000	203,000	209,000	±	6,000
2-W11-9	1	56,400	---	56,400	±	---
2-W11-14	2	125,000	116,000	121,000	±	4,500
2-W11-23	2	757,000	113,000	435,000	±	322,000
2-W11-24	2	163,000	148,000	156,000	±	7,500
2-W12-1	2	377,000	331,000	354,000	±	23,000
2-W14-2	5	74,500	51,400	61,200	±	4,330
2-W14-5	5	290,000	41,400	108,000	±	46,300
2-W14-6	14	55,500	14,500	24,400	±	3,570
2-W14-10	3	101,000	82,500	89,300	±	5,890
2-W15-2	2	4,320	3,650	3,990	±	335
2-W15-3	4	140,000	132,000	136,000	±	1,710
2-W15-4	4	699,000	397,000	539,000	±	81,900

TABLE C.43. (Nitrate contd)

Well Name[b]	No. of Samples	Concentration (ppb)[a] Maximum	Minimum	Average		
2-W15-6	4	9,320	5,900	8,000	±	786
2-W15-7	4	60,000	54,800	56,700	±	1,150
2-W15-8	1	139,000	---	139,000	±	---
2-W15-10	5	114,000	66,000	87,200	±	8,820
2-W15-11	5	131,000	95,000	110,000	±	7,920
2-W15-12	2	124,000	116,000	120,000	±	4,000
2-W15-15	3	5,800	4,490	4,940	±	429
2-W15-16	2	70,300	67,500	68,900	±	1,400
2-W15-17	2	23,200	19,500	21,400	±	1,850
2-W15-18	2	76,400	71,600	74,000	±	2,400
2-W18-3	2	115,000	113,000	114,000	±	1,000
2-W18-4	2	65,300	39,200	52,300	±	13,100
2-W18-5	3	277,000	255,000	264,000	±	6,770
2-W18-9	5	6,060	<2,500	<3,900	±	685
2-W18-15	7	1,570	<2,500	<2,030	±	227
2-W18-17	6	2,810,000	<500	<470,000	±	468,000
2-W18-20	3	<2,500	<2,500	<2,500	±	---
2-W18-21	2	2,230	2,200	2,220	±	15
2-W18-22	2	17,300	13,800	15,600	±	1,750
2-W18-23	1	5,620	---	5,620	±	---
2-W18-24	1	23,700	---	23,700	±	---
2-W19-2	12	340,000	222,000	268,000	±	10,500
2-W19-3	14	60,300	36,900	45,800	±	2,060
2-W19-5	4	4,220	<2,500	<2,810	±	477
2-W19-9	8	36,000	16,200	22,000	±	2,920
2-W19-11	4	93,100	86,200	89,700	±	1,700
2-W19-12	2	11,100	7,100	9,100	±	2,000
2-W19-13	7	21,000	17,000	18,900	±	585
2-W19-14	4	10,400	3,540	8,120	±	1,590
2-W19-15	8	107,000	70,300	88,600	±	4,690
2-W19-16	8	53,600	39,100	45,800	±	1,920
2-W19-17	3	9,870	9,660	9,740	±	64
2-W19-18	15	146,000	94,100	119,000	±	3,690
2-W19-19	12	1,450,000	1,220,000	1,330,000	±	18,300
2-W19-20	15	1,110,000	827,000	997,000	±	17,900
2-W19-21	6	600	<500	<1,520	±	440
2-W19-23	11	487,000	346,000	413,000	±	13,900
2-W19-24	14	1,270,000	854,000	1,080,000	±	31,600
2-W19-25	10	841,000	588,000	760,000	±	23,800
2-W19-26	7	1,280,000	850,000	1,110,000	±	55,300
2-W19-27	3	2,580	<2,500	<2,530	±	27
2-W21-1	2	40,700	38,700	39,700	±	1,000
2-W22-1	6	12,400	3,830	6,440	±	1,300
2-W22-2	4	6,500	3,910	5,290	±	531
2-W22-7	2	<2,500	<2,500	<2,500	±	---
2-W22-9	2	5,380	<2,500	<3,940	±	1,440
2-W22-12	4	2,770	<2,500	<2,490	±	104
2-W22-20	5	199,000	122,000	143,000	±	14,300

TABLE C.43. (Nitrate contd)

Well Name[b]	No. of Samples	Concentration (ppb)[a] Maximum	Minimum	Average		
2-W22-21	2	35,300	12,700	24,000	±	11,300
2-W22-22	7	15,800	<2,500	<10,300	±	2,170
2-W22-26	4	18,700	12,800	15,000	±	1,320
2-W23-1	4	3,290	<2,500	<2,750	±	187
2-W23-2	4	30,200	27,700	29,300	±	568
2-W23-3	4	19,500	8,410	13,500	±	2,340
2-W23-4	7	9,730	5,300	7,460	±	674
2-W23-8	1	<2,500	---	<2,500	±	---
2-W23-9	11	105,000	24,600	90,600	±	6,940
2-W23-10	7	147,000	101,000	114,000	±	6,180
2-W23-11	4	<2,500	<2,500	<2,500	±	---
2-W26-3	2	<2,500	<2,500	<2,500	±	---
2-W26-6	2	3,310	<2,500	<2,910	±	405
2-W27-1	7	63,500	28,200	46,500	±	5,940
3-1-1	2	1,920	1,570	1,750	±	175
3-1-2	2	6,900	1,810	4,360	±	2,550
3-1-4	2	1,300	761	1,030	±	270
3-1-6	2	1,810	1,690	1,750	±	60
3-1-7	4	3,800	1,670	3,000	±	510
3-1-8	2	1,160	871	1,020	±	145
3-1-9	2	<500	<500	<500	±	---
3-1-10	3	4,410	1,690	2,830	±	815
3-1-11	34	3,840	<500	<2,060	±	123
3-1-12	3	2,300	1,870	2,030	±	137
3-1-13	5	3,500	675	2,070	±	577
3-1-14	3	5,100	572	2,560	±	1,340
3-1-15	3	21,200	967	11,800	±	5,890
3-1-16A	7	2,900	1,650	2,410	±	190
3-1-16B	5	<500	<500	<500	±	---
3-1-16C	5	1,800	<500	<1,040	±	293
3-1-17A	35	2,950	<500	<1,960	±	91
3-1-17B	3	<500	<500	<500	±	---
3-1-17C	3	581	<500	<527	±	27
3-1-18A	8	22,300	19,400	21,100	±	307
3-1-18B	3	<500	<500	<500	±	---
3-1-18C	2	<500	<500	<500	±	---
3-1-19	33	3,120	901	2,010	±	90
3-2-1	3	8,780	4,500	6,670	±	1,240
3-2-2	5	13,300	<2,500	<6,640	±	2,160
3-2-3	4	18,500	5,520	14,600	±	3,050
3-3-3	4	11,100	8,610	9,930	±	535
3-3-7	3	14,600	11,900	13,700	±	900
3-3-9	5	23,300	8,870	13,900	±	2,600
3-3-10	3	12,800	8,630	10,800	±	1,210
3-3-11	4	15,400	11,300	12,900	±	976
3-3-12	4	16,400	9,500	13,200	±	1,710
3-4-1	3	13,200	11,400	12,300	±	521

TABLE C.43. (Nitrate contd)

Well Name[b]	No. of Samples	Concentration (ppb)[a] Maximum	Minimum	Average		
3-4-7	3	14,100	9,700	11,600	±	1,310
3-4-9	4	13,400	7,500	9,730	±	1,370
3-4-10	4	14,100	7,200	9,630	±	1,580
3-4-11	3	14,200	10,900	12,200	±	1,010
3-5-1	4	66,800	59,700	63,900	±	1,640
3-6-1	4	32,700	29,100	31,000	±	908
3-8-1	7	21,900	16,400	19,800	±	709
3-8-2	3	23,300	21,500	22,700	±	584
3-8-3	7	12,600	9,730	10,700	±	358
3-8-4	4	23,100	19,500	21,600	±	772
4-S1-7B	3	<2,500	<2,500	<2,500	±	---
4-S1-7C	5	27,900	24,900	26,600	±	553
4-S1-8A	6	28,800	25,600	27,600	±	504
4-S1-8B	6	28,000	25,400	26,800	±	407
6-S43-E12	1	21,200	---	21,200	±	---
6-S41-E13A	1	7,800	---	7,800	±	---
6-S41-E13B	1	4,000	---	4,000	±	---
6-S40-E14	1	990	---	990	±	---
6-S37-E14	1	3,000	---	3,000	±	---
6-S36-E13A	1	10,800	---	10,800	±	---
6-S32-E13A	1	27,900	---	27,900	±	---
6-S32-E13B	1	42,300	---	42,300	±	---
6-S31-E13	1	31,000	---	31,000	±	---
6-S31-1	1	3,620	---	3,620	±	---
6-S31-1P[c]	2	3,230	3,020	3,130	±	105
6-S30-E15A	2	16,900	14,800	15,900	±	1,050
6-S29-E12	5	27,100	18,700	23,400	±	1,780
6-S28-E0	4	9,800	8,400	8,970	±	302
6-S27-E14	12	25,600	19,800	22,000	±	524
6-S24-19	2	<2,500	<2,500	<2,500	±	---
6-S19-E13	2	22,700	21,600	22,200	±	550
6-S19-11	2	9,470	8,550	9,010	±	460
6-S18-51	2	<2,500	<2,500	<2,500	±	---
6-S14-20A	2	<2,500	<2,500	<2,500	±	---
6-S12-3	4	11,500	5,200	9,550	±	1,460
6-S12-29	4	18,900	15,200	17,100	±	756
6-S11-E12A	1	19,000	---	19,000	±	---
6-S11-E12AP[c]	2	<2,500	<2,500	<2,500	±	---
6-S6-E14A	1	3,680	---	3,680	±	---
6-S6-E4B	4	17,300	15,600	16,600	±	372
6-S6-E4D	4	25,500	23,000	24,700	±	582
6-S3-E12	7	25,600	21,400	23,300	±	486
6-S3-25	2	<2,500	<2,500	<2,500	±	---
6-1-18	4	19,500	18,600	19,200	±	202
6-2-3	4	30,900	29,000	30,200	±	409
6-2-7	1	39,900	---	39,900	±	---

TABLE C.43. (Nitrate contd)

Well Name[b]	No. of Samples	Concentration (ppb)[a] Maximum	Minimum	Average		
6-2-33A	4	3,160	<2,500	<2,920	±	149
6-3-45	2	<2,500	<2,500	<2,500	±	---
6-8-17	4	34,200	31,600	33,000	±	545
6-8-25	4	19,600	17,700	18,600	±	389
6-8-32	4	4,300	2,770	3,430	±	369
6-10-E12	7	22,400	19,100	21,300	±	405
6-10-54A	4	12,200	11,300	11,700	±	221
6-12-4B	2	27,400	26,700	27,100	±	350
6-13-64	4	2,800	<2,500	<2,580	±	75
6-14-E6T	1	22,100	---	22,100	±	---
6-14-38	7	4,000	3,290	3,590	±	94
6-14-47	1	<2,500	---	<2,500	±	---
6-15-15B	2	20,100	19,300	19,700	±	400
6-15-26	4	22,900	21,200	22,100	±	438
6-17-5	1	62,600	---	62,600	±	---
6-17-47	4	<2,500	<2,500	<2,500	±	---
6-17-70	4	47,400	41,400	44,600	±	1,320
6-19-43	4	12,400	9,140	10,700	±	667
6-19-58	4	<2,500	<2,500	<2,500	±	---
6-19-88	4	<2,500	<2,500	<2,500	±	---
6-20-E12	4	32,600	<2,500	<18,200	±	8,190
6-20-E12P[c]	2	<2,500	<2,500	<2,500	±	---
6-20-E5A	4	24,100	22,200	23,200	±	390
6-20-E5P[c]	2	<2,500	<2,500	<2,500	±	---
6-20-E5Q[c]	2	<2,500	<2,500	<2,500	±	---
6-20-E5R[c]	2	<2,500	<2,500	<2,500	±	---
6-20-20	4	36,700	35,100	36,000	±	338
6-20-39[c]	4	5,590	4,330	5,070	±	303
6-20-82	4	23,900	2,610	14,800	±	4,440
6-21-6	4	46,600	35,500	39,900	±	2,400
6-22-70	4	10,400	8,840	9,820	±	358
6-23-34	4	26,000	19,500	22,700	±	1,450
6-24-1P[c]	2	<2,500	<2,500	<2,500	±	---
6-24-1Q[c]	2	<2,500	<2,500	<2,500	±	---
6-24-1R[c]	2	<2,500	<2,500	<2,500	±	---
6-24-1S[c]	2	<2,500	<2,500	<2,500	±	---
6-24-1T	1	<2,500	---	<2,500	±	---
6-24-33	7	34,500	24,100	30,200	±	1,500
6-24-34A	4	30,300	23,600	27,100	±	1,580
6-24-34B	6	34,100	26,300	29,600	±	1,100
6-24-34C	4	34,200	27,300	30,700	±	1,490
6-24-35	4	27,800	19,100	23,000	±	1,800
6-24-46	4	9,540	8,310	9,040	±	278
6-25-33A	3	5,830	5,090	5,500	±	217
6-25-34A	3	34,100	30,900	32,600	±	933
6-25-34B	3	34,000	30,700	32,500	±	960
6-25-34C	4	35,100	29,200	32,100	±	1,210

TABLE C.43. (Nitrate contd)

Well Name[b]	No. of Samples	Concentration (ppb)[a] Maximum	Minimum	Average		
6-25-55	4	15,000	13,200	13,900	±	382
6-25-70	4	13,500	11,700	12,500	±	371
6-26-15A	4	35,900	33,700	34,700	±	469
6-26-33	3	34,200	29,100	32,100	±	1,550
6-26-34	3	35,400	31,000	33,900	±	1,430
6-26-35A	3	33,800	30,000	31,900	±	1,100
6-26-35C	3	22,100	18,500	20,500	±	1,050
6-26-89	2	2,730	<2,500	<2,620	±	115
6-27-8	4	37,800	33,000	35,400	±	987
6-28-40	4	18,900	13,700	15,300	±	1,220
6-28-40P[c]	1	<2,500	---	<2,500	±	---
6-28-52A	1	<2,500	---	<2,500	±	---
6-29-4	4	31,000	27,800	29,700	±	719
6-29-78	7	8,660	7,300	7,760	±	165
6-31-31	1	<2,500	---	<2,500	±	---
6-31-31P[c]	1	6,250	---	6,250	±	---
6-32-22	4	27,200	24,300	25,600	±	661
6-32-43	4	38,700	20,800	28,300	±	4,020
6-32-62	3	27,100	26,300	26,600	±	240
6-32-70B	7	19,700	13,200	17,700	±	796
6-32-72	7	10,600	<2,500	<7,420	±	1,030
6-32-77	7	5,770	5,200	5,560	±	71
6-33-42	4	37,100	22,100	28,600	±	3,370
6-33-56	3	9,700	9,140	9,350	±	176
6-34-39A	1	<2,500	---	<2,500	±	---
6-34-41B	4	10,800	5,600	8,000	±	1,180
6-34-42	4	15,400	6,800	10,900	±	1,940
6-34-51	4	9,300	8,000	8,690	±	266
6-35-9	4	38,300	33,500	36,400	±	1,030
6-35-66	7	28,500	20,700	23,900	±	872
6-35-70	5	28,500	26,600	27,800	±	326
6-35-78A	5	647	<2,500	<2,130	±	371
6-36-46P[c]	1	<2,500	---	<2,500	±	---
6-36-46Q[c]	1	<2,500	---	<2,500	±	---
6-36-61A	7	21,600	18,300	20,500	±	414
6-36-61B	4	26,100	<2,500	<8,730	±	5,800
6-36-93	2	45,100	36,600	40,900	±	4,250
6-37-E4	4	29,000	25,900	27,800	±	671
6-37-43	4	12,300	1,780	7,040	±	2,930
6-37-82A	5	46,700	39,300	41,900	±	1,280
6-38-15	4	55,500	50,700	52,300	±	1,080
6-38-65	5	166,000	153,000	160,000	±	2,090
6-38-70	6	245,000	216,000	228,000	±	4,980
6-39-0	1	37,400	---	37,400	±	---
6-39-39	6	15,200	<2,500	<6,660	±	2,490
6-39-79	11	9,700	4,000	6,030	±	441
6-40-1	4	43,000	37,600	40,400	±	1,110
6-40-33A	1	<2,500	---	<2,500	±	---

TABLE C.43. (Nitrate contd)

Well Name[b]	No. of Samples	Concentration (ppb)[a] Maximum	Minimum	Average		
6-40-62	7	51,000	41,100	45,700	±	1,360
6-41-1	7	41,100	36,100	39,000	±	580
6-41-23	4	15,400	13,700	14,400	±	366
6-42-2	4	38,700	35,200	37,400	±	766
6-42-12A	4	42,200	40,500	41,100	±	381
6-42-40A	6	3,650	<500	<2,060	±	496
6-42-40B	5	<2,500	<500	<2,100	±	400
6-42-40C[c]	2	<2,500	<2,500	<2,500	±	---
6-42-42B	1	6,200	---	6,200	±	---
6-43-3	7	39,900	33,200	37,600	±	814
6-43-42J	1	1,000	---	1,000	±	---
6-43-43	1	800	---	800	±	---
6-43-88	5	9,840	7,930	9,030	±	372
6-44-4	1	<2,500	---	<2,500	±	---
6-44-42	1	1,100	---	1,100	±	---
6-44-64	7	55,100	45,800	51,800	±	1,540
6-45-2	7	39,000	32,300	36,000	±	818
6-45-42	15	8,860	5,170	6,680	±	237
6-45-69A	5	21,400	20,300	20,900	±	177
6-46-4	7	30,000	27,400	28,600	±	344
6-46-21B	4	16,100	14,300	15,600	±	431
6-47-5	15	36,000	22,400	28,500	±	970
6-47-35A	1	13,900	---	13,900	±	---
6-47-46A	7	14,400	12,000	13,400	±	320
6-47-50[c]	6	8,120	4,000	6,850	±	596
6-47-60	7	23,500	19,500	22,200	±	511
6-48-7	4	5,110	2,550	4,280	±	588
6-48-18	4	5,810	4,840	5,470	±	214
6-48-71	5	25,100	19,700	22,700	±	889
6-49-13E	4	6,050	5,170	5,590	±	205
6-49-28	4	<2,500	<2,500	<2,500	±	---
6-49-55A	9	242,000	143,000	204,000	±	11,400
6-49-55B	2	<2,500	<2,500	<2,500	±	---
6-49-57	9	56,400	47,000	49,200	±	962
6-49-79	7	41,800	35,700	39,400	±	787
6-49-100C	4	11,800	<2,500	<7,000	±	2,600
6-50-30	4	<2,500	<2,500	<2,500	±	---
6-50-42	4	13,300	<2,500	<5,730	±	2,570
6-50-45[c]	2	<2,500	<2,500	<2,500	±	---
6-50-48B[c]	2	<2,500	<2,500	<2,500	±	---
6-50-53	13	595,000	506,000	553,000	±	7,980
6-50-85	7	25,800	22,000	24,300	±	517
6-51-46	2	<2,500	<2,500	<2,500	±	---
6-51-63	4	17,600	14,700	16,100	±	719
6-51-75	4	2,630	<2,500	<2,530	±	33
6-52-19	4	5,000	3,750	4,200	±	278
6-52-46A[c]	2	<2,500	<2,500	<2,500	±	---
6-52-48[c]	2	<2,500	<2,500	<2,500	±	---

TABLE C.43. (Nitrate contd)

Well Name[b]	No. of Samples	Concentration (ppb)[a] Maximum	Minimum	Average		
6-53-47A	1	5,690	---	5,690	±	---
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	12,600	<2,500	<5,030	±	2,530
6-54-45A	4	<2,500	<2,500	<2,500	±	---
6-54-57[c]	2	<2,500	<2,500	<2,500	±	---
6-55-40	2	<2,500	<2,500	<2,500	±	---
6-55-44	2	<2,500	<2,500	<2,500	±	---
6-55-50A	4	<2,500	<2,500	<2,500	±	---
6-55-50C	6	2,600	<2,500	<2,200	±	209
6-55-50D	4	<2,500	<2,500	<2,500	±	---
6-55-70	1	<2,500	---	<2,500	±	---
6-55-76	7	6,240	<2,500	<4,610	±	518
6-55-89	2	17,500	3,380	10,400	±	7,060
6-56-43	4	<2,500	<2,500	<2,500	±	---
6-56-53[c]	2	<2,500	<2,500	<2,500	±	---
6-57-29A	4	3,500	<2,500	<3,040	±	206
6-59-58	4	<2,500	<2,500	<2,500	±	---
6-59-80B	4	<2,500	<2,500	<2,500	±	---
6-60-57	4	7,320	<2,500	<3,710	±	1,210
6-60-60	1	<2,500	---	<2,500	±	---
6-61-37	4	4,200	3,570	3,860	±	137
6-61-41	4	2,900	<2,500	<2,630	±	95
6-61-62	4	52,100	46,800	50,200	±	1,190
6-61-66	4	5,300	3,820	4,480	±	313
6-62-31	4	64,100	43,800	53,100	±	4,370
6-63-25A	4	18,900	14,300	17,200	±	1,010
6-63-55	4	6,400	4,130	4,880	±	515
6-63-58	4	22,500	13,700	16,200	±	2,100
6-63-90	4	5,800	4,560	5,190	±	266
6-64-27	1	40,600	---	40,600	±	---
6-64-62	4	32,800	26,400	30,200	±	1,400
6-65-23	1	17,900	---	17,900	±	---
6-65-50	4	3,400	<2,500	<2,730	±	225
6-65-59A	4	8,300	3,880	5,620	±	970
6-65-72	7	24,400	19,400	21,100	±	621
6-65-83	7	5,300	3,890	4,770	±	197
6-66-23	4	41,800	41,000	41,600	±	193
6-66-38	4	<2,500	<2,500	<2,500	±	---
6-66-39	4	<2,500	<2,500	<2,500	±	---
6-66-58	4	4,200	<2,500	<3,030	±	397
6-66-64	4	18,100	15,100	16,400	±	647
6-66-103	3	5,200	<2,500	<3,400	±	900
6-67-51	4	<2,500	<2,500	<2,500	±	---
6-67-86	7	3,300	2,720	3,020	±	68
6-67-98	4	4,850	4,040	4,390	±	182
6-68-105	1	<2,500	---	<2,500	±	---
6-69-38	4	<2,500	<2,500	<2,500	±	---

TABLE C.43. (Nitrate contd)

Well Name[b]	No. of Samples	Concentration (ppb)[a] Maximum	Minimum	Average		
6-70-68	7	3,820	3,710	3,770	±	17
6-71-30	7	29,900	28,200	29,100	±	264
6-71-52	7	7,720	6,810	7,150	±	110
6-71-77	7	11,400	6,870	8,800	±	597
6-72-73	4	4,140	4,030	4,100	±	25
6-72-88	4	7,830	4,920	6,100	±	665
6-72-92	2	9,750	9,630	9,690	±	60
6-73-61	7	9,740	8,300	9,000	±	198
6-74-44	7	7,840	5,820	6,440	±	269
6-77-36	4	67,100	56,800	62,100	±	2,780
6-77-54	4	8,390	7,180	7,750	±	251
6-78-62	3	8,480	8,330	8,410	±	43
6-80-43P	2	<2,500	<2,500	<2,500	±	---
6-80-43Q	2	<2,500	<2,500	<2,500	±	---
6-80-43R	2	<2,500	<2,500	<2,500	±	---
6-80-43S	2	5,510	3,790	4,650	±	860
6-81-58	8	2,600	<2,500	<2,480	±	43
6-83-47	4	6,090	5,910	5,970	±	40
6-84-35AO	1	10,800	---	10,800	±	---
6-87-55	4	19,900	18,800	19,400	±	292
6-89-35	4	10,500	9,020	9,760	±	317
6-90-45	4	6,190	4,650	5,600	±	356
6-96-49	7	15,500	10,500	13,200	±	591
6-97-43	7	21,300	18,400	19,300	±	399
6-97-51A	7	22,200	19,900	20,900	±	288
6-101-48B	7	1,230	<500	<1,810	±	336
6-ATH	1	136,000	---	136,000	±	---
6-ORV-1	1	<500	---	<500	±	---
11-34-15B	1	39,700	---	39,700	±	---
11-37-16	1	865	---	865	±	---
11-39-16C	1	<500	---	<500	±	---
11-41-13C	1	8,720	---	8,720	±	---
30-42-16	1	1,690	---	1,690	±	---

(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 5.1, 5.2, and 5.3 for well locations.
(c) Wells that sample a confined aquifer or a composite of confined and unconfined aquifers.

TABLE C.44. Maximum, Minimum, and Average Chromium Concentrations in Ground-Water Samples in 1988

Well Name[b]	No. of Samples	Concentration (ppb)[a] Maximum	Minimum	Average
1-B3-1	2	36	29	33 ± 3.5
1-F5-4	3	17	14	15 ± 1.0
1-F7-1	3	<10	<10	<10 ± ---
1-F8-1	1	14	---	14 ± ---
1-H3-1	3	63	52	58 ± 3.3
1-H3-2A	4	42	33	37 ± 2.0
1-H3-2B	3	48	32	42 ± 4.9
1-H3-2C	3	<10	<10	<10 ± ---
1-H4-3	11	262	150	202 ± 11.9
1-H4-4	19	285	106	201 ± 10.8
1-H4-5	4	142	101	129 ± 9.4
1-H4-6	4	110	72	89 ± 8.1
1-H4-7	3	117	90	107 ± 8.4
1-H4-8	3	103	92	96 ± 3.5
1-H4-9	12	120	91	103 ± 2.8
1-H4-10	3	84	47	70 ± 11.6
1-H4-11	9	180	80	123 ± 10.7
1-H4-12A	10	164	54	122 ± 9.7
1-H4-12B	10	181	101	129 ± 7.9
1-H4-12C	10	298	222	267 ± 7.5
1-H4-13	3	39	21	31 ± 5.3
1-H4-14	5	422	351	381 ± 12.4
1-H4-15A	3	151	96	123 ± 15.9
1-H4-15B	3	142	114	126 ± 8.3
1-H4-16	6	12	<10	<10 ± 0.3
1-H4-17	5	93	78	87 ± 2.7
1-H4-18	10	279	192	236 ± 8.8
1-N-2	4	<10	<10	<10 ± ---
1-N-3	3	<10	<10	<10 ± ---
1-N-4	4	<10	<10	<10 ± ---
1-N-14	4	<10	<10	<10 ± ---
1-N-27	4	<10	<10	<10 ± ---
1-N-28	2	<10	<10	<10 ± ---
1-N-29	4	<10	<10	<10 ± ---
1-N-31	4	<10	<10	<10 ± ---
1-N-32	4	<10	<10	<10 ± ---
1-N-33	5	<10	<10	<10 ± ---
1-N-36	5	<10	<10	<10 ± ---
1-N-39	2	<10	<10	<10 ± ---
1-N-41	4	<10	<10	<10 ± ---
1-N-42	4	<10	<10	<10 ± ---
1-N-49	2	<10	<10	<10 ± ---
1-N-52	5	<10	<10	<10 ± ---
1-N-58	9	14	<10	<10 ± 0.4

TABLE C.44. (Chromium contd)

Well Name[b]	No. of Samples	Concentration (ppb)[a] Maximum	Minimum	Average
1-N-59	5	<10	<10	<10 ± ---
1-N-60	5	<10	<10	<10 ± ---
1-N-61	5	<10	<10	<10 ± ---
1-N-67	1	<10	---	<10 ± ---
1-N-69	1	<10	---	<10 ± ---
1-N-70	2	<10	<10	<10 ± ---
2-E13-5	4	12	<10	<11 ± 0.5
2-E13-14	4	67	28	47 ± 8.3
2-E17-1	2	<10	<10	<10 ± ---
2-E17-5	4	<10	<10	<10 ± ---
2-E17-6	5	<10	<10	<10 ± ---
2-E17-9	3	<10	<10	<10 ± ---
2-E17-12	2	<10	<10	<10 ± ---
2-E17-14	3	18	<10	<13 ± 2.7
2-E17-15	3	55	<10	<25 ± 15.0
2-E17-16	4	<10	<10	<10 ± ---
2-E17-17	2	<10	<10	<10 ± ---
2-E17-18	3	<10	<10	<10 ± ---
2-E17-19	1	<10	---	<10 ± ---
2-E17-20	1	<10	---	<10 ± ---
2-E18-1	4	<10	<10	<10 ± ---
2-E18-2	4	11	<10	<10 ± 0.3
2-E18-3	3	<10	<10	<10 ± ---
2-E18-4	3	<10	<10	<10 ± ---
2-E24-2	3	<10	<10	<10 ± ---
2-E24-8	1	12	---	12 ± ---
2-E24-12	1	<10	---	<10 ± ---
2-E24-16	1	<10	---	<10 ± ---
2-E24-17	2	<10	<10	<10 ± ---
2-E24-18	1	<10	---	<10 ± ---
2-E25-18	3	<10	<10	<10 ± ---
2-E25-19	6	<10	<10	<10 ± ---
2-E25-20	2	<10	<10	<10 ± ---
2-E25-21	3	<10	<10	<10 ± ---
2-E25-22	3	<10	<10	<10 ± ---
2-E25-23	3	<10	<10	<10 ± ---
2-E25-24	3	<10	<10	<10 ± ---
2-E25-25	7	<10	<10	<10 ± ---
2-E25-26	3	<10	<10	<10 ± ---
2-E25-27	2	<10	<10	<10 ± ---
2-E25-28	3	<10	<10	<10 ± ---
2-E25-29	2	11	<10	<11 ± 0.5
2-E25-30	1	<10	---	<10 ± ---
2-E25-31	4	<10	<10	<10 ± ---
2-E25-32	4	11	<10	<10 ± 0.3
2-E25-33	3	26	<10	<15 ± 5.3
2-E25-34	1	10	---	10 ± ---
2-E25-35	1	<10	---	<10 ± ---

TABLE C.44. (Chromium contd)

Well Name[b]	No. of Samples	Concentration (ppb)[a] Maximum	Minimum	Average		
2-E25-36	1	<10	---	<10	±	---
2-E27-5	1	<10	---	<10	±	---
2-E27-8	3	<10	<10	<10	±	---
2-E27-9	2	<10	<10	<10	±	---
2-E27-10	2	<10	<10	<10	±	---
2-E28-13	2	<10	<10	<10	±	---
2-E28-18	2	<10	<10	<10	±	---
2-E28-21	3	<10	<10	<10	±	---
2-E28-23	2	<10	<10	<10	±	---
2-E28-26	2	<10	<10	<10	±	---
2-E28-27	2	<10	<10	<10	±	---
2-E32-1	2	<10	<10	<10	±	---
2-E32-2	2	<10	<10	<10	±	---
2-E32-3	2	<10	<10	<10	±	---
2-E32-4	2	<10	<10	<10	±	---
2-E33-1A	3	11	<10	<10	±	0.3
2-E33-3	3	15	<10	<12	±	1.7
2-E33-5	3	<10	<10	<10	±	---
2-E33-8	1	<10	---	<10	±	---
2-E33-10	2	<10	<10	<10	±	---
2-E33-18	1	<10	---	<10	±	---
2-E33-21	1	<10	---	<10	±	---
2-E33-24	1	<10	---	<10	±	---
2-E33-28	2	<10	<10	<10	±	---
2-E33-29	2	<10	<10	<10	±	---
2-E33-30	3	<10	<10	<10	±	---
2-E34-1	1	<10	---	<10	±	---
2-E34-2	2	<10	<10	<10	±	---
2-E34-3	2	10	<10	<10	±	---
2-E34-5	2	<10	<10	<10	±	---
2-E34-6	2	<10	<10	<10	±	---
2-W6-2	1	36	---	36	±	---
2-W7-1	2	16	<10	<13	±	3.0
2-W7-2	2	17	<10	<14	±	3.5
2-W7-3	2	<10	<10	<10	±	---
2-W7-4	3	18	<10	<14	±	2.3
2-W7-5	2	15	11	13	±	2.0
2-W7-6	1	<10	---	<10	±	---
2-W8-1	2	14	<10	<12	±	2.0
2-W9-1	2	<10	<10	<10	±	---
2-W10-4	3	65	63	64	±	0.7
2-W10-8	1	10	---	10	±	---
2-W10-9	2	152	140	146	±	6.0
2-W10-13	1	15	---	15	±	---
2-W10-14	1	12	---	12	±	---
2-W14-2	3	10	<10	<10	±	---
2-W14-5	3	<10	<10	<10	±	---

TABLE C.44. (Chromium contd)

Well Name[b]	No. of Samples	Concentration (ppb)[a] Maximum	Minimum	Average
2-W14-6	6	11	<10	<10 ± 0.2
2-W14-10	1	<10	---	<10 ± ---
2-W15-4	2	<10	<10	<10 ± ---
2-W15-7	2	<10	<10	<10 ± ---
2-W15-10	3	21	15	17 ± 1.9
2-W15-11	3	33	22	27 ± 3.2
2-W15-15	3	<10	<10	<10 ± ---
2-W15-16	2	12	11	12 ± 0.5
2-W15-17	2	35	<10	<23 ± 12.5
2-W15-18	2	13	<10	<12 ± 1.5
2-W18-5	3	14	13	14 ± 0.3
2-W18-15	3	<10	<10	<10 ± ---
2-W18-21	2	10	<10	<10 ± ---
2-W18-22	2	<10	<10	<10 ± ---
2-W18-23	1	<10	---	<10 ± ---
2-W18-24	1	<10	---	<10 ± ---
2-W19-3	3	10	<10	<10 ± ---
2-W19-5	2	<10	<10	<10 ± ---
2-W19-9	4	<10	<10	<10 ± ---
2-W19-11	1	<10	---	<10 ± ---
2-W19-13	3	<10	<10	<10 ± ---
2-W19-15	4	<10	<10	<10 ± ---
2-W19-16	4	<10	<10	<10 ± ---
2-W19-18	3	12	<10	<11 ± 0.7
2-W19-20	3	<10	<10	<10 ± ---
2-W19-21	3	<10	<10	<10 ± ---
2-W19-24	3	15	<10	<12 ± 1.7
2-W22-1	3	<10	<10	<10 ± ---
2-W22-12	2	<10	<10	<10 ± ---
2-W22-20	3	339	296	321 ± 12.8
2-W22-22	3	<10	<10	<10 ± ---
2-W22-26	2	<10	<10	<10 ± ---
2-W23-10	4	<10	<10	<10 ± ---
2-W27-1	3	24	13	18 ± 3.3
3-1-1	2	<10	<10	<10 ± ---
3-1-2	2	<10	<10	<10 ± ---
3-1-4	2	<10	<10	<10 ± ---
3-1-6	2	<10	<10	<10 ± ---
3-1-7	4	<10	<10	<10 ± ---
3-1-8	2	<10	<10	<10 ± ---
3-1-9	2	<10	<10	<10 ± ---
3-1-10	3	<10	<10	<10 ± ---
3-1-11	3	<10	<10	<10 ± ---
3-1-12	3	<10	<10	<10 ± ---
3-1-13	5	<10	<10	<10 ± ---
3-1-14	3	<10	<10	<10 ± ---
3-1-15	3	<10	<10	<10 ± ---

TABLE C.44. (Chromium contd)

Well Name[b]	No. of Samples	Concentration (ppb)[a] Maximum	Minimum	Average		
3-1-16A	7	<10	<10	<10	±	---
3-1-16B	5	<10	<10	<10	±	---
3-1-16C	5	<10	<10	<10	±	---
3-1-17A	4	<10	<10	<10	±	---
3-1-17B	3	<10	<10	<10	±	---
3-1-17C	3	<10	<10	<10	±	---
3-1-18A	3	<10	<10	<10	±	---
3-1-18B	3	<10	<10	<10	±	---
3-1-18C	2	<10	<10	<10	±	---
3-1-19	3	<10	<10	<10	±	---
3-2-1	3	<10	<10	<10	±	---
3-2-2	1	<10	---	<10	±	---
3-3-7	3	<10	<10	<10	±	---
3-3-9	1	<10	---	<10	±	---
3-3-10	3	<10	<10	<10	±	---
3-4-1	3	<10	<10	<10	±	---
3-4-7	3	<10	<10	<10	±	---
3-4-11	3	<10	<10	<10	±	---
3-8-1	3	<10	<10	<10	±	---
3-8-2	3	<10	<10	<10	±	---
3-8-3	3	<10	<10	<10	±	---
4-S1-7C	2	<10	<10	<10	±	---
4-S1-8A	2	11	<10	<11	±	0.5
4-S1-8B	2	<10	<10	<10	±	---
6-S43-E12	1	<10	---	<10	±	---
6-S41-E13A	1	<10	---	<10	±	---
6-S41-E13B	1	<10	---	<10	±	---
6-S40-E14	1	<10	---	<10	±	---
6-S37-E14	1	<10	---	<10	±	---
6-S36-E13A	1	<10	---	<10	±	---
6-S32-E13A	1	<10	---	<10	±	---
6-S32-E13B	1	<10	---	<10	±	---
6-S31-E13	1	<10	---	<10	±	---
6-S31-1	1	<10	---	<10	±	---
6-S30-E15A	2	<10	<10	<10	±	---
6-S29-E12	1	<10	---	<10	±	---
6-S19-E13	2	<10	<10	<10	±	---
6-S3-E12	3	<10	<10	<10	±	---
6-10-E12	3	<10	<10	<10	±	---
6-12-4B	2	<10	<10	<10	±	---
6-14-38	3	<10	<10	<10	±	---
6-19-43	3	<10	<10	<10	±	---
6-20-39[c]	2	<10	<10	<10	±	---
6-23-34	4	<10	<10	<10	±	---
6-24-33	3	<10	<10	<10	±	---
6-24-34A	4	<10	<10	<10	±	---

TABLE C.44. (Chromium contd)

Well Name[b]	No. of Samples	Concentration (ppb)[a] Maximum	Minimum	Average		
6-24-34B	6	<10	<10	<10	±	---
6-24-34C	4	<10	<10	<10	±	---
6-24-35	4	<10	<10	<10	±	---
6-24-46	3	<10	<10	<10	±	---
6-25-33A	3	<10	<10	<10	±	---
6-25-34A	3	<10	<10	<10	±	---
6-25-34B	3	<10	<10	<10	±	---
6-25-34C	4	<10	<10	<10	±	---
6-26-33	3	<10	<10	<10	±	---
6-26-34	3	<10	<10	<10	±	---
6-26-35A	3	<10	<10	<10	±	---
6-26-35C	3	<10	<10	<10	±	---
6-29-78	3	<10	<10	<10	±	---
6-32-70B	3	25	20	23	±	1.5
6-32-72	3	<10	<10	<10	±	---
6-32-77	3	<10	<10	<10	±	---
6-35-66	3	26	21	24	±	1.5
6-35-70	1	<10	---	<10	±	---
6-35-78A	1	<10	---	<10	±	---
6-36-61A	3	15	<10	<13	±	1.5
6-37-E4	3	<10	<10	<10	±	---
6-37-43	3	<10	<10	<10	±	---
6-37-82A	1	<10	---	<10	±	---
6-38-65	1	<10	---	<10	±	---
6-38-70	3	<10	<10	<10	±	---
6-39-39	2	<10	<10	<10	±	---
6-39-79	3	<10	<10	<10	±	---
6-40-62	3	<10	<10	<10	±	---
6-41-1	3	<10	<10	<10	±	---
6-42-2	3	<10	<10	<10	±	---
6-42-40A	2	<10	<10	<10	±	---
6-42-42B	1	<10	---	<10	±	---
6-43-3	3	<10	<10	<10	±	---
6-43-42J	1	<10	---	<10	±	---
6-43-43	1	<10	---	<10	±	---
6-43-88	1	<10	---	<10	±	---
6-44-42	1	<10	---	<10	±	---
6-44-64	3	<10	<10	<10	±	---
6-45-2	3	<10	<10	<10	±	---
6-45-42	3	<10	<10	<10	±	---
6-45-69A	1	<10	---	<10	±	---
6-46-4	3	<10	<10	<10	±	---
6-47-5	3	<10	<10	<10	±	---
6-47-46A	3	<10	<10	<10	±	---
6-47-50[c]	2	<10	<10	<10	±	---
6-47-60	3	<10	<10	<10	±	---
6-48-71	1	<10	---	<10	±	---
6-49-55A	6	<10	<10	<10	±	---

TABLE C.44. (Chromium contd)

Well Name[b]	No. of Samples	Concentration (ppb)[a] Maximum	Minimum	Average
6-49-57	9	11	<10	<10 ± 0.2
6-49-79	3	<10	<10	<10 ± ---
6-50-53	8	10	<10	<10 ± ---
6-50-85	3	<10	<10	<10 ± ---
6-53-47A	1	<10	---	<10 ± ---
6-55-50C	2	<10	<10	<10 ± ---
6-55-76	3	<10	<10	<10 ± ---
6-65-72	3	10	<10	<10 ± ---
6-65-83	3	27	24	25 ± 0.9
6-67-86	3	26	20	22 ± 1.9
6-70-68	3	<10	<10	<10 ± ---
6-71-30	3	<10	<10	<10 ± ---
6-71-52	3	17	13	15 ± 1.2
6-71-77	3	<10	<10	<10 ± ---
6-72-73	2	<10	<10	<10 ± ---
6-73-61	3	17	12	15 ± 1.5
6-74-44	3	<10	<10	<10 ± ---
6-77-36	3	<10	<10	<10 ± ---
6-78-62	2	106	88	97 ± 9.0
6-81-58	4	16	11	13 ± 1.2
6-83-47	4	50	34	44 ± 3.4
6-96-49	3	75	67	72 ± 2.7
6-97-43	3	200	185	192 ± 4.3
6-97-51A	3	112	95	102 ± 5.2
6-101-48B	3	<10	<10	<10 ± ---
6-ATH	1	<10	---	<10 ± ---
11-34-15B	1	<10	---	<10 ± ---
11-37-16	1	<10	---	<10 ± ---
11-39-16C	1	<10	---	<10 ± ---
11-41-13C	1	<10	---	<10 ± ---
30-42-16	1	<10	---	<10 ± ---

(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 5.1, 5.2, and 5.3 for well locations.
(c) Wells that sample a confined aquifer or a composite of confined or unconfined aquifers.

TABLE C.45. Maximum, Minimum, and Average Carbon Tetrachloride Concentrations in Ground-Water Samples in 1988

Well Name[b]	No. of Samples	Concentration (ppb)[a] Maximum	Minimum	Average
1-B3-1	2	<5	<5	<5 ± ---
1-F5-4	3	<5	<5	<5 ± ---
1-F7-1	3	<5	<5	<5 ± ---
1-F8-1	1	<5	---	<5 ± ---
1-H3-1	3	<5	<5	<5 ± ---
1-H3-2A	3	<5	<5	<5 ± ---
1-H3-2B	3	<5	<5	<5 ± ---
1-H3-2C	3	<5	<5	<5 ± ---
1-H4-3	9	<5	<5	<5 ± ---
1-H4-4	19	<5	<5	<5 ± ---
1-H4-5	3	<5	<5	<5 ± ---
1-H4-6	3	<5	<5	<5 ± ---
1-H4-7	3	<5	<5	<5 ± ---
1-H4-8	3	<5	<5	<5 ± ---
1-H4-9	11	<5	<5	<5 ± ---
1-H4-10	3	<5	<5	<5 ± ---
1-H4-11	9	<5	<5	<5 ± ---
1-H4-12A	9	<5	<5	<5 ± ---
1-H4-12B	9	<5	<5	<5 ± ---
1-H4-12C	9	<5	<5	<5 ± ---
1-H4-13	3	<5	<5	<5 ± ---
1-H4-14	5	<5	<5	<5 ± ---
1-H4-15A	3	<5	<5	<5 ± ---
1-H4-15B	3	<5	<5	<5 ± ---
1-H4-16	6	<5	<5	<5 ± ---
1-H4-17	5	<5	<5	<5 ± ---
1-H4-18	9	<5	<5	<5 ± ---
1-N-2	3	<5	<5	<5 ± ---
1-N-3	2	<5	<5	<5 ± ---
1-N-4	3	<5	<5	<5 ± ---
1-N-14	4	<5	<5	<5 ± ---
1-N-27	4	<5	<5	<5 ± ---
1-N-28	4	<5	<5	<5 ± ---
1-N-29	4	<5	<5	<5 ± ---
1-N-31	4	<5	<5	<5 ± ---
1-N-32	4	<5	<5	<5 ± ---
1-N-33	5	<5	<5	<5 ± ---
1-N-36	5	<5	<5	<5 ± ---
1-N-39	2	<5	<5	<5 ± ---
1-N-41	4	<5	<5	<5 ± ---
1-N-42	4	<5	<5	<5 ± ---
1-N-49	2	<5	<5	<5 ± ---
1-N-52	5	<5	<5	<5 ± ---
1-N-58	2	<5	<5	<5 ± ---
1-N-59	1	<5	—	<5 ± ---

TABLE C.45. (Carbon Tetrachloride contd)

Well Name[b]	No. of Samples	Concentration (ppb)[a] Maximum	Minimum	Average
1-N-60	1	<5	---	<5 ± ---
1-N-61	1	<5	---	<5 ± ---
1-N-69	1	<5	---	<5 ± ---
1-N-70	2	<5	<5	<5 ± ---
2-E13-5	2	<5	<5	<5 ± ---
2-E13-14	2	<5	<5	<5 ± ---
2-E16-2	1	<5	---	<5 ± ---
2-E17-1	2	<5	<5	<5 ± ---
2-E17-5	3	<5	<5	<5 ± ---
2-E17-6	2	<5	<5	<5 ± ---
2-E17-9	1	<5	---	<5 ± ---
2-E17-12	1	<5	---	<5 ± ---
2-E17-14	2	<5	<5	<5 ± ---
2-E17-15	2	<5	<5	<5 ± ---
2-E17-16	2	<5	<5	<5 ± ---
2-E17-17	2	<5	<5	<5 ± ---
2-E17-18	2	<5	<5	<5 ± ---
2-E17-19	1	<5	---	<5 ± ---
2-E17-20	1	<5	---	<5 ± ---
2-E18-1	5	<5	<5	<5 ± ---
2-E18-2	4	<5	<5	<5 ± ---
2-E18-3	3	<5	<5	<5 ± ---
2-E18-4	3	<5	<5	<5 ± ---
2-E24-2	2	<5	<5	<5 ± ---
2-E24-16	1	<5	---	<5 ± ---
2-E24-17	2	<5	<5	<5 ± ---
2-E24-18	1	<5	---	<5 ± ---
2-E25-18	1	<5	---	<5 ± ---
2-E25-19	2	<5	<5	<5 ± ---
2-E25-20	1	<5	---	<5 ± ---
2-E25-21	2	<5	<5	<5 ± ---
2-E25-22	1	<5	---	<5 ± ---
2-E25-23	2	<5	<5	<5 ± ---
2-E25-24	2	<5	<5	<5 ± ---
2-E25-25	2	<5	<5	<5 ± ---
2-E25-26	1	<5	---	<5 ± ---
2-E25-28	1	<5	---	<5 ± ---
2-E25-30	1	<5	---	<5 ± ---
2-E25-31	1	<5	---	<5 ± ---
2-E25-32	1	<5	---	<5 ± ---
2-E25-33	1	<5	---	<5 ± ---
2-E25-34	2	<5	<5	<5 ± ---
2-E25-35	1	<5	---	<5 ± ---
2-E25-36	1	<5	---	<5 ± ---
2-E26-5	1	<5	---	<5 ± ---
2-E27-8	3	<5	<5	<5 ± ---
2-E27-9	1	<5	---	<5 ± ---

TABLE C.45. (Carbon Tetrachloride contd)

Well Name[b]	No. of Samples	Concentration (ppb)[a] Maximum	Minimum	Average		
2-E27-10	1	<5	---	<5	±	---
2-E28-7	1	<5	---	<5	±	---
2-E28-13	1	<5	---	<5	±	---
2-E28-18	1	<5	---	<5	±	---
2-E28-21	2	<5	<5	<5	±	---
2-E28-23	1	<5	---	<5	±	---
2-E28-26	1	<5	---	<5	±	---
2-E28-27	1	<5	---	<5	±	---
2-E32-1	1	<5	---	<5	±	---
2-E32-2	1	<5	---	<5	±	---
2-E32-3	1	<5	---	<5	±	---
2-E32-4	1	<5	---	<5	±	---
2-E33-1A	1	<5	---	<5	±	---
2-E33-3	1	<5	---	<5	±	---
2-E33-5	1	<5	---	<5	±	---
2-E33-10	2	<5	<5	<5	±	---
2-E33-28	1	<5	---	<5	±	---
2-E33-29	1	<5	---	<5	±	---
2-E33-30	1	<5	---	<5	±	---
2-E34-1	1	<5	---	<5	±	---
2-E34-2	1	<5	---	<5	±	---
2-E34-3	1	<5	---	<5	±	---
2-E34-5	1	<5	---	<5	±	---
2-E34-6	1	<5	---	<5	±	---
2-W6-2	1	100	---	100	±	---
2-W7-1	2	<5	<5	<5	±	---
2-W7-2	2	<5	<5	<5	±	---
2-W7-3	2	<5	<3	<4	±	1.2
2-W7-4	3	220	<5	<77	±	71.7
2-W7-5	2	25	23	24	±	1.0
2-W7-6	2	<5	<5	<5	±	---
2-W8-1	2	<5	<5	<5	±	---
2-W9-1	2	<5	<4	<5	±	0.5
2-W10-4	3	2,800	2,590	2,660	±	68.4
2-W10-8	1	49	---	49	±	---
2-W10-9	2	2,300	1,700	2,000	±	300.0
2-W10-13	1	13	---	13	±	---
2-W10-14	1	<5	---	<5	±	---
2-W11-7	2	2,500	2,080	2,290	±	210.0
2-W11-14	2	860	650	755	±	105.0
2-W14-2	3	1,050	920	983	±	37.6
2-W14-5	3	860	300	630	±	169.0
2-W14-6	10	320	280	300	±	4.2
2-W14-10	1	<3	---	<3	±	---
2-W15-4	2	2,090	1,830	1,960	±	130.0
2-W15-7	2	2,390	2,310	2,350	±	40.0
2-W15-8	1	130	---	130	±	---

TABLE C.45. (Carbon Tetrachloride contd)

Well Name[b]	No. of Samples	Concentration (ppb)[a] Maximum	Minimum	Average
2-W15-10	3	4,200	3,730	3,890 ± 153.0
2-W15-11	3	5,550	4,350	4,900 ± 350.0
2-W15-12	2	1,500	1,320	1,410 ± 90.0
2-W15-15	2	440	430	435 ± 5.0
2-W15-16	1	8,100	---	8,100 ± ---
2-W15-17	2	<5	<5	<5 ± ---
2-W15-18	1	2,600	---	2,600 ± ---
2-W18-4	2	120	98	109 ± 11.0
2-W18-5	3	3,640	3,310	3,520 ± 104.0
2-W18-9	1	210	---	210 ± ---
2-W18-15	3	120	89	106 ± 9.1
2-W18-17	2	180	22	101 ± 79.0
2-W18-21	1	130	---	130 ± ---
2-W18-22	1	<5	---	<5 ± ---
2-W18-23	1	640	---	640 ± ---
2-W18-24	1	1,400	---	1,400 ± ---
2-W19-3	3	120	49	88 ± 20.7
2-W19-5	2	<5	<3	<4 ± 1.3
2-W19-9	4	120	99	110 ± 4.3
2-W19-11	1	115	---	115 ± ---
2-W19-13	3	39	33	36 ± 1.7
2-W19-15	4	83	63	74 ± 5.2
2-W19-16	3	170	120	137 ± 16.7
2-W19-18	3	57	9	30 ± 14.3
2-W19-20	3	38	32	34 ± 2.0
2-W19-21	3	<5	<3	<4 ± 0.7
2-W19-24	3	24	16	19 ± 2.5
2-W22-1	2	<5	<5	<5 ± ---
2-W22-12	2	<5	<5	<5 ± ---
2-W22-20	3	13	10	11 ± 0.9
2-W22-22	2	<5	<5	<5 ± ---
2-W22-26	2	<5	<5	<5 ± ---
2-W23-10	4	<5	<5	<5 ± ---
2-W27-1	3	<5	<5	<5 ± ---
3-1-1	2	<5	<5	<5 ± ---
3-1-2	2	<5	<5	<5 ± ---
3-1-4	2	<5	<5	<5 ± ---
3-1-6	2	<5	<5	<5 ± ---
3-1-7	4	<5	<5	<5 ± ---
3-1-8	2	<5	<5	<5 ± ---
3-1-9	2	<5	<5	<5 ± ---
3-1-10	3	<5	<5	<5 ± ---
3-1-11	33	<5	<5	<5 ± ---
3-1-12	2	<5	<5	<5 ± ---
3-1-13	5	<5	<5	<5 ± ---
3-1-14	3	<5	<5	<5 ± ---
3-1-15	3	<5	<5	<5 ± ---

TABLE C.45. (Carbon Tetrachloride contd)

Well Name[b]	No. of Samples	Concentration (ppb)[a] Maximum	Minimum	Average		
3-1-16A	6	<5	<5	<5	±	---
3-1-16B	4	<5	<5	<5	±	---
3-1-16C	4	<5	<5	<5	±	---
3-1-17A	34	<5	<5	<5	±	---
3-1-17B	3	<5	<5	<5	±	---
3-1-17C	3	<5	<5	<5	±	---
3-1-18A	7	6	<5	<5	±	0.1
3-1-18B	3	<5	<5	<5	±	---
3-1-18C	2	<5	<5	<5	±	---
3-1-19	32	<5	<5	<5	±	---
3-2-1	3	<5	<5	<5	±	---
3-2-2	1	<5	---	<5	±	---
3-3-7	3	<5	<5	<5	±	---
3-3-9	1	<5	---	<5	±	---
3-3-10	3	<5	<5	<5	±	---
3-4-1	2	<5	<5	<5	±	---
3-4-7	3	<5	<5	<5	±	---
3-4-11	3	<5	<5	<5	±	---
3-8-1	3	<5	<5	<5	±	---
3-8-2	3	<5	<4	<5	±	0.3
3-8-3	3	<5	<5	<5	±	---
4-S1-7C	2	<5	<5	<5	±	---
4-S1-8A	2	<5	<5	<5	±	---
4-S1-8B	2	<5	<5	<5	±	---
6-S43-E12	1	<5	---	<5	±	---
6-S41-E13A	1	<5	---	<5	±	---
6-S41-E13B	1	<5	---	<5	±	---
6-S40-E14	1	<5	---	<5	±	---
6-S37-E14	1	<5	---	<5	±	---
6-S36-E13A	1	<5	---	<5	±	---
6-S32-E13A	1	<5	---	<5	±	---
6-S32-E13B	1	<5	---	<5	±	---
6-S31-E13	1	<5	---	<5	±	---
6-S31-1	1	<5	---	<5	±	---
6-S30-E15A	2	<5	<5	<5	±	---
6-S29-E12	1	<5	---	<5	±	---
6-S19-E13	2	<5	<5	<5	±	---
6-S3-E12	2	<5	<5	<5	±	---
6-10-E12	2	<5	<5	<5	±	---
6-12-4B	2	<5	<5	<5	±	---
6-14-38	2	<5	<5	<5	±	---
6-19-43	2	<5	<5	<5	±	---
6-20-39[c]	2	<5	<5	<5	±	---
6-23-34	4	7	<5	<6	±	0.5
6-24-33	4	<5	<3	<5	±	0.5
6-24-34A	6	5	<5	<5	±	---

TABLE C.45. (Carbon Tetrichloride contd)

Well Name[b]	No. of Samples	Concentration (ppb)[a] Maximum	Minimum	Average		
6-24-34B	6	6	<5	<5	±	0.2
6-24-34C	4	<5	<3	<5	±	0.5
6-24-35	4	<5	<5	<5	±	---
6-24-46	2	<5	<5	<5	±	---
6-25-33A	3	<5	<5	<5	±	---
6-25-34A	3	<5	<5	<5	±	---
6-25-34B	3	<5	<5	<5	±	---
6-25-34C	4	<5	<5	<5	±	---
6-26-33	3	<5	<5	<5	±	---
6-26-34	3	<5	<5	<5	±	---
6-26-35A	3	<5	<5	<5	±	---
6-26-35C	3	<5	<5	<5	±	---
6-29-78	2	<5	<5	<5	±	---
6-32-70B	2	<5	<5	<5	±	---
6-32-72	2	<5	<5	<5	±	---
6-32-77	2	<5	<5	<5	±	---
6-35-66	2	<5	<5	<5	±	---
6-36-61A	2	<5	<5	<5	±	---
6-37-E4	2	<5	<5	<5	±	---
6-37-43	2	<5	<5	<5	±	---
6-38-70	4	39	29	32	±	2.4
6-39-39	2	<5	<5	<5	±	---
6-39-79	5	990	430	718	±	88.7
6-40-62	2	<5	<5	<5	±	---
6-41-1	2	<5	<5	<5	±	---
6-42-2	2	<5	<5	<5	±	---
6-42-40A	2	<5	<5	<5	±	---
6-42-40B	1	<5	---	<5	±	---
6-42-42B	1	<5	---	<5	±	---
6-43-3	2	<5	<5	<5	±	---
6-43-42J	1	<5	---	<5	±	---
6-43-43	1	<5	---	<5	±	---
6-44-42	1	<5	---	<5	±	---
6-44-64	2	<5	<5	<5	±	---
6-45-2	2	<5	<5	<5	±	---
6-45-42	2	<5	<5	<5	±	---
6-46-4	2	<5	<5	<5	±	---
6-47-5	2	<5	<5	<5	±	---
6-47-46A	2	<5	<5	<5	±	---
6-47-50[c]	2	<5	<5	<5	±	---
6-47-60	2	<5	<5	<5	±	---
6-49-55A	2	<5	<5	<5	±	---
6-49-57	2	<5	<5	<5	±	---
6-49-79	2	<5	<5	<5	±	---
6-50-53	2	<5	<5	<5	±	---
6-50-85	2	<5	<5	<5	±	---
6-53-47A	1	<5	---	<5	±	---
6-55-50C	2	<5	<5	<5	±	---

TABLE C.45. (Carbon Tetrichloride contd)

Well Name[b]	No. of Samples	Concentration (ppb)[a] Maximum	Minimum	Average
6-55-76	3	<5	<5	<5 ± ---
6-65-72	2	<5	<5	<5 ± ---
6-65-83	2	<5	<5	<5 ± ---
6-67-86	2	<5	<5	<5 ± ---
6-70-68	2	<5	<5	<5 ± ---
6-71-30	2	<5	<5	<5 ± ---
6-71-52	2	<5	<5	<5 ± ---
6-71-77	2	<5	<5	<5 ± ---
6-72-73	2	<5	<5	<5 ± ---
6-73-61	2	<5	<5	<5 ± ---
6-74-44	2	<5	<5	<5 ± ---
6-77-36	7	<5	<5	<5 ± ---
6-78-62	2	<5	<5	<5 ± ---
6-81-58	4	<5	<5	<5 ± ---
6-83-47	3	<5	<5	<5 ± ---
6-96-49	2	<5	<5	<5 ± ---
6-97-43	2	<5	<5	<5 ± ---
6-97-51A	2	<5	<5	<5 ± ---
6-101-48B	2	<5	<5	<5 ± ---
6-ATH	1	<5	---	<5 ± ---
6-ORV-1	1	<5	---	<5 ± ---
11-34-15B	1	<5	---	<5 ± ---
11-37-16	1	<5	---	<5 ± ---
11-39-15	1	<5	---	<5 ± ---
11-39-16C	1	<5	---	<5 ± ---
11-39-16E	1	<5	---	<5 ± ---
11-40-15	1	<5	---	<5 ± ---
11-40-16B	1	<5	---	<5 ± ---
11-41-13C	1	<5	---	<5 ± ---
30-42-16	1	<5	---	<5 ± ---

(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 5.1, 5.2, and 5.3 for well locations.
(c) Wells that sample a confined aquifer or a composite of confined and unconfined

TABLE C.46. WDSHS and PNL Shared TLD Stations in 1988

Location	Exposure Rate (mR/day)[a]							
	First[b]		Second		Third		Fourth	
	DSHS	PNL	DSHS	PNL	DSHS	PNL	DSHS	PNL
U.S. Ecology NE Corner	0.28	0.21	*	0.22	0.21	0.22	0.27	0.22
NW Corner	0.24	0.26	*	0.24	0.23	0.23	0.26	0.23
SW Corner	0.31	0.30	*	0.28	0.35	0.33	0.32	0.29
WNP-2 Station 1	0.22	0.25	*	0.23	0.19	0.22	0.26	0.23
WNP-2 Station 4	0.19	0.23	*	0.21	0.17	0.21	0.25	0.20
WNP-2 Station 8	0.23	0.26	*	0.25	0.21	0.24	0.27	0.24
200 ESE	0.22	0.22	*	0.24	0.20	0.24	0.24	0.23
E 200E	0.25	0.26	*	0.25	0.21	0.24	0.30	0.23
N 200E	0.23	0.23	*	0.24	0.18	0.24	0.24	0.23
Rt. 11A Mile 9	0.23	0.23	*	0.24	0.18	0.22	0.24	0.22
GTE Building	0.28	0.22	*	0.23	0.16	0.23	0.23	0.22
S 200E	0.28	0.25	*	0.26	0.21	0.23	0.27	0.24
SW of BC Crib	0.23	0.24	*	0.24	0.18	0.25	0.24	0.23
Army Loop Camp	0.23	0.24	*	0.24	0.17	0.25	0.23	0.23
Yakima Barricade	0.25	0.27	*	0.25	0.21	0.25	0.24	0.23
Wye Barricade	0.20	0.21	*	0.24	0.16	0.21	0.21	0.22
Moses Lake	0.22	0.19	*	0.20	0.16	0.20	0.19	0.20
Connell	0.19	0.27	*	0.21	0.19	0.22	0.24	0.20
Richland	0.19	0.19	*	0.18	0.19	0.16	0.22	0.21
Sunnyside	0.18	0.14	*	0.21	0.19	0.21	0.21	0.20
Yakima	0.16	0.16	*	0.18	0.20	0.19	0.21	0.20

(a) TLD results for DSHS and PNL at the same location in units of milliroentgens per day.
(b) First, second, third, and fourth refer to the 1988 calendar quarters.
* No data.

TABLE C.47. Surface-Water Split Samples for 1988

Nuclide	Results (pCi/L)[a] Washington	Oregon	U.S.Testing	Supply System	SEARCH
HANFORD N8T WELL - Water Analyses					
Gross Alpha	2 ± 3	<10	0.55 ± 0.61	NR[b]	NR
Gross Beta	15,800 ± 200	18,500 ± 100	13,800 ± 100	19,000 ± 1,000	NR
^{3}H	66,900 ± 1,400	77,800 ± 800	74,000 ± 700	190,000 ±10,000	NR
^{89}Sr	<352	<300	<1030	730 ± 130	NR
^{90}Sr	8,310 ± 120	8,500 ± 300	6,680 ± 260	7,500 ± 100	NR
^{60}Co	49 ± 3	54 ± 6	45.0 ± 4.5	57.6 ± 6.9	44.7 ± 9.5
^{106}Ru	<20	<33	<69	NR	NR
^{125}Sb	32 ± 3	45 ± 16	43.1 ± 6.4	NR	NR
^{137}Cs	<3	<3	<8	<5	NR
1325-N SPRINGS (DOWNSTREAM N-REACTOR) - Water Analyses					
Gross Alpha	0.2 ± 2.0	<2	0.37 ± 0.46	NR	NR
Gross Beta	42 ± 4	41.6 ± 1.1	73.8 ± 7.8	50 ± 4	NR
^{3}H	106,000 ± 2,000	121,000 ± 1,200	111,000 ± 870	110,000 ±10,000	NR
^{89}Sr	0.1 ± 1.5	<1	<0.1	<2	NR
^{90}Sr	0.2 ± 0.5	<1	0.31 ± 0.09	<0.8	NR
^{60}Co	33.5 ± 2.4	41.1 ± 4.8	30.0 ± 4.0	39.5 ± 5.5	31.2 ± 1.7
^{106}Ru	15.2 ± 8.7	<35	13.5 ± 14.6	NR	NR
^{125}Sb	<7	<20	NR	NR	NR
^{137}Cs	<3	<7	0.4 ± 1.1	<5	NR
HANFORD FERRY LANDING - Water Analyses					
Gross Alpha	0.5 ± 1.0	<1	0.23 ± 0.33	NR	NR
Grass Beta	0.8 ± 0.5	1.8 ± 1.2	5.0 ± 2.3	29 ± 2	NR
^{3}H	<190	<330	31 ± 111	<200	NR
^{89}Sr	<1.5	<1	0.6 ± 1.1	<2	NR
^{90}Sr	0.2 ± 0.5	<1	7.2 ± 0.3	<0.8	NR
^{60}Co	<3	<6	0.15 ± 0.97	NR	0.008 ± 0.004
^{106}Ru	<20	<30	<8.1	NR	0.52 ± 0.18
^{125}Sb	<7	<20	NR	NR	NR
^{137}Cs	<3	<7	0.4 ± 0.8	NR	NR
RIVER MILE 28 SEEP - Water Analyses					
Gross Alpha	5 ± 2	2.2 ± 1.5	2.62 ± 1.12	NR	NR
Gross Beta	28 ± 5	4.9 ± 3.7	168 ± 11	59 ± 4	NR
^{3}H	127,000 ± 3,000	150,000 ±1,500	143,000 ± 980	140,000 ±10,000	NR
^{89}Sr	0.03 ± 1.00	<1	0.06 ± 0.11	NR	NR
^{90}Sr	<0.5	<1	0.79 ± 0.11	NR	NR
^{60}Co	4.6 ± 1.2	<14	4.0 ± 1.8	<5	3.98 ± 0.2
^{106}Ru	<20	<65	3.0 ± 7.6	NR	NR
^{125}Sb	<7	<42	NR	NR	NR
^{137}Cs	<3	<14	<1.1	<5	0.27 ± 0.13
^{99}Tc	NR	NR	228 ± 3	NR	NR
300 AREA SEEP 42-2 - Water Analyses					
Gross Alpha	15 ± 4	5.8 ± 1.5	7.95 ± 1.46	NR	NR
Gross Beta	15 ± 1	11 ± 2	11.6 ± 3.3	27 ± 2	NR
^{3}H	150 ± 190	<330	168 ± 115	290 ± 150	NR
^{89}Sr	1.0 ± 1.9	<0.5	0.13 ± 0.11	<10	NR
^{90}Sr	1.3 ± 0.6	<0.3	0.16 ± 0.07	180 ± 10	NR
^{60}Co	<3	<14	0.25 ± 0.80	NR	0.093 ± 0.063
^{106}Ru	<3	<6	<6	NR	0.19 ± 0.02
^{125}Sb	<7	<20	<19	NR	NR
^{137}Cs	<3	<16	0.4 ± 0.6	<5	0.093 ± 0.063
^{235}U	NR	NR	NR	NR	0.19 ± 0.02
U-Total	10.1 ± 0.5	NR	9.6	NR	NR

TABLE C.47. (Surface-Water Split Samples contd)

Nuclide	Results (pCi/L)[a] Washington	Oregon	U.S.Testing	Supply System	SEARCH	Oak Ridge
IOOF SLOUGH - Sediment Analyses by Gamma Spectrometry						
^{40}K	NR	12.0 ± 0.6	13.9 ± 0.7	13.2 ± 1.3	NR	14.3 ± 0.1
^{226}Ra	0.83 ± 0.02	0.6 ± 0.1	0.6 ± 0.05	0.98 ± 0.37	NR	0.77 ± 0.02
^{232}Th	0.82 ± 0.03	0.6 ± 0.1	0	NR	NR	0.97 ± 0.03
^{60}Co	0.067 ± 0.009	0.05 ± 0.02	0.08 ± 0.02	0.05 ± 0.03	NR	0.05 ± 0.01
^{134}Cs	<0.02	NR	NR	NR	NR	NR
^{137}Cs	0.26 ± 0.011	0.16 ± 0.03	0.27 ± 0.03	0.23 ± 0.03	0.15 ± 0.18	0.19 ± 0.01
^{152}Eu	0.070 ± 0.028	NR	NR	NR	0.12 ± 0.08	NR
^{235}U	NR	NR	NR	NR	NR	NR
IOOF Slough - Sediment Analyses by Alpha Spectrometry						
U(Total)	1.40 ± 0.04	1.34 ± 0.12	NR	NR	NR	NR
Pu(Total)	0.0021 ± 0.0028	0.0030 ± 0.0001	0.0013 ± 0.00004	NR	NR	NR
^{230}Th	0.62 ± 0.03	0.54 ± 0.05	NR	NR	NR	NR
^{232}Th	0.82 ± 0.03	0.70 ± 0.65	0.7 ± 0.1	NR	NR	NR
^{238}U	NR	NR	0.54 + 0.29	NR	NR	NR
McNary Dam - Sediment Analyses by Gamma Spectrometry						
^{40}K	NR	16.0 ± 0.5	12.5 ± 0.7	13.7 ± 1.4	NR	14.6 ± 0.2
^{226}Ra	1.0 ± 0.1	0.9 ± 0.1	0.61 ± 0.07	0.98 ± 0.3	NR	0.89 ± 0.03
^{232}Th	NR	1.2 ± 0.1	NR	NR	NR	0.98 ± 0.03
^{210}Pb	NR	NR	NR	NR	NR	1.83 ± 0.11
^{60}Co	0.28 ± 0.02	0.31 ± 0.02	0.24 ± 0.04	0.28 ± 0.004	NR	0.25 ± 0.01
^{134}Cs	0.03 ± 0.02	0.07 ± 0.02	0.02 ± 0.02	NR	NR	NR
^{137}Cs	0.75 ± 0.03	0.85 ± 0.04	0.75 ± 0.05	0.77 ± 0.07	0.75 ± 0.13	0.74 ± 0.01
^{152}Eu	0.53 ± 0.04	0.58 ± 0.04	0.61 ± 0.13	NR	0.36 ± 0.06	0.44 ± 0.02
^{235}U	NR	NR	0.13 ± 0.13	NR	NR	NR
McNary Dam - Sediment Analyses by Alpha Spectrometry						
U(Total)	2.25 ± 0.17	2.39 ± 0.21	0.86 ± 0.38	NR	NR	NR
Pu(Total)	0.0093 ± 0.0047	0.010 ± 0.001	0.0089 ± 0.0011	NR	NR	NR
^{230}Th	0.88 ± 0.03	0.68 ± 0.06	NR	NR	NR	NR
^{232}Th	0.91 ± 0.02	0.72 ± 0.07	0.92 ± 0.1	NR	NR	NR

(a) Results ±2 standard deviations for values greater than the system minimum detectable amount (MDA). Only nuclides with quantifiable activities greater than the MDA are listed.
(b) NR = not reported.

TABLE C.48. Split Foodstuff Samples (U.S. FDA and U.S. Testing Company)

Product	Laboratory	Activity, pCi/kg (except ^{3}H, µCi/kg) ^{137}Cs	^{40}K	^{90}Sr	^{3}H
Cabbage	FDA	28 ± 45	2800 ± 500*	2.1 ± 1.2*	NA
(Riverview)	UST	-2.2 ± 1.8	2920 ± 1680*	5.9 ± 7.0	NA
Potatoes	FDA	12 ± 35	4100 ± 600*	0.6 ± 0.9	NA
(Riverview)	UST	0.05 ± 3.4	4020 ± 481	5.3 ± 0.3*	NA
Potatoes	FDA	1 ± 31	4200 ± 500*	0.4 ± 0.8	NA
(Sagemoor)	UST	2.2 ± 5.4	4290 ± 266*	5.2 ± 1.9*	NA
Potatoes	FDA	34 ± 38	4400 ± 500*	-0.2 ± 0.9	NA
(Sunnyside)	UST	-4.0 ± 3.5	3870 ± 557*	4.5 ± 1 7*	NA
Apples	FDA	20 ± 36	1200 ± 500*	-0.5 ± 0.9	0.1 ± 0.1
(Riverview)	UST	4.3 ± 7.8	1120 ± 227	0.2 ± 0.7	0.0001 ± 0.00003*
Apples	FDA	-4 ± 40	1200 ± 500*	0.1 ± 0.9	0.01 ± 0.01
(Wahluke)	UST	-3.7 ± 6.8	930 ± 180*	0.6 ± 0.9	0.0002 ± 0.00005*
Wheat	FDA	25 ± 30	4600 ± 500*	4.6 ± 1.3*	NA
(Sagemoor)	UST	3.9 ± 6.8	NA	NA	12.1 ± 1.7*
Wheat	FDA	22 ± 31	4000 ± 500*	5.5 ± 1.3*	NA
(Moses Lake)	UST	0.5 ± 2.4	4450 ± 247*	7.9 ± 1.3*	NA

* Considered statistically positive.
NA = Not analyzed.

APPENDIX D

ANALYTICAL PROCEDURES AND SAMPLING SUMMARY

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.[a] 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.[b] 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[b] 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	
^{95}ZrNb		

Da=daughters

Strontium-90 is leached from glass fiber filters[b] 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[b] with nitric acid, extracted into hexone, and, then back extracted into water. A portion of the water extract is purified, electrodeposited onto a stainless steel planchet, and then counted with an alpha spectrometer.

Plutonium is leached from glass fiber filters[b] with nitric acid and passed through an anion-exchange resin. The plutonium 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 TEDA-treated activated charcoal (90% and 70% efficient for methyl iodine at 2.6 and 5.2 m^{3}/h, respectively) and then counted on a Ge(Li) detector with a multichannel, pulse-height analyzer.

Iodine-129 is collected on a special petroleum-base charcoal. Iodine is removed from

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(a) Procedures Manual, UST-RD-PM, U.S. Testing Co., Inc., Richland, Washington.
(b) >99% efficient for 0.3 μm particles.

the charcoal, purified, and determined by mass spectrometry.

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 to remove unwanted gases. 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. See page D.1 for list of radionuclides included in gamma scan analysis.

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.

Uranium in the water sample is adsorbed onto anion resin following wet ashing, purified, electrodeposited onto a stainless steel planchet and then counted with an alpha 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 mass spectrometry 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 mass spectrometry.

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.

Iodine-129 in foodstuff samples (other than milk) is determined after the sample is dried and weighed. The dried sample is counted directly with a low-energy photon detector (LEPD) system.

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.

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 is extracted into hexone from the sample following dry ashing. Uranium is back-extracted into water, purified, fused in a fluoride flux, and then analyzed with a fluorimeter as total uranium.

Plutonium, Strontium, and Gamma-Emitting Radionuclides are measured using the procedures described for foodstuffs.

SOIL AND SEDIMENT

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 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, sieved to pass a 2-mm screen, and weighted. The dried sample is counted directly with a low-energy photon detector (LEPD) system.

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 U.S. Geological Survey (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 Ge(Li) detector is used to count the samples. The standards are traceable to the National Institute of Standards and Technology (formally 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 Sediments 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,* (EPA 1982).

Fluoride is measured by ion chromatograph (see "Inorganic Anions") or by an electrode method to attain a lower detection level (50 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 (50 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 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 being 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.

TABLE D.1. Radiological Monitoring Sampling Summary

Medium Sampled	Type of Analysis	Scheduled Frequency of Collection	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	1,000 min	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^{-6} 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
	$^{239,240}Pu$	Quarterly	1 L	1,000 min	0.10 pCi/L	1,000 mL	On Site
	Uranium (natural)	M,Q[f]	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

TABLE D.1. (Radiological Monitoring Sampling Summary contd)

Medium Sampled	Type of Analysis	Scheduled Frequency of Collection	Approximate Sample Size	Count Time	Minimum Detectable Concentration (MDC)	Analysis Aliquot Size	Sampling Location
Ground water (contd)	^{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
	Uranium (isotopic)	Monthly comp.	40 L	1,000 min	0.06 pCi/L	100-1,000 mL	Off Site
Resin	^{129}I	Quarterly comp.	6,000 L water	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 water	1,000 min	0.01 pCi/L	250-500 L	Off Site/ On Site
Resin	$^{239,240}Pu$	Quarterly comp.	6,000 L water	24-72 h	0.0005 pCi/L	1,500-3,000 L	Off Site/ On Site
Particulate	$^{239,240}Pu$	Quarterly comp.	6,000 L water	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
	^{90}Sr	Quarterly	10 L	100 min	2.0 pCi/L	1 L	Off Site
	^{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	0.00001 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

TABLE D.1. (Radiological Monitoring Sampling Summary contd)

Medium Sampled	Type of Analysis	Scheduled Frequency of Collection	Approximate Sample Size	Count Time	Minimum Detectable Concentration (MDC)	Analysis Aliquot Size	Sampling Location
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
	$^{239,240}Pu$	Annually	2 kg	1,000 min	0.0006 pCi/g	100 g	Off Site
Produce and farm products	^{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
	$^{239,240}Pu$	Annually	2 kg	1,000 min	0.0006 pCi/g	100 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 (boneless muscle)	100 min	0.005 pCi/g	100 g	Off Site
	Gamma scan (^{137}Cs)	Semiannually	1 chicken (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	1 L	150 min	300 pCi/L	5 mL	Off Site
	Gamma scan (^{137}Cs)	Annually	1 L	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
Ducks and gamebirds	^{90}Sr	20 per year	1 bird (bone)	100 min	0.005 pCi/g	100 g	On Site
	Gamma scan (^{137}Cs)	20 per year	1 fish carcass	1,000 min	0.015 pCi/g	250-500 g	Off Site/ On Site
Ducks	Gamma scan (^{137}Cs)	32 per year	1 duck (breast)	1,000 min	0.015 pCi/g	250-500 g	On Site
Game birds	Gamma scan (^{137}Cs)	22 per year	1 bird (muscle)	1,000 min	0.015 pCi/g	250-500 g	On Site

TABLE D.1. (Radiological Monitoring Sampling Summary contd)

Medium Sampled	Type of Analysis	Scheduled Frequency of Collection	Approximate Sample Size	Count Time	Minimum Detectable Concentration (MDC)	Analysis Aliquot Size	Sampling Location
Ducks and amebirds (contd)	Gamma Scan (^{137}Cs)	20 per year	1 bird (boneless muscle)	1,000 min	0.015 pCi/g	500 g	On Site
Deer	Gamma Scan (^{137}Cs)	8 per year	1 kg (muscle)	1,000 min	0.015 pCi/g	250-500 g	On Site
	^{90}Sr	8 per year	250 g (bone)	100 min	0.0006 pCi/g	100 g	
	$^{239,240}Pu$	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
	$^{239,240}Pu$	12 per year	1 liver	1,000 min	0.0006 pCi/g	100 g	On Site
Soil	^{90}Sr	Annually	1.5 kg	100 min	0.005 pCi/g	100 g	Off Site/ On Site
	Gamma scan (^{137}Cs)	Annually	1.5 kg	100 min	0.02 pCi/g	500 g	Off Site/ On Site
	Uranium (LEPD)	Annually	1.5 kg	500 min	1.0 pCi/g	100 g	Off Site/ On Site
	$^{239,240}Pu$	Annually	1.5 kg	1,000 min	0.0006 pCi/g	100 g	Off Site/ On Site
	^{241}Am	Annually	1.5 kg	1,000 min	0.05 pCi/g	10 g	Off Site/ On Site
Native vegetation	Gamma scan (^{137}Cs)	Annually	2 kg	1,000 min	0.03 pCi/g	125 g	Off Site/ On Site
	^{90}Sr	Annually	2 kg	200 min	0.005 pCi/g	100 g	Off Site/ On Site
	Total U	Annually	2 kg	NA	0.01 pCi/g	10 g	Off Site/ On Site
	$^{239,240}Pu$	Annually	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) Five locations.
(c) Twelve locations.
(d) Four locations.
(e) Nine 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.

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, HNO_3 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[e]
Sulfate			500
Fluoride	P, None	70-IC[f,g]	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. (Analytical Methods for Chemicals in Ground Water 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			

TABLE D.2. (Analytical Methods for Chemicals in Ground Water contd)

Constituent	Collection and Preservation[a,b]	Methods[c]	Detection Limit, ppb[d]
1,2,3,4-trichlorobenzene			
1,2,3-trichlorobenzene			
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) Detection limit 2500 when five-fold dilution used.
(f) 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).
(g) IC = ion chromatography.
(h) LDL = Low detection level.
(i) Measurement resolution.

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

TABLE D.3. (Volatile Organic Compounds and Detection Limits 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

APPENDIX E

DATA SUMMARIES

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. Such values are considered as below detection. 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 x_i is the ith measurement and n is the number of measurements.

The standard error of $\bar{x}$ was computed as

$$SE = \sqrt{\frac{S^2}{n}}$$

where S^2, the variance of the n measurements, was computed as

$$S_M^2 = \frac{1}{n-1} \sum_{i=1}^{n} (x_i - \bar{x})^2$$

This estimator, S^2, includes the variance among the samples and the counting variance. The estimated S^2 may occassionally be less than the average counting variance.

APPENDIX F

DOSE CALCULATIONS

APPENDIX F

DOSE CALCULATIONS

The radiation dose that the public could have potentially received from 1988 Hanford operations is calculated in terms of the "dose equivalent" and "effective dose equivalent." These dose quantities are given in units of millirems (mrem) (mSv) for individuals and in units of person-rems (person-Sv) for the collective dose received by 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 B.5, Appendix B). This appendix describes how the doses were calculated for this report.

The transport of radionuclides from the environment to the body is predicted 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.

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 environmental transport models. Dietary and exposure parameters were then applied to calculate radionuclide intakes and radiation doses to man. 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 (Napier et al. 1988a,b,c), 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

Revised DOE Guidance for Dose Calculations

Calculations of radiation doses to the public from radionuclides released into the environment are performed to demonstrate compliance with applicable standards and regulations.

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). As in the past, when concentrations of radionuclides in the environment are too low to measure, then doses are calculated from effluent data using environmental transport and dosimetry models.

Estimated radiation doses from DOE operations have previously been reported in terms of the dose equivalent (or simply, dose), which is a measure of the energy absorbed by tissue (rads), 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 effective dose equivalent is the sum of individual committed (50-year) 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 internal or external sources, and the two sources are to be summed.

In addition to implementing the effective dose equivalent 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 equivalent takes into account the long-term internal exposure from radionuclides taken into the body during the current year. 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 in close 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 released from Hanford. 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 100-N Reactor site
- 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. However, evaluation of the collective population doses to all residents within an 80-km radius of Hanford Site operations provides an indication of the overall radiation exposure of the surrounding population. The 80-km population dose equivalent and effective dose equivalent represent the summed products of the individual doses for the number of individuals involved for all potential exposure pathways.

The pathways for the maximally exposed individual were assumed to also be applicable to the offsite population with the addition of drinking water drawn from the Columbia River. 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

(a) 1 rem (0.01 Sv) = 1000 mrem (10 mSv).

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. A total population of approximately 70,000 in the three cities drink water derived from the Columbia River.

- **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 around the 100, 200, 300, and 400 Areas during 1988 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 used for pathway and dose calculations have been documented in GENII (Napier et al. 1988).

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 beginning in 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

The potential offsite radiation dose is related to the extent of external exposure to or intake of radionuclides that are released from 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 Hanford Dose Overview Panel has the responsibility for defining standard, documented computer codes and input parameters to be used for radiation dose calculations for the public in the vicinity of the Hanford Site. Only procedures, models, and parameters defined by the Hanford Dose Overview Panel were used to calculate the radiation doses. The calculations were then reviewed by the Dose Overview Panel. 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 Meteorological 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.

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.

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.

TABLE F.5. Annual Average Atmospheric Dispersion ($\bar{X}/Q'$) Around the 100-N Area During 1988 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	5.79×10^{-8}	4.90×10^{-8}	4.21×10^{-8}	3.34×10^{-8}	2.69×10^{-8}	1.60×10^{-8}	7.39×10^{-9}	4.10×10^{-9}	2.78×10^{-9}	2.07×10^{-9}
NNE	3.43×10^{-8}	3.15×10^{-8}	2.82×10^{-8}	2.32×10^{-8}	1.93×10^{-8}	1.23×10^{-8}	6.13×10^{-9}	3.57×10^{-9}	2.48×10^{-9}	1.89×10^{-9}
NE	5.41×10^{-8}	3.18×10^{-8}	2.86×10^{-8}	2.39×10^{-8}	2.01×10^{-8}	1.31×10^{-8}	6.81×10^{-9}	4.07×10^{-9}	2.88×10^{-9}	2.21×10^{-9}
ENE	7.70×10^{-8}	5.27×10^{-8}	4.50×10^{-8}	3.70×10^{-8}	3.09×10^{-8}	2.02×10^{-8}	1.06×10^{-8}	6.42×10^{-9}	4.56×10^{-9}	3.51×10^{-9}
E	1.80×10^{-7}	1.12×10^{-7}	9.30×10^{-8}	7.54×10^{-8}	6.24×10^{-8}	4.03×10^{-8}	2.10×10^{-8}	1.27×10^{-8}	9.08×10^{-9}	7.02×10^{-9}
ESE	1.45×10^{-7}	7.34×10^{-8}	6.01×10^{-8}	4.92×10^{-8}	4.12×10^{-8}	2.73×10^{-8}	1.46×10^{-8}	8.90×10^{-9}	6.36×10^{-9}	4.92×10^{-9}
SE	1.26×10^{-7}	5.08×10^{-8}	4.15×10^{-8}	3.37×10^{-8}	2.78×10^{-8}	1.78×10^{-8}	9.02×10^{-9}	5.33×10^{-9}	3.74×10^{-9}	2.86×10^{-9}
SSE	9.25×10^{-8}	3.65×10^{-8}	2.93×10^{-8}	2.35×10^{-8}	1.93×10^{-8}	1.23×10^{-8}	6.39×10^{-9}	3.86×10^{-9}	2.75×10^{-9}	2.12×10^{-9}
S	1.42×10^{-7}	6.74×10^{-8}	5.56×10^{-8}	4.49×10^{-8}	3.70×10^{-8}	2.33×10^{-8}	1.16×10^{-8}	6.68×10^{-9}	4.62×10^{-9}	3.49×10^{-9}
SSW	1.12×10^{-7}	5.62×10^{-8}	4.42×10^{-8}	3.52×10^{-8}	2.87×10^{-8}	1.80×10^{-8}	8.87×10^{-9}	5.14×10^{-9}	3.56×10^{-9}	2.69×10^{-9}
SW	7.50×10^{-8}	3.35×10^{-8}	2.72×10^{-8}	2.21×10^{-8}	1.83×10^{-8}	1.19×10^{-8}	6.11×10^{-9}	3.65×10^{-9}	2.57×10^{-9}	1.97×10^{-9}
WSW	6.76×10^{-8}	3.49×10^{-8}	2.98×10^{-8}	2.51×10^{-8}	2.14×10^{-8}	1.47×10^{-8}	8.20×10^{-9}	5.14×10^{-9}	3.73×10^{-9}	2.91×10^{-9}
W	1.20×10^{-7}	8.36×10^{-8}	7.01×10^{-8}	5.75×10^{-8}	4.79×10^{-8}	3.13×10^{-8}	1.63×10^{-8}	9.71×10^{-9}	6.84×10^{-9}	5.24×10^{-9}
WNW	1.06×10^{-7}	6.31×10^{-8}	4.87×10^{-8}	3.80×10^{-8}	3.06×10^{-8}	1.87×10^{-8}	9.07×10^{-9}	5.22×10^{-9}	3.61×10^{-9}	2.73×10^{-9}
NW	8.35×10^{-8}	4.96×10^{-8}	3.82×10^{-8}	3.00×10^{-8}	2.44×10^{-8}	1.52×10^{-8}	7.46×10^{-9}	4.29×10^{-9}	2.96×10^{-9}	2.23×10^{-9}
NNW	4.71×10^{-8}	4.96×10^{-8}	4.28×10^{-8}	3.42×10^{-8}	2.77×10^{-8}	1.68×10^{-8}	7.83×10^{-9}	4.34×10^{-9}	2.92×10^{-9}	2.17×10^{-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 1988 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	7.70×10^{-8}	4.51×10^{-8}	3.79×10^{-8}	3.13×10^{-8}	2.63×10^{-8}	1.73×10^{-8}	9.16×10^{-9}	5.53×10^{-9}	3.92×10^{-9}	3.02×10^{-9}
NNE	4.17×10^{-8}	2.65×10^{-8}	2.44×10^{-8}	2.06×10^{-8}	1.75×10^{-8}	1.17×10^{-8}	6.13×10^{-9}	3.66×10^{-9}	2.58×10^{-9}	1.97×10^{-9}
NE	5.78×10^{-8}	3.38×10^{-8}	3.15×10^{-8}	2.67×10^{-8}	2.26×10^{-8}	1.49×10^{-8}	7.75×10^{-9}	4.62×10^{-9}	3.25×10^{-9}	2.49×10^{-9}
ENE	5.35×10^{-8}	3.80×10^{-8}	3.51×10^{-8}	3.02×10^{-8}	2.61×10^{-8}	1.80×10^{-8}	9.97×10^{-9}	6.21×10^{-9}	4.48×10^{-9}	3.49×10^{-9}
E	9.23×10^{-8}	7.32×10^{-8}	6.76×10^{-8}	5.75×10^{-8}	4.90×10^{-8}	3.29×10^{-8}	1.75×10^{-8}	1.06×10^{-8}	7.57×10^{-9}	5.83×10^{-9}
ESE	9.02×10^{-8}	8.10×10^{-8}	7.36×10^{-8}	6.15×10^{-8}	5.16×10^{-8}	3.36×10^{-8}	1.73×10^{-8}	1.02×10^{-8}	7.14×10^{-9}	5.44×10^{-9}
SE	1.52×10^{-7}	8.96×10^{-8}	7.51×10^{-8}	6.11×10^{-8}	5.06×10^{-8}	3.26×10^{-8}	1.67×10^{-8}	9.92×10^{-9}	6.97×10^{-9}	5.33×10^{-9}
SSE	1.56×10^{-7}	8.28×10^{-8}	6.51×10^{-8}	5.04×10^{-8}	4.01×10^{-8}	2.38×10^{-8}	1.10×10^{-8}	6.08×10^{-9}	4.10×10^{-9}	3.06×10^{-9}
S	2.37×10^{-7}	1.10×10^{-7}	7.66×10^{-8}	5.57×10^{-8}	4.26×10^{-8}	2.35×10^{-8}	1.00×10^{-8}	5.34×10^{-9}	3.54×10^{-9}	2.60×10^{-9}
SSW	2.03×10^{-7}	9.67×10^{-8}	6.89×10^{-8}	5.09×10^{-8}	3.94×10^{-8}	2.22×10^{-8}	9.59×10^{-9}	5.11×10^{-9}	3.38×10^{-9}	2.47×10^{-9}
SW	1.20×10^{-7}	5.07×10^{-8}	3.51×10^{-8}	2.56×10^{-8}	1.95×10^{-8}	1.08×10^{-8}	4.63×10^{-9}	2.47×10^{-9}	1.64×10^{-9}	1.21×10^{-9}
WSW	9.37×10^{-8}	4.11×10^{-8}	2.84×10^{-8}	2.06×10^{-8}	1.58×10^{-8}	8.75×10^{-9}	3.79×10^{-9}	2.04×10^{-9}	1.35×10^{-9}	9.99×10^{-10}
W	1.39×10^{-7}	5.21×10^{-8}	3.83×10^{-8}	2.93×10^{-8}	2.33×10^{-8}	1.38×10^{-8}	6.38×10^{-9}	3.52×10^{-9}	2.37×10^{-9}	1.76×10^{-9}
WNW	8.16×10^{-8}	3.78×10^{-8}	2.91×10^{-8}	2.26×10^{-8}	1.82×10^{-8}	1.10×10^{-8}	5.19×10^{-9}	2.91×10^{-9}	1.98×10^{-9}	1.48×10^{-9}
NW	6.64×10^{-8}	2.93×10^{-8}	2.40×10^{-8}	1.94×10^{-8}	1.61×10^{-8}	1.04×10^{-8}	5.40×10^{-9}	3.26×10^{-9}	2.31×10^{-9}	1.78×10^{-9}
NNW	5.33×10^{-8}	2.30×10^{-8}	2.14×10^{-8}	1.85×10^{-8}	1.60×10^{-8}	1.10×10^{-8}	5.98×10^{-9}	3.68×10^{-9}	2.64×10^{-9}	2.05×10^{-9}

(a) Calculated from meteorological data collected at the Hanford Meteorology Tower.

TABLE F.7. Annual Average Atmospheric Dispersion ($\bar{X}/Q'$) Around the 300 Area During 1988 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	4.94×10^{-6}	1.03×10^{-6}	4.90×10^{-7}	3.03×10^{-7}	2.13×10^{-7}	1.04×10^{-7}	4.06×10^{-8}	2.05×10^{-8}	1.31×10^{-8}	9.44×10^{-9}
NNE	2.88×10^{-6}	5.87×10^{-7}	2.78×10^{-7}	1.72×10^{-7}	1.20×10^{-7}	5.88×10^{-8}	2.27×10^{-8}	1.14×10^{-8}	7.29×10^{-9}	5.23×10^{-9}
NE	2.47×10^{-6}	4.81×10^{-7}	2.26×10^{-7}	1.38×10^{-7}	9.63×10^{-8}	4.67×10^{-8}	1.78×10^{-8}	8.89×10^{-9}	5.65×10^{-9}	4.04×10^{-9}
ENE	2.33×10^{-6}	4.53×10^{-7}	2.13×10^{-7}	1.31×10^{-7}	9.11×10^{-8}	4.43×10^{-8}	1.70×10^{-8}	8.49×10^{-9}	5.40×10^{-9}	3.87×10^{-9}
E	2.61×10^{-6}	5.54×10^{-7}	2.65×10^{-7}	1.64×10^{-7}	1.15×10^{-7}	5.64×10^{-8}	2.19×10^{-8}	1.10×10^{-8}	7.06×10^{-9}	5.07×10^{-9}
ESE	2.26×10^{-6}	4.69×10^{-7}	2.24×10^{-7}	1.38×10^{-7}	9.71×10^{-8}	4.77×10^{-8}	1.86×10^{-8}	9.36×10^{-9}	5.99×10^{-9}	4.30×10^{-9}
SE	2.49×10^{-6}	5.23×10^{-7}	2.49×10^{-7}	1.54×10^{-7}	1.08×10^{-7}	5.33×10^{-8}	2.07×10^{-8}	1.05×10^{-8}	6.69×10^{-9}	4.81×10^{-9}
SSE	3.73×10^{-6}	7.84×10^{-7}	3.74×10^{-7}	2.31×10^{-7}	1.62×10^{-7}	7.94×10^{-8}	3.08×10^{-8}	1.55×10^{-8}	9.91×10^{-9}	7.11×10^{-9}
S	5.04×10^{-6}	1.08×10^{-6}	5.18×10^{-7}	3.21×10^{-7}	2.25×10^{-7}	1.11×10^{-7}	4.30×10^{-8}	2.17×10^{-8}	1.39×10^{-8}	9.95×10^{-9}
SSW	2.16×10^{-6}	4.17×10^{-7}	1.95×10^{-7}	1.19×10^{-7}	8.27×10^{-8}	4.00×10^{-8}	1.52×10^{-8}	7.59×10^{-9}	4.82×10^{-9}	3.45×10^{-9}
SW	8.01×10^{-7}	1.44×10^{-7}	6.63×10^{-8}	4.02×10^{-8}	2.78×10^{-8}	1.33×10^{-8}	5.01×10^{-9}	2.48×10^{-9}	1.57×10^{-9}	1.12×10^{-9}
WSW	6.89×10^{-7}	1.16×10^{-7}	5.21×10^{-8}	3.12×10^{-8}	2.13×10^{-8}	1.00×10^{-8}	3.65×10^{-9}	1.76×10^{-9}	1.10×10^{-9}	7.74×10^{-10}
W	1.61×10^{-6}	3.10×10^{-7}	1.45×10^{-7}	8.92×10^{-8}	6.22×10^{-8}	3.03×10^{-8}	1.16×10^{-8}	5.81×10^{-9}	3.70×10^{-9}	2.65×10^{-9}
WNW	2.55×10^{-6}	5.22×10^{-7}	2.48×10^{-7}	1.53×10^{-7}	1.08×10^{-7}	5.28×10^{-8}	2.05×10^{-8}	1.03×10^{-8}	6.63×10^{-9}	4.76×10^{-9}
NW	4.29×10^{-6}	9.29×10^{-7}	4.46×10^{-7}	2.77×10^{-7}	1.94×10^{-7}	9.59×10^{-8}	3.74×10^{-8}	1.89×10^{-8}	1.21×10^{-8}	8.74×10^{-9}
NNW	3.85×10^{-6}	7.98×10^{-7}	3.81×10^{-7}	2.36×10^{-7}	1.65×10^{-7}	8.12×10^{-8}	3.16×10^{-8}	1.60×10^{-8}	1.02×10^{-8}	7.34×10^{-9}

(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 1988 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	4.43×10^{-6}	9.33×10^{-7}	4.46×10^{-7}	2.76×10^{-7}	1.94×10^{-7}	9.57×10^{-8}	3.73×10^{-8}	1.89×10^{-8}	1.21×10^{-8}	8.73×10^{-9}
NNE	3.27×10^{-6}	6.44×10^{-7}	3.04×10^{-7}	1.87×10^{-7}	1.30×10^{-7}	6.35×10^{-8}	2.44×10^{-8}	1.22×10^{-8}	7.81×10^{-9}	5.59×10^{-9}
NE	2.46×10^{-6}	4.85×10^{-7}	2.29×10^{-7}	1.40×10^{-7}	9.81×10^{-8}	4.78×10^{-8}	1.84×10^{-8}	9.21×10^{-9}	5.87×10^{-9}	4.21×10^{-9}
ENE	1.61×10^{-6}	3.15×10^{-7}	1.48×10^{-7}	9.12×10^{-8}	6.37×10^{-8}	3.10×10^{-8}	1.19×10^{-8}	5.97×10^{-9}	3.80×10^{-9}	2.72×10^{-9}
E	2.49×10^{-6}	4.98×10^{-7}	2.35×10^{-7}	1.45×10^{-7}	1.01×10^{-7}	4.94×10^{-8}	1.91×10^{-8}	9.55×10^{-9}	6.09×10^{-9}	4.37×10^{-9}
ESE	2.21×10^{-6}	4.45×10^{-7}	2.10×10^{-7}	1.29×10^{-7}	9.02×10^{-8}	4.39×10^{-8}	1.69×10^{-8}	8.42×10^{-9}	5.36×10^{-9}	3.83×10^{-9}
SE	3.26×10^{-6}	6.61×10^{-7}	3.13×10^{-7}	1.92×10^{-7}	1.35×10^{-7}	6.56×10^{-8}	2.53×10^{-8}	1.27×10^{-8}	8.07×10^{-9}	5.78×10^{-9}
SSE	2.49×10^{-6}	5.19×10^{-7}	2.47×10^{-7}	1.52×10^{-7}	1.07×10^{-7}	5.22×10^{-8}	2.02×10^{-8}	1.01×10^{-8}	6.48×10^{-9}	4.65×10^{-9}
S	3.27×10^{-6}	7.06×10^{-7}	3.38×10^{-7}	2.10×10^{-7}	1.47×10^{-7}	7.24×10^{-8}	2.82×10^{-8}	1.43×10^{-8}	9.14×10^{-9}	6.57×10^{-9}
SSW	2.76×10^{-6}	5.46×10^{-7}	2.57×10^{-7}	1.57×10^{-7}	1.10×10^{-7}	5.34×10^{-8}	2.05×10^{-8}	1.03×10^{-8}	6.53×10^{-9}	4.68×10^{-9}
SW	1.85×10^{-6}	3.82×10^{-7}	1.82×10^{-7}	1.12×10^{-7}	7.86×10^{-8}	3.85×10^{-8}	1.49×10^{-8}	7.51×10^{-9}	4.81×10^{-9}	3.46×10^{-9}
WSW	1.04×10^{-6}	1.95×10^{-7}	9.08×10^{-8}	5.55×10^{-8}	3.86×10^{-8}	1.87×10^{-8}	7.15×10^{-9}	3.57×10^{-9}	2.28×10^{-9}	1.63×10^{-9}
W	1.43×10^{-6}	2.78×10^{-7}	1.30×10^{-7}	7.93×10^{-8}	5.51×10^{-8}	2.66×10^{-8}	1.01×10^{-8}	5.01×10^{-9}	3.18×10^{-9}	2.27×10^{-9}
WNW	1.08×10^{-6}	2.04×10^{-7}	9.49×10^{-8}	5.79×10^{-8}	4.02×10^{-8}	1.94×10^{-8}	7.34×10^{-9}	3.65×10^{-9}	2.31×10^{-9}	1.65×10^{-9}
NW	1.56×10^{-6}	2.89×10^{-7}	1.34×10^{-7}	8.15×10^{-8}	5.65×10^{-8}	2.72×10^{-8}	1.03×10^{-8}	5.10×10^{-9}	3.23×10^{-9}	2.30×10^{-9}
NNW	2.65×10^{-6}	5.46×10^{-7}	2.59×10^{-7}	1.60×10^{-7}	1.12×10^{-7}	5.46×10^{-8}	2.11×10^{-8}	1.06×10^{-8}	6.76×10^{-9}	4.84×10^{-9}

(a) Calculated from meteorological data collected at the 400 Area and the Hanford Meteorology Tower.

TABLE F.9. Food Pathway Parameters Used in 1988 Dose Calculations

	Holdup, days (except as noted)[a]		Growing Period, days	Yield, kg/m^2	Irrigation Rate, $L/m^2/month$
	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	(100)[b]	(100)	45	2	200
Pasture	(0)	(0)	30	1.5	200
Red Meat	15	34			
Hay	(100)	(100)	45	2	200
Grain	(100)	(180)	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.
(b) Values in ( ) are the holdup in days between harvest and consumption by farm animals.

TABLE F.10. Dietary Parameters Used in 1988 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]	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.

TABLE F.11. Residency Parameters Used in the 1988 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.

TABLE F.12. Recreational Parameters Used in the 1988 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.

TABLE F.13. Documentation of 100-N Area Airborne Release Dose Calculation for 1988

Facility name:	100-N Area
Releases:	See Table G.1
Meteorological conditions:	1988 annual average, calculated from data collected at the 100-N Area and the Hanford Meteorology Station from January 1988 through December 1988, using the computer code HANCHI; (see Table F.5)
$\bar{X}$ /Q':	Maximally exposed individual, 7.6 x 10^{-9} s/m^3 at 30 km SE; 80-km population, 1.4 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 1.272, 5-5-88
Doses calculated:	Chronic, 1-year exposure, 50-year committed internal dose equivalent, and annual effective 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. 12-4-87 Food Transfer Library, Rev. 2-24-88 External Dose Factor Library, Rev. 5-9-88 Internal Dose Factor Library, Rev.3-17-88

TABLE F.14. Documentation of 100-N Area Liquid Release Dose Calculation for 1988

Facility name:	100-N Area
Releases:	See Table G.5
Mean river flow:	100,000 cfs (2830 m^3/s)
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 1.272, 5-5-88
Doses calculated:	Chronic, 1-year exposure, 50-year committed internal dose equivalent, and annual effective dose equivalent to individual and population
Pathway considered:	External exposure to irrigated soil, to river water and to shoreline sediments Ingestion of aquatic foods and irrigated farm products
Files addressed:	Radionuclide Library, Rev. 12-4-87 Food Transfer Library, Rev. 2-24-88 External Dose Factor Library, Rev. 5-9-88 Internal Dose Factor Library, Rev. 3-17-88 Bioaccumulation Factor Library, Rev. 4-4-88

TABLE F.15. Documentation of 200 Areas Airborne Release Dose Calculation for 1988

Facility name:	200 Areas
Releases:	See Table G.1
Meteorological conditions:	1988 annual average, calculated from data collected at the Hanford Meteorology Station from January 1988 through December 1988, using the computer code HANCHI; (see Table F.6)
$\bar{X}/Q'$:	Maximally exposed individual, 1.7×10^{-8} s/m^3 at 26 km ESE; 80-km population, 1.7×10^{-3} person-s/m^3
Release height:	89-m effective stack height
Population distribution:	341,000 (see Table F.2)
Computer code:	GENII, Version 1.272, 5-5-88
Doses calculated:	Chronic, 1-year exposure, 50-year committed internal dose equivalent, 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. 12-4-87 Food Transfer Library, Rev. 2-24-88 External Dose Factor Library, Rev. 5-9-88 Internal Dose Factor Library, Rev. 3-17-88

TABLE F.16. Documentation of 300 Area Airborne Release Dose Calculation for 1988

Facility name:	300 Area
Releases:	See Table G.1
Meteorological conditions:	1988 annual average, calculated from data collected at the 300 Area and the Hanford Meteorology Station from January 1988 through December 1988, using the computer code HANCHI; (see Table F.7)
$\bar{X}/Q'$:	Maximally exposed individual, 7.6×10^{-8} m^3/s at 13 km N; 80-km population, 6.1×10^{-3} person-s/m^3
Release height:	10 m
Population distribution:	265,000 (see Table F.3)
Computer code:	GENII, Version 1.272, 5-5-88
Doses calculated:	Chronic, 1-year exposure, 50-year committed internal dose equivalent, 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. 12-4-87 Food Transfer Library, Rev. 2-24-88 External Dose Factor Library, Rev. 5-9-88 Internal Dose Factor Library, Rev. 3-12-88

TABLE F.17. Documentation of 400 Area Airborne Release Dose Calculation for 1988

Facility name:	400 Area
Releases:	See Table G.1
Meteorological conditions:	1988 annual average, calculated from data collected at the 400 Area and the Hanford Meteorology Station from January 1988 through December 1988, using the computer code HANCHI, (see Table F.8)
$\bar{X}/Q'$:	Maximally exposed individual, 4.5×10^{-8} s/m^3 at 11 km NE; 80-km population, 3.6×10^{-3} person-s/m^3
Release height:	10 m
Population distribution:	264,000 (see Table F.4)
Computer code:	GENII, Version 1.272, 5-5-88
Doses calculated:	Chronic,1-year exposure, 50-year committed internal dose equivalent, 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. 12-4-87 Food Transfer Library, Rev.2-24-88 External Dose Factor Library, Rev.5-9-88 Internal Dose Factor Library, Rev. 3-17-88

APPENDIX G

EFFLUENTS AND WASTE DISPOSAL

APPENDIX G

EFFLUENTS AND WASTE DISPOSAL

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 1988 as reported by the contractors (see Section 2.3, "1988 Unusual Occurrences").

EFFLUENTS AND WASTE DISPOSAL

Radioactive and nonradioactive materials were released to the environment during operations at Hanford in 1988. 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 National Pollutant Discharge Elimination System (NPDES) Discharge Monitoring Reports.

Airborne Releases

Radioactive and nonradioactive effluents discharged to the atmosphere during 1988 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 Uranium Oxide (UO_3) Plant, and the Plutonium Uranium Extraction (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 1988 are summarized in Tables G.3 and G.4.

Radioactive liquids discharged into the Columbia River from operating facilities during 1988 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 and the small quantities of other radionuclides that may have reached the Columbia River from ground disposal in the 300 Area (Table G.3) 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 1988.

Nonradioactive solid wastes were buried in sanitary landfills near the 200 Areas. The quantities of nonradioactive solid wastes buried during 1988 are also included in Table G.6.

TABLE G.1. Radionuclides in Gaseous Effluents Discharged to the Atmosphere in 1988

		Release, Ci[a]			
Radionuclide[b]	Half-Life	100 Areas	200 Areas	300 Area	400 Area
^{3}H	12.3 yr		500.		(c)
^{14}C	5730 yr		5.		
^{51}Cr	27.7 d				37.
^{54}Mn	312 d	0.00034			
^{60}Co	5.3 yr	0.0023		$<5 \times 10^{-5}$[d]	
^{85}Kr	10.7 yr		200,000		
^{90}Sr	28.8 yr	1.3×10^{-5}	0.0001	<0.001[e]	2.1×10^{-5}
^{95}Zr	64.0 d		$<2 \times 10^{-5}$		
^{95}Nb	36 d		$<4 \times 10^{-5}$		
^{103}Ru	39.4 d		<0.0005		
^{106}Ru	367 d		0.18		
^{113}Sn	115 d		0.02		
^{125}Sb	2.7 yr		0.04		
^{129}I	1.6×10^{7} yr		0.6		
^{131}I	8.0 d		<0.0004	0.0008	1.0×10^{-5}
^{134}Cs	2.1 yr		$<2 \times 10^{-5}$		
^{137}Cs	30.0 yr	0.00046	8×10^{-4}		
^{144}Ce	284 d		<0.0001		
^{147}Pm	2.62 yr		0.0007		
^{208}Tl	3.1 min		0.4		
^{212}Pb	10.6 h		2.		
^{212}Bi	60.6 min		1.		
^{212}Po	3×10^{-7} s		0.8		
^{216}Po	0.15 s		20.		
^{220}Rn	55.6 s		20.		
^{234}U	2.4×10^{5} yr		3×10^{-6}	2.7×10^{-6}[f]	
^{235}U	7.0×10^{8} yr		1×10^{-7}	1×10^{-7}[f]	
^{236}U	2.3×10^{7} yr		2×10^{-7}		
^{238}U	4.5×10^{9} yr		2×10^{-6}	2.6×10^{-6}[f]	
^{238}Pu	87.7 yr	7×10^{-8}	3×10^{-5}		
$^{239,240}Pu$	2.4×10^{4} yr	4×10^{-7}	0.0002	$<6 \times 10^{-4}$	

TABLE G.1. (Radionuclides in Gaseous Effluent contd)

Radionuclide[b]	Half-Life	Release, Ci[a] 100 Areas	200 Areas	300 Area	400 Area
^{241}Pu	14.4 yr		0.002		
^{241}Am	433 yr		$<6 \times 10^{-5}$		

(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 4.6×10^{-5} Ci reported as gross beta assumed to be ^{60}Co for dose calculations.
(e) Includes 1.4×10^{-3} Ci reported as gross beta products, assumed to be ^{90}Sr for dose calculations.
(f) Includes fractional contribution from 5.3×10^{-6} Ci originally reported as gross alpha.

TABLE G.2. Nonradioactive Constituents in Gaseous Effluents Discharged to the Atmosphere in 1988

Constituent	Release, kg[a] 100 Areas	200 Areas	300 Area	1100 Area
Particulates	21,000	280,000	12,000	510
Nitrogen oxides	170,000	710,000	140,000	2,700
Sulfur oxides	540,000	1,100,000	250,000	1,700
Carbon monoxide	34,000	79,000	18,000	100
Hydrocarbons	6,900	40,000	9,100	6.8
Carbon tetrachloride	---	0	---	---
Ammonia	---	16,000	---	---

(a) Values are those reported by operating contractors.
(b) -- indicates no value reported by the operating contractor.

TABLE G.3. Radionuclides in Liquid Effluents Discharged to Ground Disposal Facilities in 1988

Radionuclide	Half-Life	Release, Ci[a]		
		100 Areas	200 Areas	300 Area
^{3}H	12.3 yr	64	3,200	(b)
^{54}Mn	312 d	5.9		
^{60}Co	5.3 yr	11		
^{89}Sr	50.5 d	2.8		
^{90}Sr	28.8 yr	15	<0.8	
^{99}Mo	66.0 h	0.60		
^{103}Ru	39.4 d		<0.002	
^{106}Ru	367 d	2.8	<0.1	
^{113}Sn	115 d		0.016	
^{125}Sb	2.7 yr	0.83		
^{129}I	1.6×10^{7} yr		<0.007	
^{134}Cs	2.1 yr	0.32		
^{137}Cs	30.2 yr	8.0	<1.6	
^{144}Ce	284 d	2.1		
^{147}Pm	2.62 yr		<0.042	
Unidentified beta				0.077
Short-lived radionuclides[c]				
^{234}U	2.4×10^{5} yr		0.0029[d]	0.0048
^{235}U	7.0×10^{8} yr		0.0001[d]	0.00022
^{236}U	2.3×10^{7} yr		0.0002[d]	
^{238}U	4.5×10^{9} yr		0.0019[d]	0.0048
^{238}Pu	87.7 yr	0.0081	<0.006	
$^{239,240}Pu$	2.4×10^{4}	0.044	<0.4	
^{239}Np	2.4 d			
^{241}Pu	14.4 yr		0.27	
^{241}Am	433 yr		<1.1	

(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 0.0051 Ci of gross uranium reported by contractor.

TABLE G.4. Nonradioactive Constituents in Liquids Discharged to Ground Disposal Facilities in 1988

Constituent	Release, kg[a]		
	100 Areas	200 Areas	300 Area
Total organic carbon	(b)	9,800	26,400
Nitrates		6,600	2,700
Copper			45
Fluoride			350
Chromium			12
Aluminum sulfate	180,000		38,600
Ammonium hydroxide		50,000	
Polyacrylamide	450		110
Sulphuric acid	33,000		
Sodium sulphate	410,000		
Lead			16
Mercury			0.45
Silver			3.6
Volume (m^3)			1,600,000

(a) Values are those reported by operating contractors.
(b) Blank entry indicates no value reported by the operating contractor.

TABLE G.5. Radionuclides in Liquid Effluents Discharged to the Columbia River in 1988 from the 100 Areas

Radionuclide	Half-Life	Release, Ci[a]
^{3}H	12.3 yr	64
^{54}Mn	312 d	0.14
^{60}Co	5.3 yr	0.35
^{90}Sr	28.8 yr	2.2
^{137}Cs	30.2 yr	0.12
$^{239,240}Pu$	2.4×10^{4} yr	5.2×10^{-4}

(a) Values are those reported by contractors.

TABLE G.6. Composition of Solid Wastes Buried on the Site During 1988

Constituent	Quantities[a]
Radioactive	
Uranium	2.0×10^7 g
Plutonium	9.5×10^3 g
Americium	0.0 g
Thorium	1.6×10^5 g
Strontium	1.1×10^5 Ci
Ruthenium	3.1 Ci
Cesium	1.2×10^5 Ci
Other fission and activation products	1.4×10^5 Ci
Nonradioactive	
Nonhazardous trash, refuse	4.3×10^4 m^3
Asbestos	1.0×10^3 m^3
Septic sludge	1,300 m^3

(a) Values are those reported by the operating contractors.

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