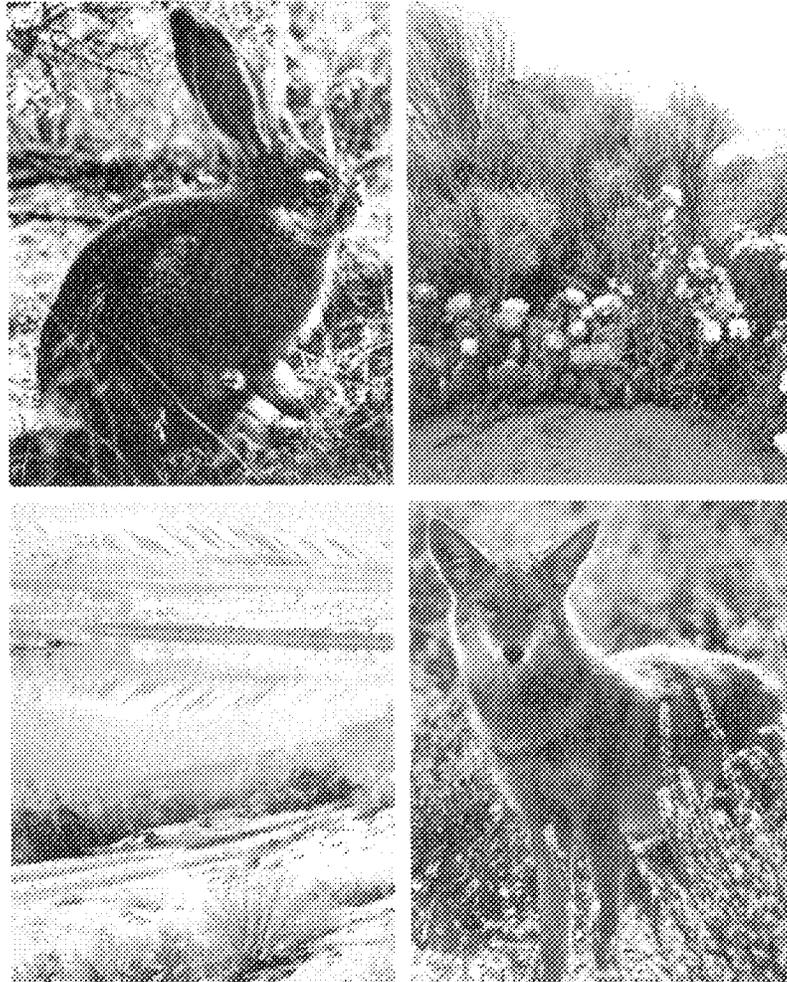


Environmental Monitoring at Hanford for 1986



Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute



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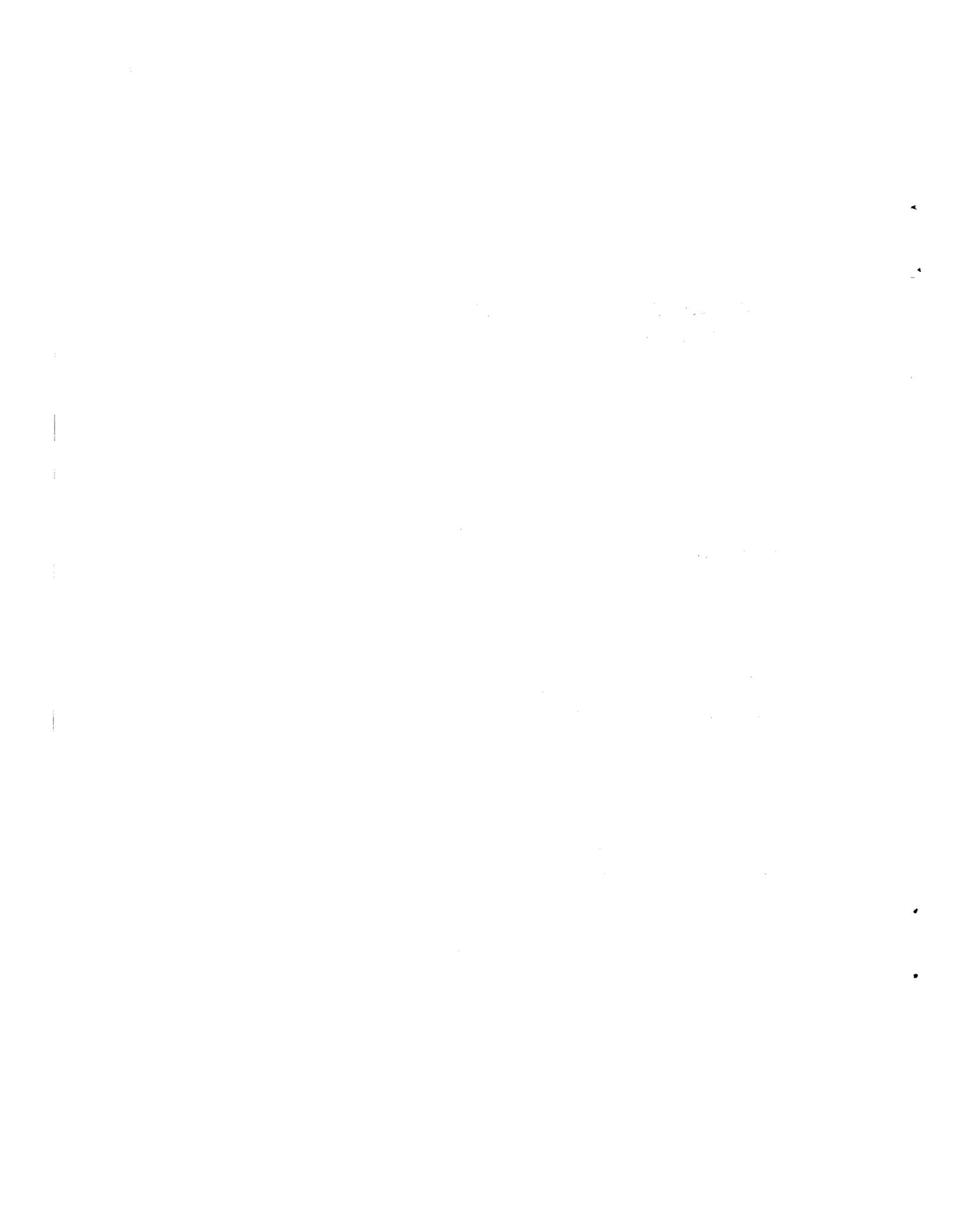
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Pacific Northwest Laboratory
Richland, Washington 99352



PREFACE

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

This report represents a single, comprehensive source of environmental monitoring data collected during 1986 by PNL's Environmental Monitoring Group in the offsite and onsite environments. Appendix A contains data and data summaries for results obtained during 1986 that include statistical estimates of variation. Information in Appendix A is intended for readers with a scientific interest or for those who wish to evaluate results in a manner not included here.

ACKNOWLEDGMENTS

Numerous PNL personnel were responsible for a productive environmental monitoring program during 1986. Important contributions were made by those people who collected samples, maintained equipment, provided laboratory analyses, managed data, evaluated results, and provided clerical support. The programs described in this report were managed by the Office of Hanford Environment under the direction of R. H. Gray and M. S. Hanson. Preparation of this report was coordinated by M. S. Trevathan, Technical Coordinator, and M. E. Strong, Lead Editor. Special thanks go to L. K. Groves, P. C. Hays, V. A. Leslie, and S. G. Weiss for technical editing. Valuable Word Processing support was provided by B. J. Cunningham, M. C. Jochen, D. J. Kennedy, G. M. Schneider, L. M. Valdez, and P. C. Young.

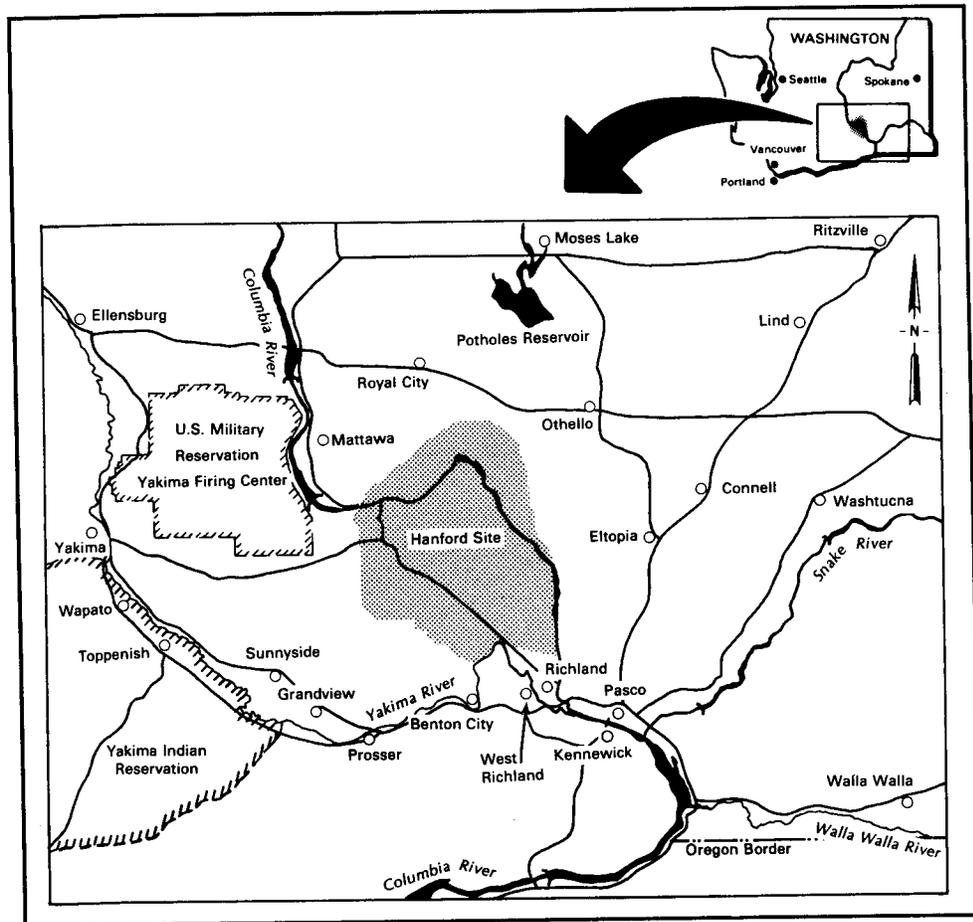
SUMMARY

Environmental monitoring activities performed by the Pacific Northwest Laboratory for the U.S. Department of Energy (DOE) on the Hanford Site for 1986 are discussed in this report. Samples of environmental media were collected to estimate radionuclide and chemical concentrations at locations in the geographical area shown in the figure below. Coverage within the monitored area was expanded in 1986 to include the communities of Prosser, Mattawa, Eltopia, Kennewick, and Yakima. Results are discussed in detail in subsequent sections of this report.

Surveillance of radioactivity in the Hanford vicinity during 1986 indicated concentrations well below applicable DOE and U.S. Environmental Protection Agency (EPA) standards

(Appendix C). Radioactive materials released from Hanford operations (Appendix G) were generally dispersed to levels that were indistinguishable above background 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 Site operations and natural background levels.

Of environmental significance during 1986 was the reactor accident at the Chernobyl Nuclear Power Station in the U.S.S.R. that occurred on April 26. Approximately 81 million curies of radioactive materials were released to the atmosphere as a result of the accident, with fallout



Geographical Sampling Area

occurring primarily in areas in the U.S.S.R. and Europe.^(a) By May 5, the first indication of the Chernobyl plume in Washington State occurred when radiiodine was detected in samples of rainwater collected in Richland. Fission products attributable to Chernobyl were occasionally detected in air, milk, leafy vegetables, soil, and native vegetation throughout the region during the months following the accident. More detail on the impact of Chernobyl on the routine environmental monitoring results during 1986 are summarized in the paragraphs and sections that follow.

ENVIRONMENTAL MONITORING RESULTS

Air -- In 1986, the average Hanford Site perimeter concentrations of ⁸⁵Kr, ¹⁰⁶Ru, ¹²⁹I, and uranium were numerically greater than levels measured at distant monitoring stations; however, the differences were not large enough to be statistically significant (at the 5% significance level). Concentrations of ¹⁰³Ru, ¹⁰⁶Ru, ¹³¹I, ¹³⁴Cs, and ¹³⁷Cs increased at the perimeter in 1986 compared to 1985. These increases were also observed at distant locations, indicating they were the result of the Chernobyl plume. Concentrations of ^{239,240}Pu at the perimeter in 1986 showed a general decrease from 1985 following the installation of additional controls at the PUREX Plant in late 1985. No perimeter annual average radionuclide concentration exceeded 0.17% of the applicable DOE Derived Concentration Guide (DCG) (Appendix C). The total dose as a result of air emissions is compared to the Clean Air Act dose standards in the section entitled "Potential Radiological Dose from 1986 Hanford Operations." Annual average nitrogen dioxide concentrations at all sampling locations remained well below federal and Washington State ambient air standards. (See "Air Monitoring.")

Ground Water -- Although ground water at the Hanford Site is not used as a public drinking water supply, all concentrations were compared to EPA drinking water standards (DWS) and DOE-Derived Concentration Guides. The observed impacts on ground water during 1986 were generally similar to those in previous years.

Tritium and nitrate are still the most widespread constituents attributable to Site operations. These two constituents continue to move slowly with the general ground-water flow and discharge to the Columbia River. (See "Surface Water Monitoring.")

Radionuclides in ground water including tritium, gross beta, ⁶⁰Co, ¹⁰⁶Ru, ¹³¹I, and ⁹⁰Sr were observed to be above the DWS in the immediate vicinity of operational areas. Only tritium in the 200W Area and ¹³¹I and ⁹⁰Sr in the 100N Area were observed to be above the DCG. Nitrate concentrations exceeded the DWS at isolated locations in the 100, 200, and 300 Areas and in the 600 Area to the southwest of the old Hanford townsite. Chromium was measured above the DWS at the 100H and 100D Areas. Increased monitoring for nonradiological constituents since 1985 provided new information on chemicals in the ground water. One chemical, carbon tetrachloride, was observed to be above the DWS in two wells near the 200W Area.

Surface Water -- Very low levels of some radionuclides continued to be detected in samples of Columbia River water collected upstream of the Site at Priest Rapids Dam and downstream of the Site at the Richland Pumphouse during 1986. As in past years, radionuclides consistently observed in measurable quantities in the river water were ³H, ⁹⁰Sr, ¹²⁹I, ²³⁴U, ²³⁸U, and ^{239,240}Pu. Concentrations of ⁹⁰Sr, ²³⁴U, ²³⁸U, and ^{239,240}Pu were similar in water collected from both locations. Tritium and ¹²⁹I concentrations were consistently higher in water collected at the Richland Pumphouse than in water from Priest Rapids Dam. Iodine-131, ¹³⁴Cs, and ¹³⁷Cs were occasionally identified at similar levels in water collected from both locations, apparently due to fallout associated with Chernobyl. All of the radionuclides observed in Columbia River water during 1986 exist in worldwide fallout as well as in effluents from Hanford facilities. Tritium and uranium are also naturally occurring in the environment. Concentrations of radionuclides identified in the river water during 1986 were very low and in all cases well below concentration limits established for drinking water by the EPA and the State of Washington.

Nonradiological water quality parameters measured upstream and downstream of the Site during 1986 were generally within Washington

(a) Eisenbud, M. 1987. Environmental Radioactivity. 3rd ed. Academic Press, Inc., New York.

State Water Quality Standards. Results observed during 1986 were similar to those reported during previous years and there was no indication during the year of any deterioration of the water quality along this stretch of the Columbia River.

Four onsite ponds were routinely sampled for radiological constituents during 1986. Concentrations of radionuclides observed during the year in the water collected from these ponds were similar to those observed during past years. The concentration of some radionuclides was higher than those in the Columbia River. (See "Surface Water Monitoring.")

Food and Farm Products -- Low levels of radionuclides attributable to worldwide fallout were observed in most samples of foodstuffs and farm products. In addition, low levels of ^{131}I from Chernobyl fallout were detected in milk samples. Foodstuffs irrigated with water taken from the Columbia River downstream of the Site were sampled again in 1986 to determine if elevated concentrations of radionuclides were present. All results were similar to the low concentrations found in foodstuffs grown in other adjacent sampling areas, indicating no measurable impact as a result of Hanford operations. (See "Food and Farm Product Monitoring.")

Wildlife -- Samples of deer, rabbits, game birds, ducks, and fish were collected where the potential for radionuclide uptake was considered most likely, or at locations nearby where wildlife samples were available. No influence of Chernobyl fallout was noted for samples of wildlife. However, samples of ducks, fish, and rabbits collected on Site contained low levels of ^{90}Sr and ^{137}Cs attributable to Hanford operations. Other radionuclide concentrations in wildlife were typical of levels attributable to worldwide fallout. (See "Wildlife Monitoring.")

Soil and Vegetation -- Low concentrations of radionuclides were measured in onsite and off-site samples of soil and vegetation during 1986. Levels were similar for perimeter and distant sampling locations. Evaluations of 1986 sample results provided no indication of any discernible increases in the concentrations of radionuclides except for offsite vegetation samples collected after the Chernobyl incident. Vegetation samples contaminated with Chernobyl fallout contained ^{131}I and other radionuclides not usually detected in vegetation. Results from special soil

samples collected off site and downwind of Hanford did not indicate a buildup of radionuclides attributable to Hanford operations. (See "Soil and Vegetation Monitoring.")

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

POTENTIAL RADIATION DOSES FROM 1986 HANFORD OPERATIONS

Measured external radiation exposure and calculated radiation doses to the public from 1986 Hanford operations were well below applicable regulatory limits. The calculated effective dose potentially received by a maximally exposed individual (i.e., the individual who receives the maximum calculated radiation dose using maximum assumptions for all routes of exposure) was about 0.09 mrem for 1986. This is essentially the same as the dose of 0.1 mrem estimated for 1985. The collective effective dose to the population residing within 80 km of the Site was 9 man-rem, the same value estimated for 1985. These doses are much less than the doses received from common sources of radiation, such as natural background radiation. They are also much less than the recently recommended DOE radiation protection standards for protection of the public, which are an average of 100 mrem/yr for prolonged exposure and 500 mrem/yr for occasional annual exposure to a maximally exposed individual. (See "Potential Radiological Doses from 1986 Hanford Operations.")

QUALITY ASSURANCE

Comprehensive quality assurance (QA) programs were maintained to ensure that the data collected were representative of actual concentrations in the environment. These programs covered surface and ground-water monitoring. Standard quality assurance/quality control techniques were used during the sample

collection, laboratory analysis, data management, and dose calculation activities. Quality control (QC) samples were regularly submitted to the laboratories to check their performance. Laboratories also participated in interlaboratory

cross-check programs for evaluation of their performance against standard reference samples. The QA/QC evaluations determined that the quality of the monitoring data was good. (See "Quality Assurance.")

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1.0 INTRODUCTION

A variety of nuclear and nonnuclear activities have been conducted at the Hanford Site since 1943. The most environmentally significant activities were the production of nuclear materials for national defense and the associated chemical processing and management of waste products. The U.S. Department of Energy (DOE) conducts effluent control, effluent monitoring, and environmental monitoring at the Hanford Site through contractor organizations. Results are reported to regulatory agencies and the public to demonstrate compliance with applicable rules and regulations. An environmental monitoring program has been conducted at the Hanford Site for the past 43 years. Environmental monitoring has been conducted since 1965 by the Pacific Northwest Laboratory (PNL), which is operated for the DOE by the Battelle Memorial Institute.

Environmental monitoring activities provide for the measurement, interpretation, and evaluation of samples and other types of measurements to assess current onsite and offsite environmental impact, to determine compliance with pertinent regulations, and to evaluate the near-term adequacy of onsite waste management practices. Results are not intended to characterize the Hanford environs for long-term waste disposal. The PNL monitoring program does not include effluent or environmental monitoring within the production or processing areas operated through other contractor organizations. Radionuclide monitoring data are aimed at assessing the radiation exposures from current effluent releases in terms of potential radiation dose and at determining compliance with state and federal regulations. Pathways of potential environmental impact are evaluated, with emphasis on the most important pathways.

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

- Environmental Surveillance at Hanford for CY (monitoring results for the offsite environs)
- Environmental Status of the Hanford Site for CY (monitoring results for the onsite environs)
- Ground-Water Monitoring at the Hanford Site (monitoring results for the onsite subsurface environs).

Beginning in 1985, these three reports were combined into one report that summarizes the data collected each calendar year. This report includes information on all samples and measurements made in the offsite and onsite environment. A brief description of the Hanford Site and ongoing operations, the nature of environmental monitoring activities, and the results and interpretation of environmental monitoring data for 1986 are included. The radiological impact of Hanford operations was assessed by calculating the potential radiation dose to people living in the vicinity of the Hanford Site.

This report emphasizes the radiological status of the Hanford environment and vicinity. Chemical concentrations in air and ground water are also discussed. In general, the data were compared to both background or control measurements taken at distant locations during 1986 and to data obtained during the past 5 years. The "Potential Radiological Doses from 1986 Hanford Operations" section discusses an assessment of radiological doses from the Hanford Site. Potential doses are calculated for a hypothetical maximally exposed individual and for the local population. The dose rates at publicly accessible areas are also discussed.

Radionuclide data are expressed in terms of curies, microcuries, picocuries, or attocuries. The curie (Ci) is the fundamental unit used to express radioactivity and defines the amount of a substance present based on its rate of radioactive disintegration. A microcurie (μCi) is one millionth (10^{-6}) of a curie. A picocurie (pCi)

is one millionth-millionth (10^{-12}) of a curie. An attocurie (aCi) is one millionth-millionth-millionth (10^{-18}) of a curie. Environmental monitoring results are often very small numbers that are best expressed as picocuries or attocuries. Metric units are used throughout the report. As an additional aid in expressing small and variable environmental results, data are graphed using either linear or logarithmic (compressed) scales. The radionuclides and corresponding symbols commonly used in this report are listed in Table 1.1. A more complete account of radionuclides addressed by environmental monitoring may be found in Tables G.1 and G.3, Appendix G. Gross alpha and gross beta results are from screening-type analyses that measure all alpha or beta radiation in the sample, without specifying the radionuclide present.

TABLE 1.1. Radionuclide Nomenclature

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

Chemicals and the corresponding symbols used in this report are listed in Table 1.2. Chemical data are expressed as micrograms per liter ($\mu\text{g/L}$) or, occasionally, milligrams per liter (mg/L). Because concentrations of chemicals in environ-

TABLE 1.2. Chemical Constituent Nomenclature

Constituent	Symbol
Aluminum	Al
Ammonium	NH_4^+
Arsenic	As
Barium	Ba
Beryllium	Be
Bicarbonate	HCO_3
Boron	B
Cadmium	Cd
Calcium	Ca
Carbonate	CO_3
Chloride	Cl
Chromium (species)	Cr^{6+}
Chromium (total)	Cr
Copper	Cu
Fluoride	F
Lead	Pb
Magnesium	Mg
Manganese	Mn
Mercury	Hg
Nickel	Ni
Nitrate	NO_3
Phosphate	PO_4
Potassium	K
Silver	Ag
Sodium	Na
Sulfate	SO_4
Vanadium	V

mental media are often very small numbers, they are best expressed in these units.

Environmental monitoring data for 1986 are listed in Appendix A, and a glossary and list of acronyms and abbreviations are presented in Appendix B. Applicable standards and special permits are presented in Appendix C. Sample analysis procedures are described in Appendix D, and data analysis methods are summarized in Appendix E. Dose calculation methods used in the calculations for 1986 are given in Appendix F. Appendix G contains effluent data as reported by the contractors.

2.0. BACKGROUND INFORMATION

2.1. DESCRIPTION OF THE HANFORD SITE

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

The U.S. Department of Energy's Hanford Site is located in a rural region of southeastern Washington and occupies an area of 1,500 km². The Site (shown in Figure 2.1) lies about 320 km northeast of Portland, Oregon, 270 km southeast of Seattle, Washington, and 200 km southwest of Spokane, Washington. The Columbia River flows through the northern edge of the Hanford 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 the most abundant, while the cottontail rabbit is the most abundant of the small-game animals. Coyotes are also abundant. The bald eagle is a regular winter visitor to the relatively large areas of uninhabited land comprising the Hanford Site.

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 Hanford Site's eastern boundary. The river drains a total area of approximately 70,800 km² enroute to the Pacific Ocean. The flow of the Columbia River is regulated by 11 dams within the United States, 7 upstream and 4 downstream of the Site. Priest Rapids Dam is the nearest impoundment upstream of the Site, and McNary Dam is the nearest dam downstream. (The Hanford reach of the Columbia River extends from Priest Rapids Dam to the head of Lake Wallula, which is created by McNary Dam.) This is the only stretch of the Columbia River within the U.S. that is not impounded by a dam. The width of the river

varies from approximately 300 m to about 1000 m. The flow through this stretch of the river is relatively swift, with numerous bends and several islands present throughout the reach.

The flow rate of the Columbia River in this region is regulated primarily by Priest Rapids Dam. Hanford reach flows fluctuate significantly because of the relatively small storage capacity and operational practices of the nearby upstream dams. A minimum flow rate of 1,000 cubic meters per second (m³/s) [36,000 cubic feet per second (cfs)] has been established at Priest Rapids. Typical daily flows range from 1,000 m³/s (36,000 cfs) to 7,000 m³/s (250,000 cfs) with peak spring runoff flows of up to 12,600 m³/s (450,000 cfs) being recorded. Typical annual average flows at Priest Rapids Dam are 3,100 m³/s (110,000 cfs) to 3,400 m³/s (120,000 cfs). Monthly mean flows typically peak from April through June and are at the lowest levels from September through October.

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

FIGURE 2.1. 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, 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. Because these criteria do not include specific limits for radionuclides, Environmental Protection Agency (EPA) and State of Washington drinking water limits were used for comparison. Other surface water on the Site consists of West Lake (a small, natural pond) and a number of ditches and artificial ponds created for routine disposal of waste water.

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

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

Land near the Hanford Site is primarily used for agriculture and for 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 is shared between a state wildlife management area and a federal wildlife refuge. The northeast slope of the Rattlesnake Hills along the southwestern boundary of the Site is designated as the Arid Lands Ecology Reserve (ALE) and is used for ecological research by DOE.

The major population center nearest to the Hanford Site is the Tri-Cities area (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 area. More detail on Site characteristics and activities is available in "The Final Environmental Statement, Waste Management Operations, Hanford Reservation" (ERDA 1975).

SUBSURFACE CHARACTERISTICS OF THE SITE

The DOE operations on the Site have resulted in the production of large volumes of waste water that have historically been discharged to the ground through cribs, ditches, and ponds. These discharges greatly influence the physics and chemistry of the subsurface. Approximately 25 billion liters of liquid effluent in the 200 Areas and 2.6 billion liters of liquid effluent in the 100N Area were disposed to the ground during 1986, including process cooling water and water containing low-level radioactive wastes. The discharge of waste water to the ground at the Hanford Site began in the mid-forties and reached a peak in 1955. After 1955, discharge to cribs declined because of improved treatment of waste streams and the deactivation of various facilities (Graham et al. 1981). Since the restart of the Plutonium and Uranium Extraction (PUREX) Plant and related facilities in late 1983, discharge of PUREX-related effluents has resumed.

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

Geologic and hydrologic properties of the subsurface, including stratigraphy and physical and chemical properties of the host rock, influence the movement of the 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 main geologic units beneath the Hanford Site include, in ascending order, the Columbia River Basalt Group, the Ringold Formation, and a series of glaciofluvial sediments informally known as the Hanford formation. A generalized geologic cross section of the Site is shown in Figure 2.2.

The Columbia River Basalt Group is a thick series of basalt flows. The basalts have been warped and folded, producing anticlines that, in some places, crop out at the land surface. The Ringold Formation overlies the basalts except in some localized areas. This formation consists of fluvial and lacustrine sediments and is separated into four lithologic units: basal, lower, middle, and upper. The basal and middle units consist mostly of semiconsolidated gravels and sands, whereas the lower and upper units consist mainly of bedded silts and sands. Beneath the 200-West Area, sediments of the upper Ringold Formation have been reworked by the wind and deposited as a silt layer called the Palouse soil. The Hanford formation rests atop the Ringold Formation or Palouse soil. The Hanford formation also rests atop basalts in places where

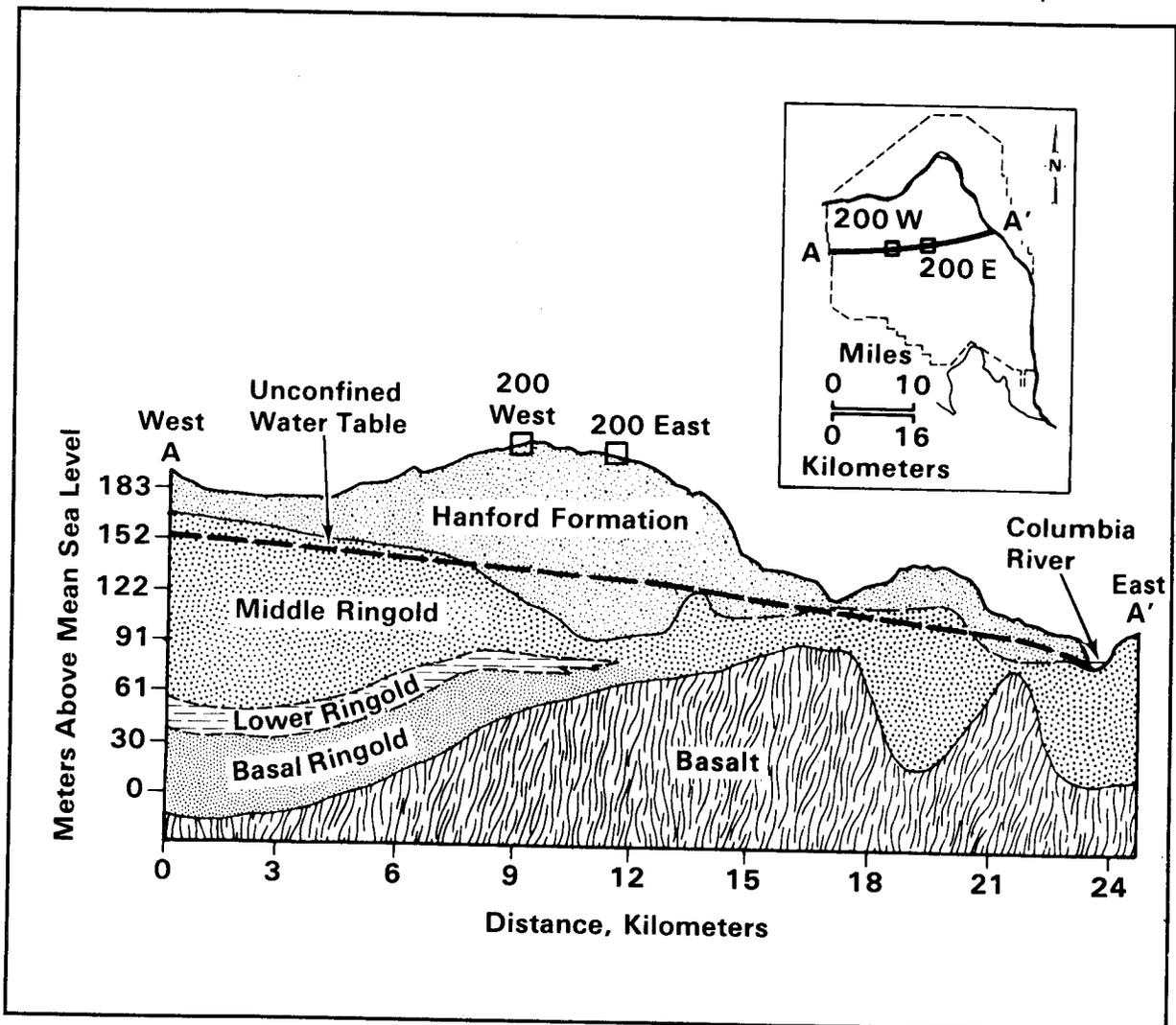


FIGURE 2.2. Geologic Cross Section of the Site (modified from Tallman et al. 1979)

the Ringold formation has been removed. These sediments were deposited by the ancestral Columbia River when it was swollen by glacial meltwater. The glaciofluvial sediments consist primarily of gravels and sands, with some silts (Newcomb, Strand and Frank 1972).

Hydrology

Both confined and unconfined aquifers are present beneath the Hanford Site. The confined aquifers, in which the 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 anticlinal basalt ridges that ring the basin and by the Yakima and Columbia rivers. The basalt ridges above the water table have a low permeability and act as a barrier to lateral flow of the ground water (Gephart et al. 1979). The saturated thickness of the unconfined aquifer is greater than 61 m in some areas of the Hanford Site and pinches out along the flanks of the basalt anticlines. The 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. The elevation of the water table above mean sea level for June of 1986 is shown in Figure 2.3.

Recharge to the unconfined aquifer originates from several sources (Graham et al. 1981). Natural recharge occurs from precipitation at higher elevations and runoff from ephemeral streams to the west, such as Cold Creek and Dry Creek. 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 pre-

cipitation directly on the Hanford Site because of a high rate of evapotranspiration under native soil and vegetation conditions. However, present studies, such as those described by Heller, Gee, and Meyers (1985), suggest that precipitation may contribute more recharge to the ground water than was originally thought.

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

The operational discharge of water has created ground-water mounds near each of the major waste-water disposal facilities in the Separations Area and in the 100 and 300 Areas (Figure 2.3). These mounds have altered the local flow pattern in the aquifer, which is generally from the recharge areas in the west to the discharge areas (primarily the Columbia River) in the east. Water levels in the unconfined aquifer have changed continuously during Site operations because of variations in the volume of waste water discharged. Consequently, the movement of ground water and its associated constituents has also changed with time.

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

Liquid Effluent Movement

If significant quantities of liquid effluents are discharged to the ground at the Hanford Site waste disposal facilities, then these effluents would percolate downward through the unsaturated zone to the water table. As

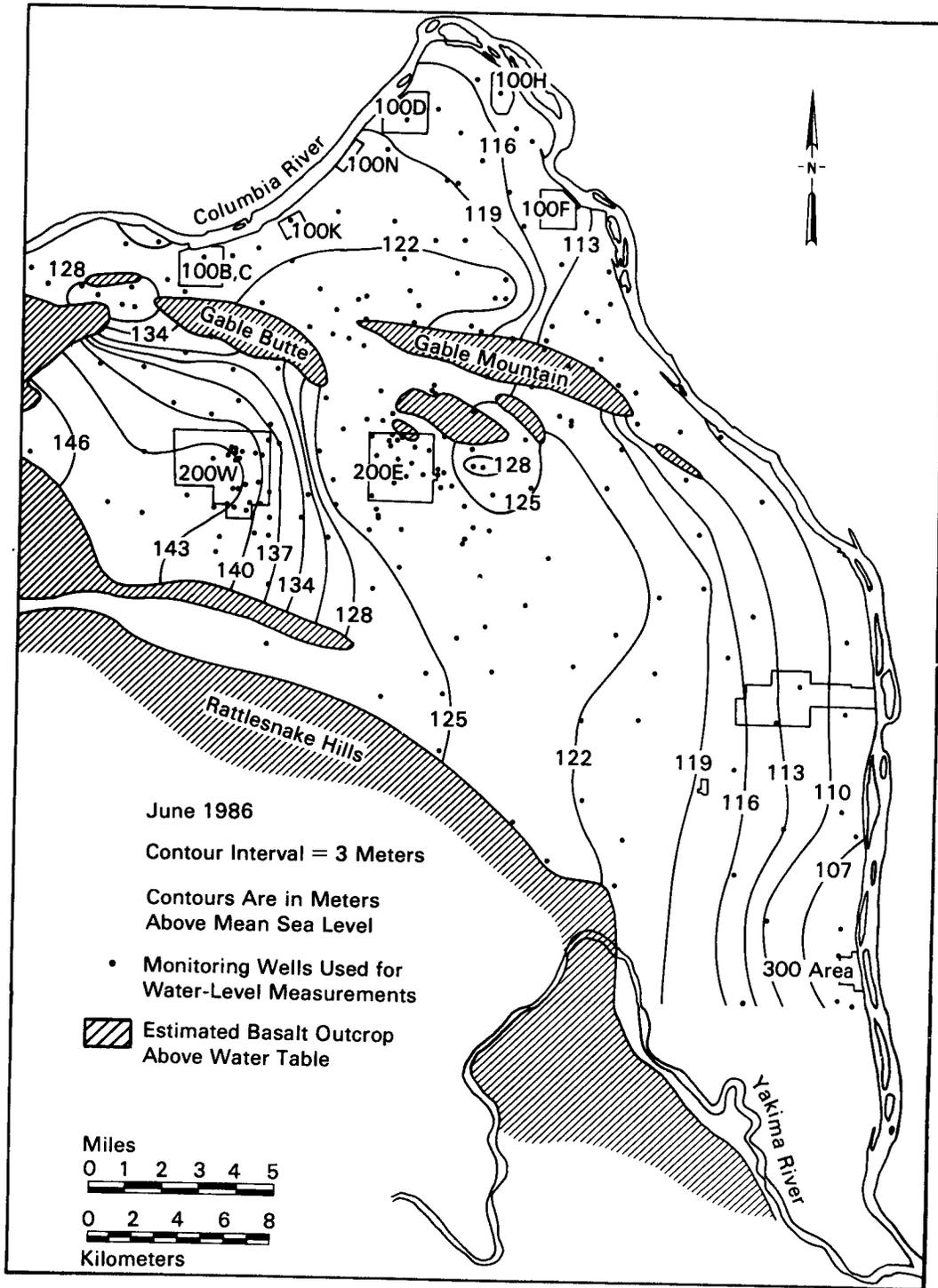


FIGURE 2.3. Water Table Elevations for June 1986 (Schatz and Jensen 1986)

effluents move through the unsaturated zone, adsorption onto soil particles, chemical precipitation, and ion exchange delays the movement of some uncomplexed radionuclides, such as ^{90}Sr , ^{137}Cs , and $^{239,240}\text{Pu}$. Other ions, such as nitrate (NO_3), and radionuclides, such as ^3H , ^{129}I , and ^{99}Tc , are not retained by the soil as readily. These constituents move through the soil column at varying rates and eventually enter the ground water. Subsequently, the nonattenuated constituents move downgradient in the same direction as and at a rate nearly or often equal to the flow of ground water. As the constituents move with the ground water, radionuclide concentrations are reduced by spreading (dispersion) and radioactive decay.

MAJOR ACTIVITIES

Previously, the Hanford Site housed and operated up to nine production reactors, including eight with once-through cooling by treated river water. Between December 1964 and January 1971, all eight reactors with once-through cooling were deactivated. The N Reactor, which is the production reactor remaining in operation, has a closed primary cooling loop.

Four major DOE operating areas exist at the Hanford Site [i.e., 100, 200, 300, and 400 Areas (Figure 2.1)]. The 100 Areas include facilities for the N Reactor and the eight deactivated production reactors along the Columbia River. The reactor fuel reprocessing plant (PUREX), Plutonium Finishing Plant (Z Plant), and waste-management facilities are on a plateau about 11.3 km from the river, in the 200 Areas. The 300 Area, just north of the city of Richland, contains the reactor fuel manufacturing facilities and research and development laboratories. The Fast Flux Test Facility (FFTF) is located in the 400 Area, approximately 8.8 km northwest of the 300 Area.

Privately owned facilities located within the Hanford Site boundaries include the Washington Public Power Supply System (Supply System) Hanford generating station adjacent to N Reactor, the Supply System power reactor and office buildings, and a low-level radioactive-waste burial site operated by U.S. Ecology. The Advanced Nuclear Fuel Corp. (formerly Exxon) fuel fabrication facility is immediately adjacent to the Hanford Site.

Principal DOE operating contractors at Hanford during 1986 included the following:

Rockwell Hanford Operations (Rockwell) -- responsible for fuel reprocessing, waste management, and Site support services, such as plant security, fire protection, central stores, and electrical power distribution.

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

UNC Nuclear Industries (UNC) -- responsible for fabricating N Reactor fuel, operating the N Reactor, and decommissioning formerly used DOE facilities, including deactivated production reactors.

Westinghouse Hanford Company (WHC)-- responsible for operating the Hanford Engineering Development Laboratory (HEDL), including advanced reactor developments and the FFTF test reactor.

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

Operational Highlights

Highlights of operational activities at Hanford during 1986 were

- The N Reactor operated for 182 days, during which time it supplied steam used by the Supply System to generate 860 megawatts of electrical power. Since its startup, the N Reactor has supplied steam for the production of over 65 billion kilowatt-hours of electrical power, which has been supplied to the Bonneville Power Administration grid covering the Pacific Northwest.
- The PUREX Plant fuel reprocessing facility located in the 200E Area completed a third year of operation since restart of operations in 1983. The uranium oxide plant (UO_3 Plant) operated as needed through 1986. The Plutonium Reclamation Facility at Z Plant operated throughout the year as well.

- The FFTF operated successfully during 1986 and achieved a 98% operational efficiency factor for the year. The test reactor was also used to produce radioactive elements for medical and commercial purposes.
- Several 100-Area retired facilities underwent various stages of decommissioning. The 1608-Lift Stations at 100-D, -F, and -H Areas and the 183-B Water Treatment Facility were prepared for demolition. The 107-H Retention Basin underwent interim stabilization. The 117-D

Filter Building and the 115-D/DR Gas Recirculation Facility both underwent final decommissioning. After demolition, the sites were backfilled and restored to the natural contour of the land.

Work at Hanford during 1986 also included Hanford National Environmental Research Park (NERP) studies, ALE studies, and Basalt Waste Isolation Project (BWIP) activities, and continued operation of a variety of national research and laboratory facilities.

2.2 ENVIRONMENTAL MONITORING

K. R. Price

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

SCOPE

The scope of environmental monitoring activities encompasses all potential effluents, including chemical and radioactive materials. 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 the appropriate facility manager are notified if off-standard conditions or adverse trends are detected in the environment near operating areas.

OBJECTIVES

The objectives of the program include the following:

- assessing environmental impacts to the off-site public during 1986 from Hanford Site operations
- verifying that in-plant controls for the containment of radioactive and nonradioactive materials within controlled areas (on the Site) are adequate

- monitoring to determine potential buildup of long-lived radionuclides in uncontrolled areas (off the Site)
- providing reassurance to the regulatory agencies and the public that the DOE monitoring program is capable of adequately assessing operational impacts and identifying noteworthy changes in the radiological and nonradiological status of the environment.

CRITERIA

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

The primary pathways available for the movement of radioactive materials and chemicals from

Hanford operations to the public are the atmosphere, surface water, and ground water. Figure 2.4 illustrates these potential routes and the subsequent network of possible exposure pathways to man. The significance of each pathway is determined from data and models that estimate the amount of radioactive material potentially available to be transported along the pathway and its resultant radiation dose. To ensure that radiological analyses of samples are sufficiently sensitive, minimum detectable concentrations of critical radionuclides in air, water, and food were established and appear in Table D.1, Appendix D. The minimum detectable concentrations for other types of samples are also listed in the table.

ENVIRONMENTAL PROTECTION STANDARDS AND PERMITS

Operations at the Hanford Site are controlled to conform to a variety of federal and state standards and permits. Radiological releases are regulated by DOE orders pursuant to the Atomic Energy Act and the Clean Air Act. Nonradiological releases at the Site 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 "Environmental Protection, Safety, and Health Protection Program of DOE Operations" (USDOE 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 on Radiation Protection (ICRP 1977; 1979-1982). These revisions are contained in a DOE directive, "Radiation Standards for Protection of the Public in the Vicinity of DOE Facilities," Revision 1, September 3, 1985. (See Table C.3, Appendix C.) The standards limit exposure to members of the public to 100 mrem per year for prolonged periods of exposure, 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. Dose calculations reflecting the revised standards are now calculated using 50-year Committed Dose Equivalent Factors and Effective Dose Equivalent Factors.

The radionuclide concentration guides for air and water in DOE Order 5480.1A are no longer current. Instead, DOE has prepared draft tables of Derived Concentration Guides (DCG) that are similar in form to the tables in DOE Order 5480.1A but reflect the new standard.

As stated in DOE Order 5480.1A, DOE is required to cooperate with the Environmental Protection Agency (EPA), state, interstate, and local agencies in the prevention, control, and abatement of environmental pollution. Hence, both radiological and chemical monitoring of the ground water are performed at the Hanford Site.

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

Applicable ambient air quality standards are enforced by the Benton-Franklin-Walla Walla Counties Air Pollution Control Authority. Standards for nitrogen dioxide in air are also given in Appendix C. The Clean Air Act of 1977 requires facilities emitting pollutants that may affect air quality to have Prevention of Significant Deterioration (PSD) permits. A PSD permit was issued to DOE-RL by EPA in 1980 and legally limits the amount of oxides of nitrogen released annually from the PUREX Plant and the UO₃ Plant.

The release of chemical wastes to the environment is restricted by limits described in the Resource Conservation and Recovery Act (RCRA). Chemical waste activities on the Hanford Site are regulated jointly by EPA and WDOE. Waste regulations require facilities that treat, store, or dispose of chemical wastes to have permits. Facilities that are known to have received chemical wastes but do not intend to continue operations

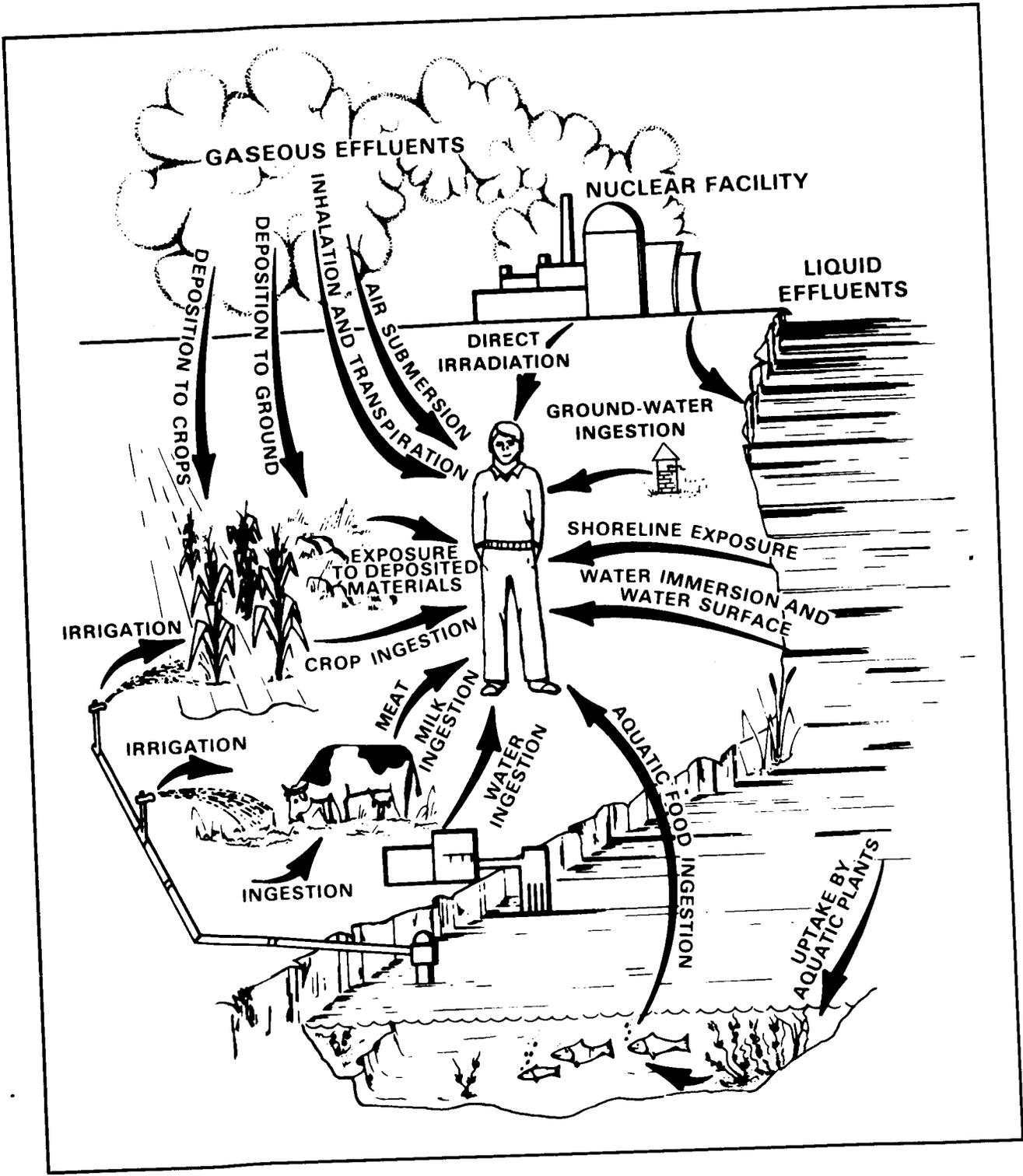


FIGURE 2.4. Potential Radiation Exposure Pathways

must submit closure and post-closure permit applications. The DOE has submitted the appropriate permit applications for several active and inactive facilities seeking closure.

PROGRAM DESCRIPTION

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

In response to increasing DOE, regulatory agency, and public interest in chemicals, a new project was initiated in 1985 to assess the potential environmental impacts from the release of chemicals from operations at the Hanford Site. Monitoring of selected chemicals has been conducted since 1985 in conjunction with groundwater monitoring. Ground-water sampling for chemicals was expanded in 1986 to identify locations on the Site that needed further study.

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

Laboratory analyses of samples for radioactivity and chemicals were conducted by U.S. Testing Company, Inc. (UST), Richland, Washington. Analyses of environmental dosimeters for penetrating radiation were performed by PNL. Ground-water sample analyses were performed by PNL's analytical laboratories and HEHF. Water quality measurements, temperature, and flow rates for the Columbia River were taken by 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 2.1. Geographic Distribution of Environmental Sample Types and Measurement Locations

Sample Types	Sample Locations				
	Total Number	Onsite	Perimeter	Communities	Distant
Air	50	21	14	9	6
Ground Water	362	362	-	-	-
Columbia River	3	-	2	1	-
Irrigation Water	1	-	1	-	-
Drinking Water	8	8	-	-	-
Ponds	4	4	-	-	-
Foodstuffs	8	-	5	1	2
Wildlife	10	9	1	-	-
Soil & Vegetation	38	16	13	3	6
Dose Rate	91	31	45	9	6
Waste Site Surveys	72	72	-	-	-
Railroad/Roadway Surveys	16	16	-	-	-
Shoreline Survey	14	-	14	-	-

RELATED PROGRAMS, SPECIAL STUDIES, AND REPORTS

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

Operating Areas Monitoring

Each of the major contractors (i.e., UNC, Rockwell, WHC, and PNL) measure and record the amounts of liquids, gases, and solids and the concentrations of radioactivity and hazardous substances contained in the effluents they release to the environment. Effluent releases reported by the operating contractors are summarized in Appendix G. Operating contractors take environmental measurements near their facilities to audit the control of environmental releases and the general conditions of the local environment around their operations. These measurements supplement the extensive onsite and offsite monitoring done by PNL for DOE. Annual environmental reports are published by UNC and Rockwell.

Drinking-Water Monitoring

Drinking water was supplied to DOE-operated facilities on the Hanford Site during 1986 by

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

Resource Conservation and Recovery Act Monitoring

Established by the U.S. Congress in 1976, RCRA is a comprehensive program to regulate and monitor the movement of hazardous wastes from generation to final disposal. One aspect of RCRA involves ground-water monitoring at waste facilities. Ground-water monitoring programs designed to comply with RCRA were initiated at the 183H Solar Evaporation Basins and the 300-Area Process Trenches in the 100H and 300 Areas, respectively (Figure 2.1). During 1986, a similar program began at the Nonradioactive Dangerous Waste Landfill, 3 miles southeast of the 200E Area (Figure 2.1). Monitoring activities are described in USDOE (1987).

Nonradiological Air Monitoring

Nonradiological pollutants in atmospheric releases from chemical-processing plants and fossil-fueled steam plants at Hanford consisted primarily of the oxides of nitrogen (NO_x). The Hanford Environmental Health Foundation operated a nine-station network to sample ambient air nitrogen dioxide (NO_2) in 1986. Total suspended particulate monitoring was initiated at the BWIP exploratory shaft site during 1986. Those results are summarized in the "Air Quality Monitoring" section.

Wildlife Census

The purpose of the wildlife census was to determine the population status of a few key wildlife and fish species that inhabit the Hanford Site. Information on changing populations of spawning chinook salmon and nesting Canada geese

has been obtained for 32 consecutive years. The American bald eagle is a "threatened" species in the state of Washington (USEPA 1986a). Aerial censuses of bald eagles have been obtained since the 1960s. In recent years, the status of nesting hawks, long-billed curlews, and great blue herons has been added to the wildlife census. In general, the conservative use of the land and water resources of the Hanford Site has benefited indigenous wildlife species. The number of spawning salmon has increased in recent years in response to fisheries management practices. The number of bald eagles has also increased because of the increased food supply of spawned-out, dead salmon. The population of nesting geese has remained relatively stable. Results of the wildlife census were reported recently in a scientific journal (Rickard and Watson 1985).

Public Information Activities

Environmental monitoring personnel participated in various public meetings throughout Washington and Oregon in 1986 to provide an overview of the program and to discuss results from the previous year's environmental monitoring effort. Meetings were held with a variety of public interest groups, including the local Farm Bureau.

In March 1986, the Draft Environmental Impact Statement for Disposal of Hanford Defense High-Level, Transuranic and Tank Wastes (HDW-EIS) was released for public comment. The purpose of the HDW-EIS was to provide environmental input for the selection and implementation of final disposal actions for high-level, transuranic, and tank wastes located at the Hanford Site, and for the construction, operation, and decommissioning of waste treatment facilities that may be required in implementing waste disposal alternatives. The public comment period closed in August 1986, and responses to public comment are now being prepared along with a revision of the Draft HDW-EIS.

A cooperative effort among DOE, the states of Washington and Oregon, and Greenpeace Northwest was again established to collect and analyze water samples from the Columbia River and riverbank springs. A sufficient quantity of water was collected from each location to provide an aliquot to PNL (for DOE), the Washington Department of Social and Health Services, and the Oregon Department of Human Resources.

Numerous documents containing historical information on environmental monitoring and effluent releases at Hanford were released to the public in February 1986. The State of Washington formed the Hanford Health Effects Panel to review the documents and to hold a public hearing in Richland, Washington. Additional information was provided to the panel during the public hearing held in September.

The Soviet nuclear reactor accident at the Chernobyl nuclear power plant released considerable amounts of radioactive materials into the atmosphere in late April 1986. Radioactive particles

and gases were first measured at Richland on May 5, 1986. The results from subsequent measurements of radionuclides in air and foodstuffs were forwarded to the appropriate state agencies of Washington and Oregon. State and federal agencies cooperated in their efforts to keep the public informed and to issue warnings when appropriate. Iodine-131, ^{106}Ru , ^{134}Cs , ^{137}Cs , and ^{90}Sr were the predominant radionuclides present during peak levels of fallout in the month of May. Radionuclide levels in air returned to normal by July 1986. The presence of radionuclides from the Chernobyl incident were measurable in other environmental media for the remainder of the year.

3.0 ENVIRONMENTAL MONITORING RESULTS

3.1 AIR MONITORING

R. K. Woodruff

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

Many of the radionuclides released to the environment at Hanford are also found worldwide from two other sources: those that are naturally occurring and those resulting from worldwide nuclear weapons testing fallout. The samples collected on the Site during 1986 contained contributions from these three sources, as well as from the Chernobyl plume. Those samples collected at distant community locations within the region essentially contained contributions from only natural and fallout sources, as evidenced by comparison with data obtained before restart of the PUREX Plant and by comparison with locations outside the region. An exception occurred in May and June during the passage of the Chernobyl plume. During this period, concentrations of several radionuclides were dramatically higher across the region. The influence of Hanford emissions on local radionuclide levels is indicated by the difference between concentrations measured at distant community locations within the region and concentrations measured closer to the Site. Data from EPA and DOE's Environmental Measurements Laboratory monitoring stations outside the region, to the extent available, were comparable with local regional data.

In 1986, the average Hanford Site perimeter concentrations of ^{85}Kr , ^{106}Ru , ^{129}I , and uranium were numerically greater than levels measured at distant monitoring stations. These differences, however, were not large enough to be statistically significant (at the 5% significance level). Concentrations of ^{106}Ru , ^{131}I , and ^{137}Cs observed at the perimeter were higher in 1986 than 1985. These increases were also observed at distant locations and were predominately the result of the Chernobyl plume. No perimeter annual average radionuclide concentration exceeded 0.17% of the applicable DOE Derived Concentration Guide (Appendix C). The total dose from air emissions is compared to Clean Air Act dose standards in the section "Potential Radiological Doses from 1986 Hanford Operations." Annual average NO_2 concentrations at all sampling locations remained well below federal and Washington State ambient air standards.

SAMPLE COLLECTION AND ANALYSIS

Radioactivity in the 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

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

relatively distant communities (see Figure 3.1 and Table A.1). 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 in all directions, with emphasis in the prevailing downwind directions to the south and east of the Site, to characterize concentrations at the nearest locations where the public could reside. Continuous

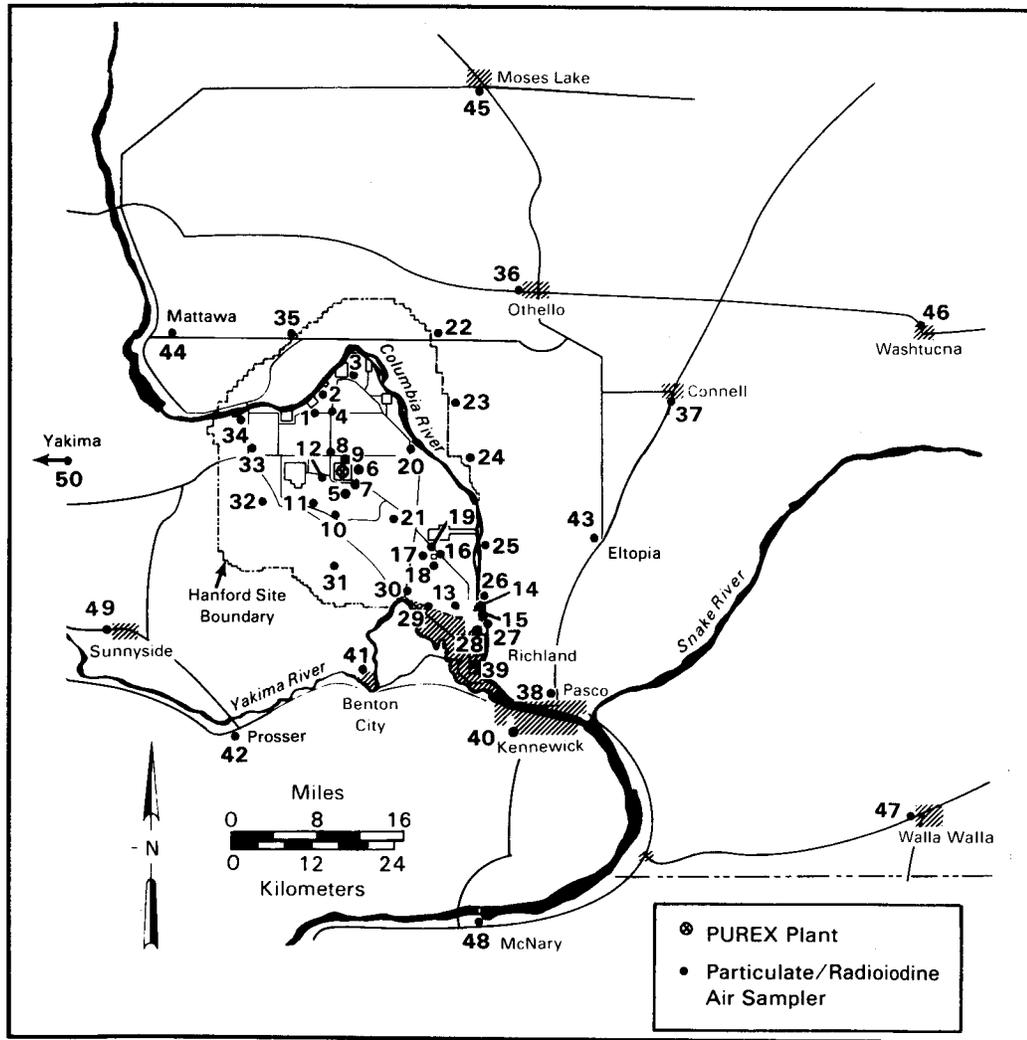


FIGURE 3.1. Air Sampling Locations (see Table A.1, Appendix A, for location key)

samplers located in Benton City, Connell, Eltopia, Kennewick, Mattawa, Othello, Pasco, Prosser, and Richland allowed characterization of air concentrations where the largest numbers of people are located. Samplers located at McNary Dam and in the distant communities of Moses Lake, Sunnyside, Walla Walla, Wash-tucna, and Yakima provided data from relatively unaffected locations for comparison.

Samples were collected according to the documented schedule established before each monitoring year. The distribution of air sample analysis types in 1986 is summarized in Table 3.1. Radionuclides in airborne dust were sampled for 2 weeks by continuously drawing air at a flow rate of 2.6 m³/h through a 5-cm-dia, high-

efficiency, fiber glass filter.^(a) (Airborne dust that has been removed from the air by rain or dry deposition to the soil or vegetation is contained in soil and vegetation samples. See "Soil and Vegetation Monitoring.") The filters were collected every 2 weeks, held for 7 days, and analyzed for gross beta radioactivity. The holding period was necessary to allow for the decay of short-lived, naturally occurring radionuclides, which would otherwise obscure the detection of the lower levels of longer-lived radionuclides potentially present from Hanford emissions. The gross beta measurement provides a current indication of changes in environmental trends that could warrant special attention. In addition, filters

(a) Measured efficiencies exceed 99% for 0.3- μ m dioctylphthalate particles.

TABLE 3.1. Number of Locations by Air Sample Analysis Types

Locations	Particulates				Gases					
	Gross Beta	Gross Alpha	⁸⁹ Sr, ⁹⁰ Sr		Uranium	¹³¹ I	¹²⁹ I	³ H	¹⁴ C	⁸⁵ Kr
			²³⁸ Pu	^{239,240} Pu						
Onsite	21	17	8/23(a)		4/13(a)	7/21(b)	1	6	2	2
Perimeter	14	10	7/14		2/4	5/14	2	8	None	4
Nearby Communities	9	2	5/9		None	1/9	None	1	None	3
Distant Communities	6	2	4/6		2/2	2/6	1	2	2	2

(a) Number of composites/number of locations represented in the composites.
 (b) Number of locations analyzed routinely/number of locations sampled routinely.

from selected locations were analyzed for gross alpha radioactivity in a similar manner and for a similar purpose.

For most of the radionuclides of interest, the amount present in the atmosphere that could have been collected on a filter by continuously sampling for 2 weeks was too small to be measured with the accuracy desired. Because the accuracy of a 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 prescribed nearby locations were then combined to form a geographical composite. (The 22 geographical composites used in 1986 are listed in Table A.1, Appendix A.) Each of the monthly geographical composites was analyzed for 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 ¹³¹I was sampled by drawing a 2.6 m³/h air flow through a 6.3-cm-dia by 2.5-cm-deep cartridge containing activated charcoal.(a)

(a) The coconut-shell activated carbon is impregnated with triethylene diamine. Retention efficiencies are 99% for both elemental and methyl-iodide.

These cartridges were placed downstream of the particle filter at each air sampling station. Charcoal cartridges from prescribed sampling locations were exchanged biweekly and analyzed for ¹³¹I. The cartridges from the remaining locations were exchanged monthly to maintain fresh adsorption media, but were analyzed only if ¹³¹I 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 at four locations and combined to form quarterly composite samples for analysis.

Atmospheric water vapor was collected for tritium analysis by continuously passing air through cartridges of silica gel at a flow rate of 0.014 m³/h for 4 weeks. The collected moisture was removed from the silica gel and analyzed. The silica gel cartridges were exchanged every 4 weeks. Historical tritium data for air moisture at Hanford as well as tritium data for other media have been reported in terms of activity per liter of water. Therefore, the trend of concentrations since 1981 is shown in this section in terms of pCi/L of atmospheric water. Because the DCG is stated in terms of activity per cubic meter of air, tritium results for 1986 are reported in pCi/m³ of air in

the tables of Appendix A. The comparability of the two measures was demonstrated in the 1984 annual report (Price 1984).

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 m³/h. The trapped carbon dioxide (CO₂) was then analyzed for ¹⁴C content and the atmospheric concentration calculated. Soda-lime cartridges were changed every 8 weeks.

Samples of air for ⁸⁵Kr analysis were collected using a small pump that continuously filled a collection bag with air at a low flow rate. About 0.3 m³ of air was collected over 4-week sampling periods throughout the year. The entire sample of air was analyzed for ⁸⁵Kr.

Nine locations were sampled for NO₂ by HEHF to assess onsite and potential offsite nitrogen oxide impacts, primarily in relation to PUREX Plant emissions. The sample locations are depicted on the map in Figure 3.2 and identified in Table 3.2. The NO₂ sampling was performed in accordance with EPA Designated Equivalent Method EQN-1277-028 (TGS-ANSA Method). The NO₂ sampling unit consisted of a bubbler assembly with absorbing solution, operated by a sequential sampling pump. The pumps were set to sequence on a 24-h basis; thus, all sample results are midnight-to-midnight, 24-h integrated averages. Total suspended particulate sampling was performed at location 10 in Figure 3.2. All sampling was performed in accordance with EPA Test Method (Section 2.2), Reference Method for the Determination of Suspended Particulate in the Atmosphere (High-Volume Method) and Washington State Air Pollution Regulations (Chapter 18-40 Washington Administrative Code) "Suspended Particulate."

RESULTS

Onsite, perimeter, and nearby and distant community maximum, minimum, and average concentrations for gross beta and gross alpha radiation are summarized for all measurement locations in Tables A.2 and A.3, Appendix A. Maximums, minimums, and annual averages are summarized for specific detectable radionuclides, or others of special interest, in Table A.4, Appendix A. Onsite results from each sampling station near the major operating areas are summarized in

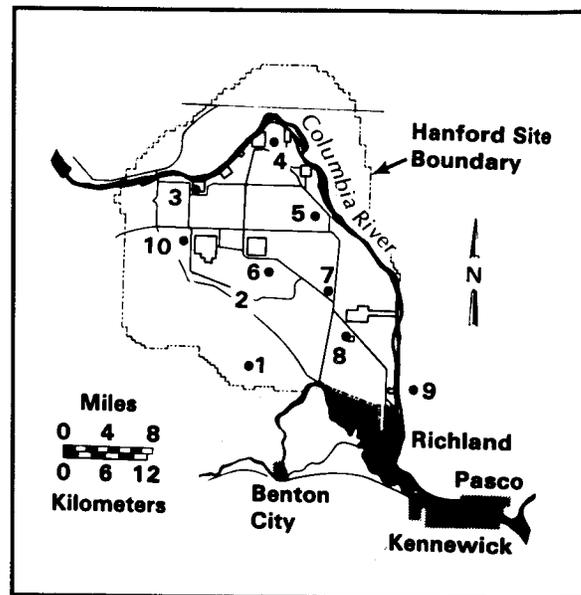


FIGURE 3.2. Nitrogen Dioxide Sampling Locations (Numbers 1 - 9) and Total Suspended Particulate Sampling Location (Number 10)

Tables A.5 through A.11, Appendix A. Fifty-four radionuclides were analyzed in the monthly composite gamma energy analyses (see Appendix D, Page D.1), but only ¹³⁷Cs was detectable with any consistency.

Results of gross beta and gross alpha radioactivity in airborne particulate samples collected in 1986 at distant and perimeter stations are given in Tables A.2 and A.3, Appendix A. Gross beta levels for 1986, as shown in Figure 3.3, peaked during winter, repeating the pattern of recent years. A peak monthly average of 0.4 pCi/m³ occurred during passage of the Chernobyl plume in May, resulting in an annual average about twice that of 1985. As shown in Table A.2, Appendix A, gross beta levels were about the same on the Site, at the Site perimeter, and in nearby and distant communities, indicating that Hanford was not a significant contributor to the higher average. If Hanford operations had been an important source, concentrations would have shown a significant decrease with distance from the Hanford Site.

The gross alpha values shown in Table A.3, Appendix A, were also essentially the same at all distances, indicating that the observed levels

TABLE 3.2. Ambient Nitrogen Dioxide (NO₂) Concentrations in the Hanford Environs for 1986

Location	Map Location ^(a)	Number of 24-h Samples	Annual Average (ppm NO ₂)	% Samples Less Than Detection Limit (0.003 ppm NO ₂)	Maximum Sample (ppm NO ₂)
ALE	1	268	<0.007 ± 0.009	1.5	0.049
100B	3	174	<0.007 ± 0.008	2.3	0.026
100D	4	262	<0.007 ± 0.007	0.7	0.023
Old Hanford Townsite	5	233	<0.007 ± 0.008	2.1	0.026
200W	2	177	<0.006 ± 0.006	2.3	0.017
Wye Barricade	7	176	<0.009 ± 0.012	6.8	0.032
400 Area	8	262	<0.007 ± 0.008	3.4	0.027
Sullivan Barn	9	239	<0.009 ± 0.009	0.4	0.032
Army Barracks	6	288	<0.009 ± 0.007	0.7	0.023

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

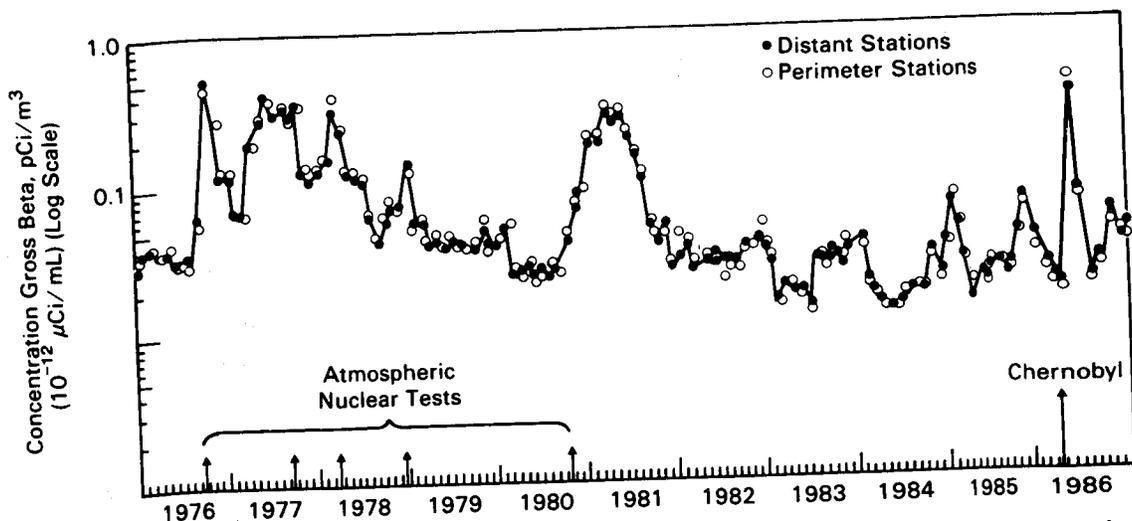


FIGURE 3.3. Monthly Average Gross Beta Radioactivity in Airborne Particulate Samples, 1976 Through 1986

were predominantly a result of natural sources and worldwide fallout. Regional gross alpha levels were essentially unchanged from 1985 levels.

With the resumption of PUREX Plant operations in 1983, ambient air concentrations of ⁸⁵Kr increased at most sampling locations above the preoperational levels of about 19 pCi/m³, as shown in Figure 3.4. The map in Figure 3.5 shows the annual average ⁸⁵Kr concentrations for 1986 at each sampling location. As expected, both figures show that concentrations

were highest on the Site, near the source, and decreased rapidly with distance off the Site. The individual ⁸⁵Kr sample concentrations were quite variable, ranging from 28 to 6100 pCi/m³ at the 200E SE location (Figure 3.1, map location 7), reflecting changing meteorology and source emissions, and from 15 to 40 pCi/m³ at Yakima, reflecting essentially background conditions. The rapid decrease in concentration shown in Figure 3.4 at the end of the year resulted from the cessation of PUREX operations in October. Annual average concentrations off the Site were similar to 1985

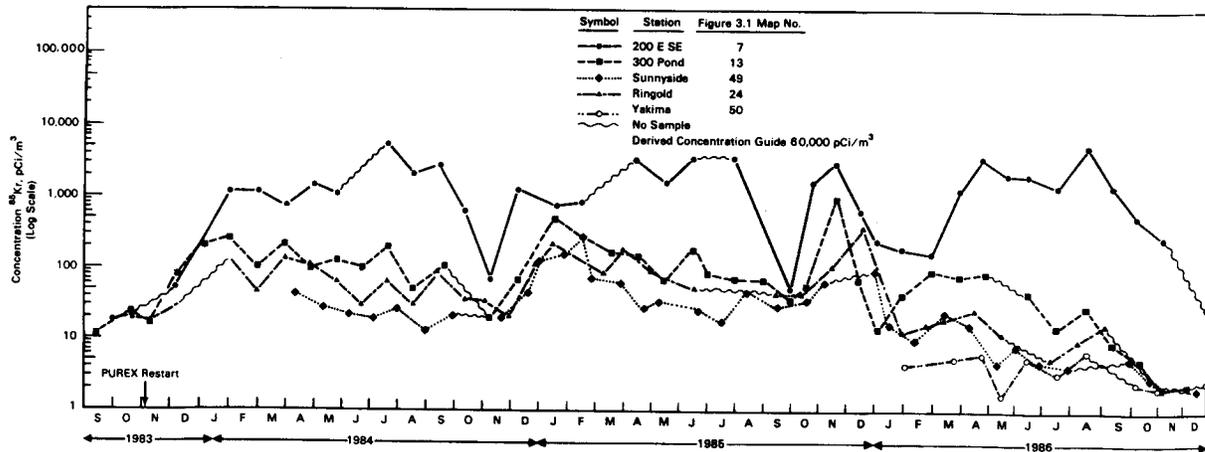


FIGURE 3.4. Krypton-85 Air Concentrations at Selected Locations

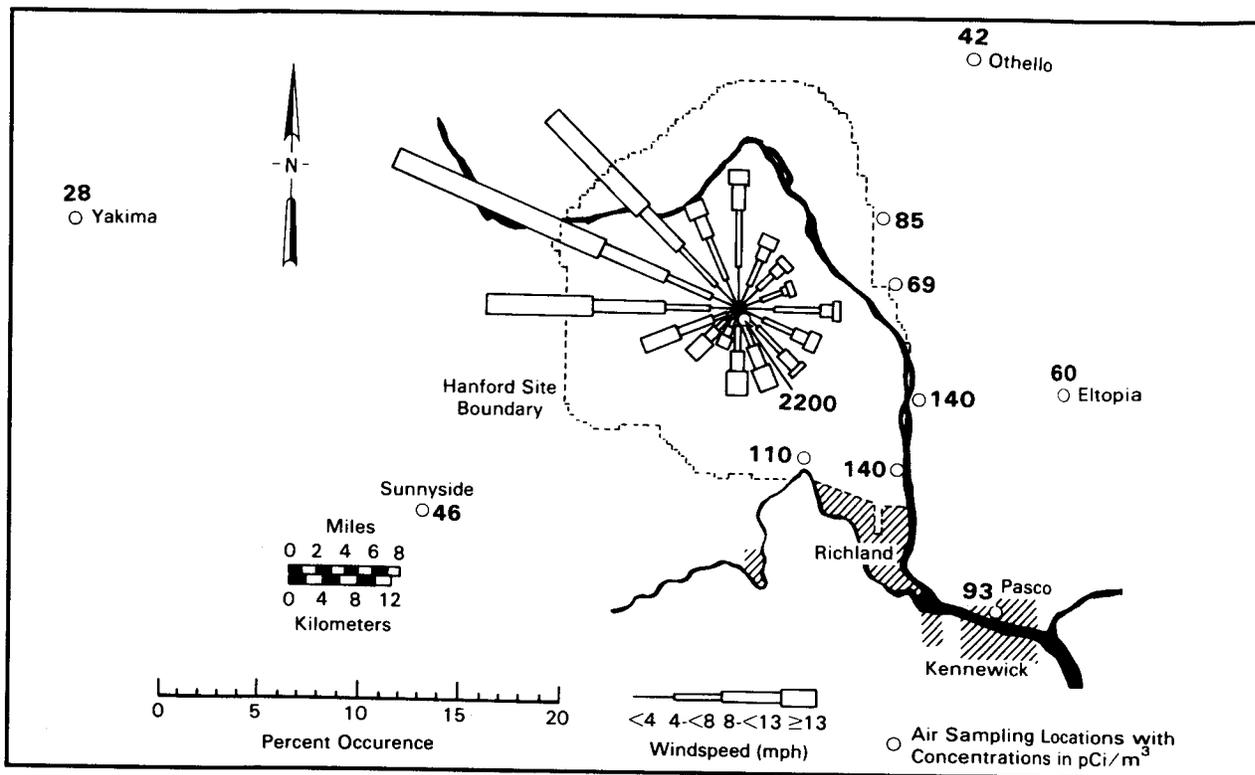


FIGURE 3.5. Annual Average ^{85}Kr Concentrations (pCi/m^3) in Air and the 200-Area Windrose (showing direction from which wind blew) for 1986

levels. As in 1985, the measurements close to the PUREX Plant show the effect of the prevailing northwest winds in the 200 Areas; measurements along the perimeter indicate that much of the time the stack plume turns south toward Richland before it crosses the eastern Site perimeter. This pattern is also demonstrated in the historical record (Healy et al. 1958) and is

consistent with measured wind flow patterns on the Site. The perimeter annual average ^{85}Kr concentration ($100 \text{ pCi}/\text{m}^3$) was 0.17% of the current DCG of $60,000 \text{ pCi}/\text{m}^3$.

Onsite ^{90}Sr levels in 1986, as shown in Table A.4, Appendix A, and in Figure 3.6 returned to levels more typical of recent years. Figure 3.6

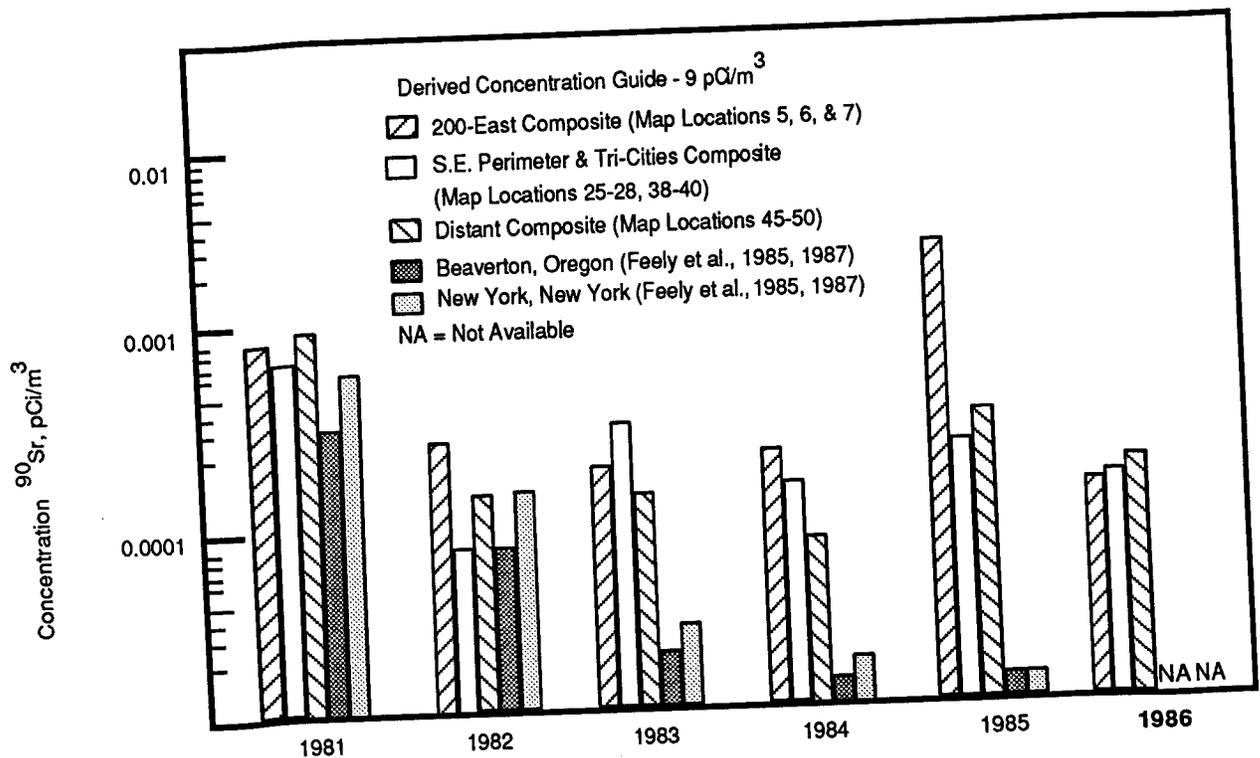


FIGURE 3.6. Annual Average ⁹⁰Sr Air Concentrations in the Hanford Environs Compared to Other U.S. Locations

shows the variation from 1981 to 1986 for the 200E-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. Also shown are the measurements for two other U.S. locations in northern latitudes recently reported by the DOE Environmental Measurements Laboratory (EML) as part of its international fallout monitoring program (Feely et al. 1985, 1987). Environmental Measurements Laboratory data for 1986 are not yet available. Most of the increase noted in Figure 3.6 for the 200E-Area composite sample in 1985 is the result of an inadvertent airborne release from a liquid-waste diversion box in the C Tank Farm that occurred in January (see "Effluents, Waste Disposal, and Unusual Occurrences" section of the 1985 Annual Report). There was no apparent influence of the Chernobyl incident on ⁹⁰Sr concentrations. The annual average Site perimeter concentration (0.00012 pCi/m³) was only 0.0013% of the applicable DCG.

Quarterly air sampling for ¹²⁹I began in July 1984. Iodine-129 was detected at the four locations that sampled it in 1986 as shown in Figure 3.7. (Because of the low level of ¹²⁹I concentrations, they are reported in aCi/m³ rather than pCi/m³.) Concentrations at the perimeter were consistently larger than those observed at Yakima, but not sufficiently larger to be statistically different (at the 5% level of significance). Concentrations were quite variable and ranged from 170 to 1700 aCi/m³ at the 200E SE location, and from 0.2 to 0.9 aCi/m³ at Yakima. The average onsite concentration increased from 1985 to 1986. The reported distant measurement appears to have decreased; however, the distant location was changed from Sunnyside to Yakima for 1986. The annual average ¹²⁹I concentration at the perimeter (16 aCi/m³) was only 0.00002% of the DCG of 70,000,000 aCi/m³ (70 pCi/m³).

Average (January - November) tritium concentrations, expressed in pCi/m³ of air, measured at the Site perimeter and off the Site were similar,

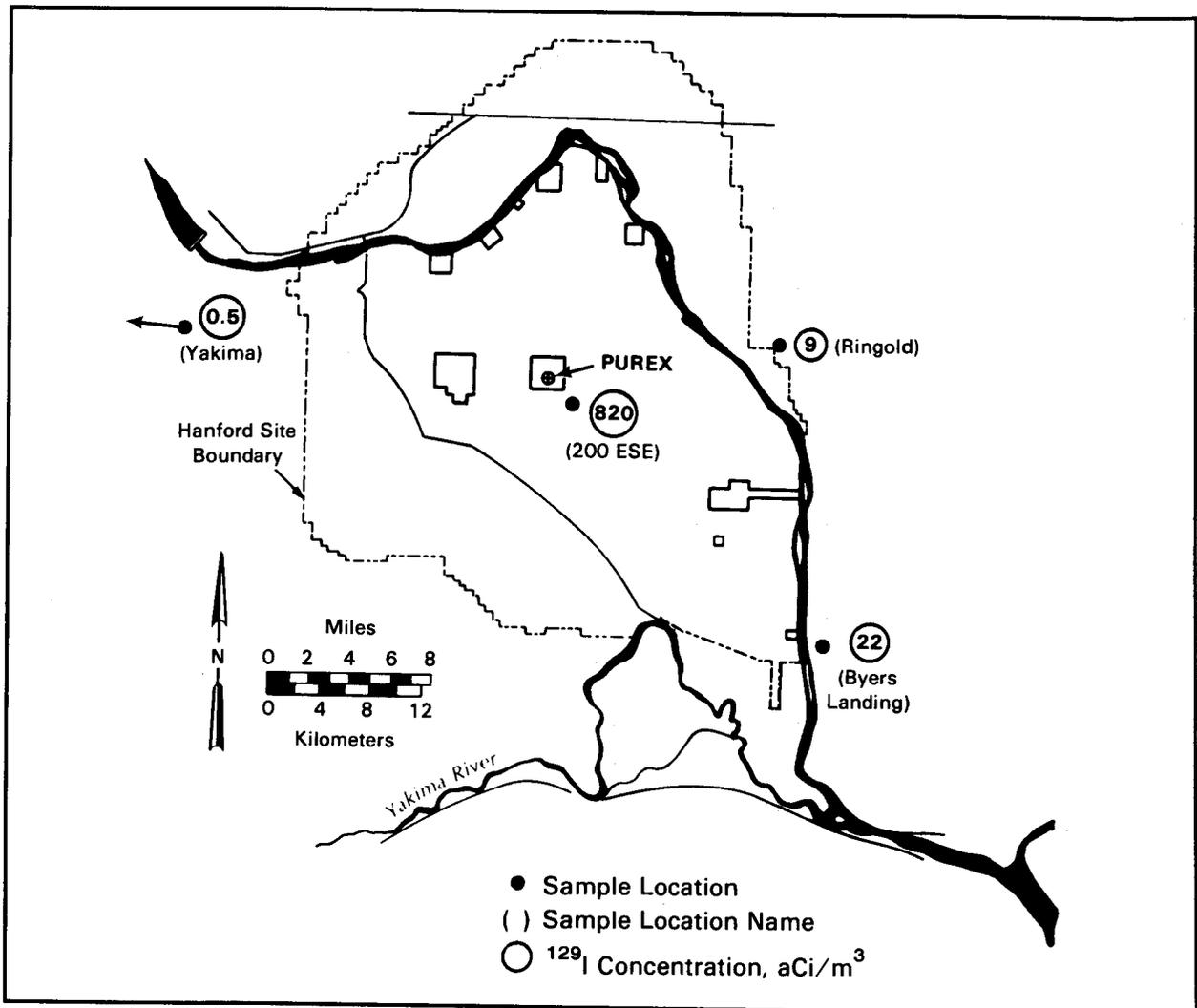


FIGURE 3.7. Iodine-129 Concentrations (aCi/m³) in Air in the Hanford Environs for 1986 (Concentration Guide 70,000,000 aCi/m³)

as shown in Table A.4, Appendix A. (December results are excluded because of sample contamination during the analytical procedure.) Onsite concentrations were highest at the sampling locations immediately downwind of the PUREX Plant, and the onsite average concentration was higher than the offsite average. Figure 3.8 traces the annual trend of ³H concentration in atmospheric water vapor, in terms of pCi/L of atmospheric water, for three individual locations and the average of two distant community locations. The effect of the restart of the PUREX Plant on air ³H concentrations from 1983 to 1986 is clear at the 200E SE sampling location. There appears to be no effect in either the distant communities or

Richland. Concentrations at these distant locations are comparable to concentrations in surface water bodies across the nation (USEPA Quarterly Reports 1981a-1986b). Concentrations at the Fir Road location on the southeast perimeter continued to appear larger than concentrations at the distant locations, but were comparable to or less than levels in recent years. The annual average perimeter concentration of tritium in air (1.1 pCi/m³) was only 0.0006% of the DCG of 200,000 pCi/m³.

Air concentrations of ^{239,240}Pu decreased from 1985 to 1986 following the installation of additional source controls at the PUREX Plant. The perimeter annual average concentration

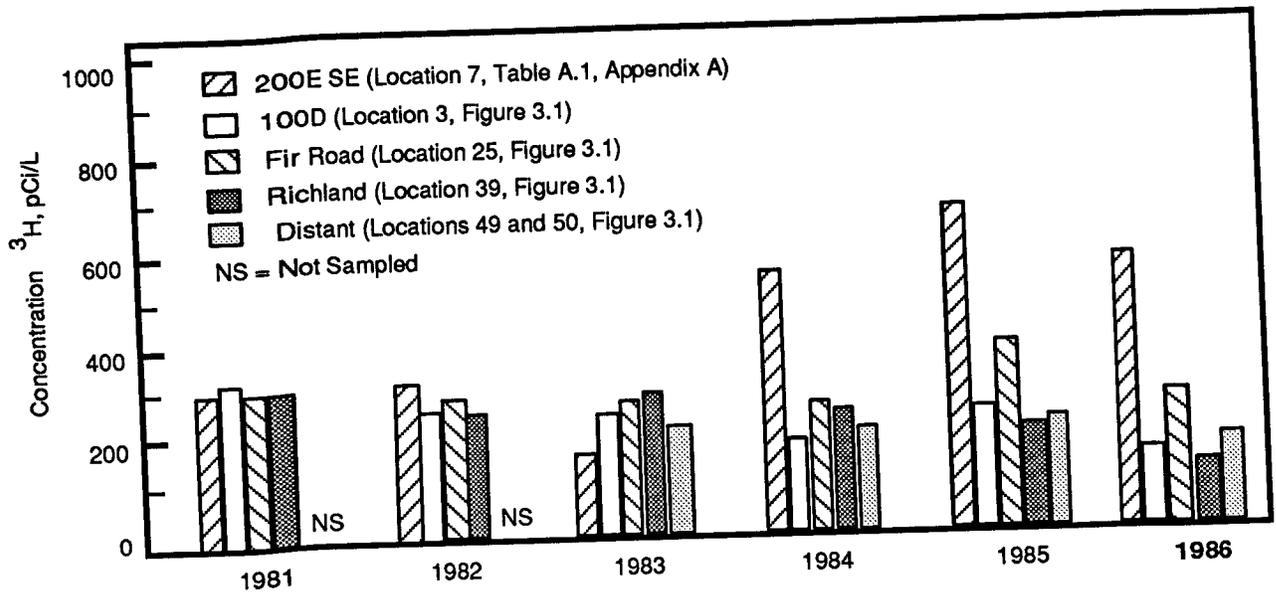


FIGURE 3.8. Annual Average Tritium Concentrations (pCi/L of water) in Atmospheric Water Vapor (distant locations not sampled (NS) in these years results for December 1986 excluded because of sample contamination)

decreased from about 3 aCi/m³ in 1985 to less than 1 aCi/m³ in 1986. The 1986 perimeter and offsite averages were similar and near regional background levels. The annual averages of all onsite, perimeter, and near and distant community samples are shown in Table A.4, Appendix A. The annual average concentration of ^{239,240}Pu (less than 1 aCi/m³) at the Site perimeter was less than 0.005% of the DCG (20,000 aCi/m³).

The most recent data for ^{239,240}Pu reported by the EPA for Seattle, Spokane, and Portland for 1981 through 1985 (USEPA Quarterly Reports 1981-1986) are compared in Figure 3.9 with measurements from two independent efforts at the Hanford Site. The Hanford southeast perimeter and Tri-Cities composite data were obtained from the routine monitoring program previously described in this section. The 300-Area, high-volume air sampler has been operated since 1961 independent of the routine program, to collect high-volume samples and higher precision measurements of worldwide fallout radionuclides. Comparison of the 300-Area, high-volume air sampler data with the EPA data for Seattle, Spokane, and Portland indicates that levels from all four sites for 1981 through 1983 were very similar. The routine monitoring program recorded data that were higher in 1981 through 1983 than the EPA or high-volume data, but the routine data were

biased high because the analytical technique used was less sensitive. In 1984, a more sensitive routine monitoring analytical technique was initiated, resulting in a better comparison between the routine and high-volume air sampling results from 1984 through 1986. The routine sampling effort data for the southeast perimeter and Tri-Cities sampling locations, and the 300-Area, high-volume air sample results, indicate that perimeter concentrations of ^{239,240}Pu in the predominant downwind flow direction in 1986 were similar to recent regional levels.

Uranium concentrations in airborne particulate matter at the perimeter were similar to distant samples in 1986, as shown in Table A.4, Appendix A. Perimeter concentrations decreased from 1985 levels, while the onsite average concentration was essentially unchanged. The perimeter annual average concentration (0.000062 pCi/m³) was only 0.06% of the DCG of 0.1 pCi/m³.

Ruthenium-106 was routinely monitored through monthly composite gamma energy analyses but was infrequently detected. The results obtained for ¹⁰⁶Ru in 1986 are included in Tables A.4 and A.6 through A.8, Appendix A. Annual average concentrations of ¹⁰⁶Ru in 1986 were higher than in 1985. Levels increased with the passage of the Chernobyl

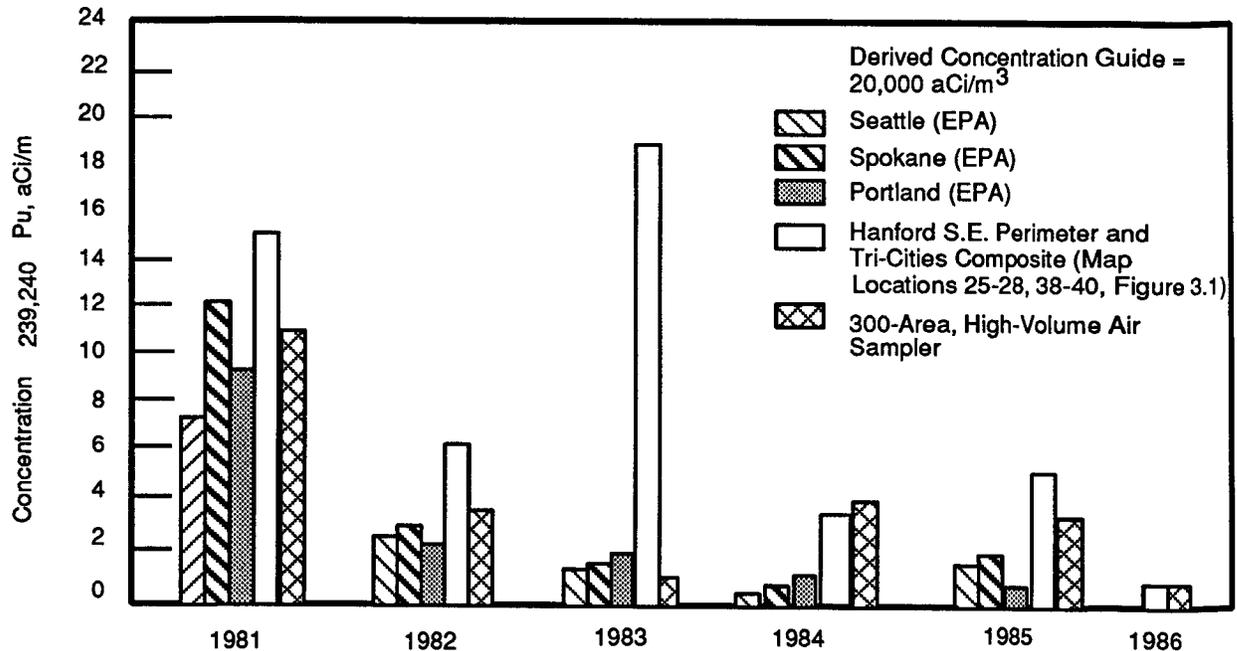


FIGURE 3.9. Annual Average ^{239,240}Pu Air concentrations in the Northwest and Hanford Environs for 1981 Through 1986

plume, and the relative similarity of the onsite, perimeter, and offsite levels indicates that the interyear increase was substantially attributable to that event. The annual average ¹⁰⁶Ru concentration at the perimeter (0.002 pCi/m³) was only 0.007% of the DCG.

Cesium-137 and ¹³¹I concentrations increased substantially during the Chernobyl plume passage, causing the annual averages to increase from 1985 to 1986. The relative similarity of the onsite, perimeter, and offsite concentrations indicates Hanford was not a factor in the increase. The annual average perimeter concentrations of ¹³⁷Cs and ¹³¹I (0.009 and 0.02 pCi/m³) are only 0.002 and 0.005% of their DCG of 400 pCi/m³ (for both). Concentrations of ¹⁰³Ru and ¹³⁴Cs were also detectable across the sampling network during the Chernobyl plume passage, but returned to nondetectable levels immediately after.

The comparisons discussed in the above paragraphs are based on the measured numerical results without taking into account the uncertainty in the data or their averages. However, statistical analyses of the monthly and quarterly composite particulate data and all the gaseous radionuclide data were also conducted to take such uncertainty into account when

evaluating the effect of Hanford Site operations on the environment. The main comparison of interest was between the average distant community concentrations, which represent natural and worldwide fallout sources, and the average at the perimeter of the Hanford Site, which represents natural and worldwide fallout sources, as well as any residual Hanford contributions. None of the analyses demonstrated a statistical difference between average distant community concentrations and average perimeter concentrations at the 5% significance level.

Nitrogen dioxide data collected by the network in 1986, and shown in Table 3.2, indicated that the highest annual average result (0.009 mg/L) was observed at the Army Barracks, Wye Barricade, and Sullivan barn sampling locations (Figure 3.2, map location numbers 6, 7, and 9). The Wye Barricade also had the highest average in 1984 and 1985. The applicable federal and Washington State annual average ambient air standard for NO₂ is 0.05 mg/L.

Total suspended particulates were sampled near the 200W Area (Figure 3.2, map location 10) during 1986. Monthly averages ranged from 14.5 to 92.6 µg/m³, and the annual average was 34.7 µg/m³. The monthly 24-h maximum sample ranged from 15 to 397 µg/m³. While

the Washington State and federal 24-h maximum standards are 260 and 150 $\mu\text{g}/\text{m}^3$ above background levels, respectively, an

applicable regulatory background level has not been established for the Hanford area.

3.2 GROUND-WATER MONITORING

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Ground water was monitored during 1986 throughout the Hanford Site in support of the overall objectives described in "Environmental Monitoring". Monitoring activities were conducted to 1) determine the distribution of certain mobile radionuclides and nitrate, 2) relate the distribution of these constituents to Site operations, 3) determine concentrations of chemicals resulting from natural and offsite sources, and 4) identify the chemicals that resulted from Site operations. Samples from 362 wells were collected and analyzed during 1986, primarily from the unconfined (shallow) aquifer. An expanded chemical monitoring effort in 1985 and early 1986 provided information on many additional constituents at 90 of the 362 wells.

Although ground water is not used as a public drinking water supply, average concentrations for 1986 in all monitoring wells were compared to EPA drinking water standards (DWS) (see Tables C.2 and C.3, Appendix C) and DOE Derived Concentration Guides (DCG) (see Table C.6, Appendix C) for drinking water in controlled areas (inaccessible to the public).^(a) Radiological monitoring results indicated that tritium, gross beta, ^{60}Co , ^{106}Ru , ^{131}I , ^{129}I , and ^{90}Sr concentrations near operating areas were at levels above the DWS. Only tritium in the 200W Area and ^{131}I and ^{90}Sr in the 100N Area were observed to be above the DCG. Tritium continued to move slowly with the general ground-water flow and discharge into the Columbia River (see "Surface Water Monitoring"). Monitoring results also indicated that certain chemicals regulated by EPA and the State of Washington were 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 the 600 Area to the southwest of the old Hanford townsite. Chromium concentrations were observed to be above the DWS at the 100H and 100D Areas only. Carbon tetrachloride was observed to be above the DWS in wells near the 200W Area. Samples from five wells near the 200 Areas were tested for additional organic constituents regulated by the State of Washington. Concentrations of these chemicals were below detection levels in all five wells.

The primary source of ground-water contamination in 1986 was liquid wastes disposed to the soil column by Site operations. Both active and inactive waste disposal sites contributed to the distribution of radionuclides and chemicals in the ground water beneath the Hanford Site. The presence of some chemicals in the ground water was attributed to both Site operations and natural background levels.^(b)

-
- (a) Ground water beneath the Hanford Site is used for drinking at four nonpublic locations, as described in "Radiological Impact on Drinking Water from Wells" (Section 4). These drinking water sources, which are monitored jointly by PNL and HEHF (Somers 1987), showed concentrations below applicable standards for all radionuclides.
- (b) Other monitoring programs also provided information on the impact of Site operations during 1986. Routine ground-water sampling programs were conducted at the 183-H Solar Evaporation Basins, the 300-Area Process Trenches, and the Nonradioactive Dangerous Waste Landfill (NRDW) to comply with the Resource Conservation and Recovery Act (RCRA) (USDOE 1987). Rockwell evaluated the quality of the ground water in the Separations Area to ensure compliance with Rockwell and DOE monitoring guidelines, to assess the performance of waste disposal and storage, and to determine the impacts of operations on the ground water (Law and Schatz 1986). UNC Nuclear Industries prepared an environmental monitoring report for the 100 Areas (Jacques 1987).

SAMPLE COLLECTION AND ANALYSIS

Ground-water samples from a network of 362 ground-water monitoring wells were analyzed for concentrations of radionuclides and chemicals. The 362 wells constructed to sample the unconfined aquifer, confined aquifer, or both are identified in Figure 3.10.(a)

Ground-water monitoring wells at the Site are primarily 15 or 20 cm in diameter and are constructed with steel casing. Screens or perforated casing are used to complete the wells below the water table. Most wells are equipped with submersible pumps. Bailers were used to dip water from wells incapable of producing enough water to allow pumping, and the airlift method was used to collect samples from wells too narrow to allow placement of submersible pumps or use of bailers.

Samples from the unconfined aquifer were collected just below the water table. Maximum concentrations for some radionuclides were measured near the top of the aquifer at a few locations at Hanford (Eddy et al. 1978). Wells fitted with submersible pumps were sampled after pumping a sufficient length of time to allow equilibration of temperature, pH, and specific conductivity. This purging process ensures that any standing water in the well has been removed to allow collection of a sample that is representative of the ground water near the well.

Most of the samples for the expanded, sitewide chemical monitoring effort were collected with submersible pumps. Sample bottles remained capped until just before filling. If any unavoidable, potential sources of volatile organics existed nearby (e.g., car exhausts or open fuel tanks), they were noted on field record forms. Wells were purged with a submersible pump for at least 15 min and until the temperature, pH, and specific conductivity of the water stabilized. Samples to be analyzed for chemicals prone to volatilization or adsorption were collected with

fluorocarbon plastic (Teflon) bailers after purging. [Either bladder pumps or bailers made of fluorocarbon resin or stainless steel are acceptable sampling devices for RCRA ground-water monitoring (USEPA 1986b)]. The bailer was slowly lowered into the well, allowed to fill, and slowly raised two times to rinse the bailer before sample collection. Water was poured slowly into sample containers to prevent trapping of air bubbles and subsequent volatilization of organics. Sampling methods followed documented sampling procedures (USDOE 1986b). All samples were preserved in an unfiltered form. Samples were sealed to prevent tampering, transported to the laboratory on ice, and traced with rigorous chain-of-custody procedures.

Ground-water samples were analyzed for radionuclides (primarily tritium) and nitrate. Analyses for gross alpha and gross beta activity at certain wells provided guidance on the need for analysis of additional radionuclides. Wells in the 100H, 300, and 400 Areas were sampled for two regulated nonradioactive constituents, Cr and F. The number of results obtained from these analyses in 1986 is listed in Table 3.3. Most samples were collected quarterly; others were obtained monthly, semiannually, or annually. (See Tables A.12 through A.27 for numbers of samples collected during 1986 for each well and constituent.) The number of wells sampled, samples collected, and analyses performed for each area are listed in Table 3.4.

In 1985 and early 1986, selected constituents were added to the list of chemicals historically monitored sitewide. Ninety of the 362 wells were sampled for these additional chemicals (Figure 3.11). Wells selected for this chemical monitoring included those near the major operating areas, within the radionuclide plumes, and far removed from site operations. (The sampling network did not include wells within the 100H Area or the 300 Area because extensive sampling was already being conducted in those areas for compliance with RCRA.) Seventy-five of these 90 wells were sampled once during 1985. The remaining 15 wells were sampled in early 1986. In addition, 22 of the wells were sampled a second time in 1986. The samples were analyzed for primary drinking water constituents, ground-water quality parameters, ground-water contamination indicators, and site-specific constituents (Table 3.5). The list of constituents from EPA required in RCRA

(a) For easier reading of well numbers on Figure 3.10, numbers identifying the operational area have been omitted. The digits (99) assigned to all well structures have been deleted in the figure as well as throughout the text and tables.

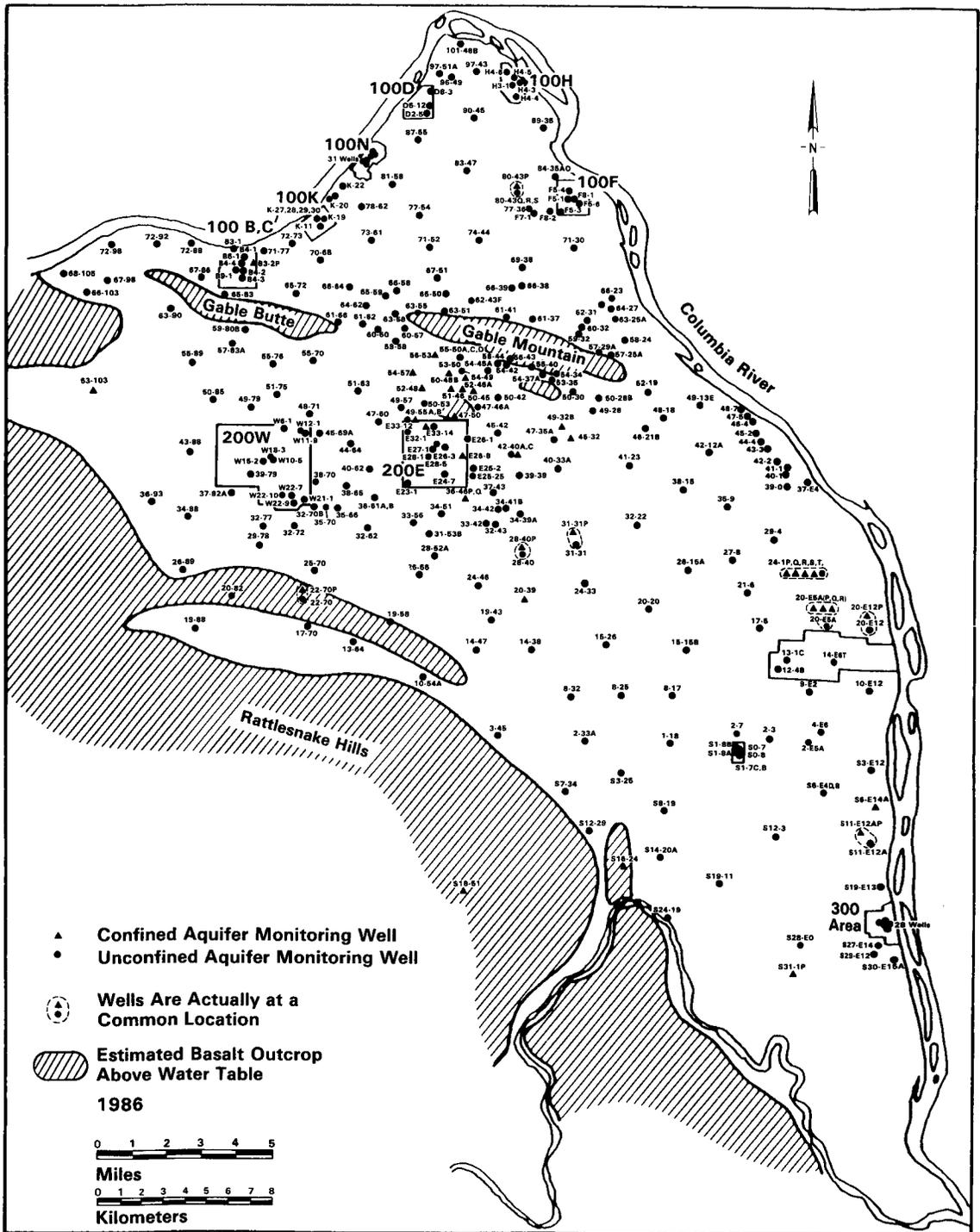


FIGURE 3.10. Location of Ground-Water Monitoring Wells Sampled in 1986 (first digit of well number has been dropped)

TABLE 3.3. Number of Ground-Water Monitoring Results for 1986 (not including new sitewide chemical monitoring constituents)

Constituent	Number of Results
³ H	1282
Gross Alpha	16
Gross Beta	152
⁶⁰ Co	619 (a)
¹³⁷ Cs	48 (b)
¹⁰³ Ru	5 (c)
¹⁰⁶ Ru	51 (d)
¹²⁵ Sb	42 (e)
¹³¹ I	54 (f)
¹²⁹ I	18
U (total)	195
Uranium Isotopes	36 (g)
Plutonium Isotopes	24 (h)
⁸⁹ Sr	12
⁹⁰ Sr	128
NO ₃	638
F	172
Cr	<u>159</u>
Total	3651

- (a) Reflects the number of gamma scans performed.
 (b) 48 out of 619 gamma scans detected ¹³⁷Cs.
 (c) 5 out of 619 gamma scans detected ¹⁰³Ru.
 (d) 51 out of 619 gamma scans detected ¹⁰⁶Ru.
 (e) 42 out of 619 gamma scans detected ¹²⁵Sb.
 (f) 54 out of 619 gamma scans detected ¹³¹I.
 (g) 12 analyses yielding 36 isotopic results.
 (h) 12 analyses yielding 24 isotopic results.

monitoring programs (USEPA 1984) was included, as well as materials known to have been used in Hanford operations. Three radiological analyses (radium, gross alpha, and gross beta) were included because they are part of EPA's constituent list for RCRA monitoring programs. Although a preliminary summary of results for the above-mentioned 75 wells sampled in 1985 was included in last year's environmental monitoring report (Price 1986), all results for 1985 and 1986 are discussed in this report. To ensure that no chemicals were overlooked, samples from five wells adjacent to the 200E and 200W Areas, 6-42-40A, 6-37-43, 6-48-71, 6-34-51, and 6-32-77 (Figure 3.11), were analyzed in 1986 for over 375 chemicals regulated by RCRA and the State of Washington (see Appendix D, Table D.3) (WDOE 1986). The Hanford Environmental Health Foundation provided additional sitewide water quality analyses on 43 wells.

Radiological analyses were performed by PNL with standard radiometric methods. Analyses for chemicals (and radium, gross alpha, and gross beta for the sitewide chemical monitoring of 90 wells) were performed by UST of Richland, Washington, with EPA-approved procedures (USEPA 1982) or other standard methods. In a few cases where standard methods were not available, in-house methods were developed and documented by PNL. Specific conductance and pH were measured in the field at the time of

TABLE 3.4. Number of Wells Sampled, Collected, and Analyses Performed for Ground-Water Monitoring in 1986

Area	Number of Wells Sampled	Number of Samples Collected	Number of Analyses Performed (a)
100	63	260	820
200	28	47	94
300	28	112	754
400	6	20	92
600 (b)	<u>237</u>	<u>910</u>	<u>1891</u>
Total	362	1349	3651

- (a) Not including expanded sitewide chemical monitoring.
 (b) The 600 Area encompasses all of the Hanford Site not included in the operating Areas (100, 200, 300, and 400 Areas.)

FIGURE 3.11. Location of Ground-Water Monitoring Wells Sampled in 1986 for Expanded Chemical Monitoring (first digit of well number has been dropped)

TABLE 3.5. Analyses for Sitewide Chemical Monitoring

<u>Ground-Water Contamination Indicators</u>	<u>Primary Drinking-Water Constituents</u>	<u>Ground-Water Quality Characteristics</u>	<u>Site-Specific Constituents (a)</u>
pH	Arsenic	Chloride	Beryllium
Specific conductance	Barium	Iron	Osmium
Total organic halogen (TOX)	Cadmium	Manganese	Strontium
Total organic carbon (TOC)	Chromium	Phenols	Zinc
	Fluoride	Sodium	Calcium
	Lead	Sulfate	Nicotinic Acid
	Nitrate		Nickel
	Mercury		Copper
	Silver		Vanadium
	Endrin		Antimony
	Lindane		Aluminum
	Methoxychlor		Potassium
	Toxaphene		Arochlor 1016
	2,4-D		Arochlor 1221
	2,4,5-TP Silvex		Arochlor 1232
	Radium		Arochlor 1242
	Gross Alpha		Arochlor 1248
	Gross Beta		Arochlor 1254
	Coliform		Arochlor 1260
	Alpha-BHC		Tetrachloromethane
	Beta-BHC		Benzene
	Gamma-BCH		Dioxane
	Delta-BHC		Methyl ethyl ketone
			Pyridine
			Toluene
			1,1,1-trichloroethane
			1,1,2-trichloroethane
			Trichloroethylene
			Perchloroethylene
			Xylene-o,p
			Xylene-m
			1,2-dichlorobenzene
			1,3-dichlorobenzene
			1,4-dichlorobenzene
			Hexachlorobenzene
			Pentachlorobenzene
			1,2,4,5-tetrachlorobenzene
			1,2,4-trichlorobenzene
			Hexachloropropene
			Hexachlorophene
			Naphthalene
			1,2,3-trichlorobenzene
			1,3,5-trichlorobenzene
			1,2,3,4-tetrachlorobenzene
			1,2,3,5-tetrachlorobenzene
			Chlorobenzilate
			Formalin
			Phosphate
			Kerosene
			Ammonium ion
			Strychnine
			Maleic hydride

(a) Only selected samples taken near operating areas were analyzed for these constituents.

collection, in accordance with documented procedures. Further details on analyses are found in Appendix D and in the "Quality Assurance" section.

RADIOLOGICAL MONITORING RESULTS FOR THE UNCONFINED AQUIFER

Ground-water monitoring for certain radiological constituents at the Hanford Site was based on past and/or present waste management practices. Table 3.6 identifies major constituents associated with Site operations. Radiological monitoring results for tritium, gross alpha, gross beta, ^{60}Co , ^{137}Cs , ^{106}Ru , ^{125}Sb , ^{131}I , ^{129}I , uranium (total and isotopic), and strontium isotopes are discussed below. (Nitrate and Cr results are discussed in this section in "Chemical Monitoring Results for the Unconfined Aquifer.")

Past monitoring results have shown that tritium is present in ground water; it also appears to be the most mobile radionuclide at the Site. As a result, tritium reflects the extent of contamination in the ground water from Site operations. Figure 3.12 illustrates the 1986 distribution of average tritium concentrations in the unconfined aquifer, resulting from 40 years of Site operations. Contours of tritium concentrations shown in Figure 3.12 were drawn based on the analysis of ground-water samples collected from monitoring wells. For each well, an average value of up to 12 tritium measurements was used. (The contour level of 5000 pCi/L serves to delineate tritium concentrations above background levels; this contour was not used in previous reports.) A summary of tritium concentrations in wells sampled during 1986 is presented in Appendix A, Table A.12.

Tritium plumes in the 100 Areas are the result of liquid waste disposal during past and present reactor operations. During 1986, tritium concentrations exceeded the DWS (20,000 pCi/L) beneath isolated portions of the 100B, 100F, 100K, and 100N Areas. Tritium distributions beneath the 100B and 100F Areas appeared to have stabilized or diminished slightly from 1985 to 1986. The highest tritium concentration within the 100 Areas was observed in well 1-K-30 (see Figure 3.10 for location). The average tritium concentration in that well increased from 420,000 pCi/L in 1985 to about 640,000 pCi/L

in 1986. However, this increase remained within the range of concentrations measured since 1981 (470,000 to 880,000 pCi/L). No other wells within the 100K Area had concentrations in this range, although tritium concentrations above background levels appeared in well 1-K-29 (averaging 27,000 pCi/L) during 1986. Tritium concentrations in wells surrounding the 100N Area remained relatively stable during the past year. The range of average yearly tritium concentrations in the immediate vicinity of the 100N Area liquid disposal facilities was about 30,000 to 110,000 pCi/L. The tritium distribution beneath the 100N Area changed because liquid effluent disposal to the 1301N Liquid Waste Disposal Facility (LWDF) was discontinued and the 1325N LWDF, which is farther from the Columbia River than the 1301N LWDF, was activated. All concentrations observed in the 100 Areas were significantly lower than the DCG (2,000,000 pCi/L) for tritium.

Several tritium plumes emanated from the 200 Areas. The distribution of tritium beneath the 200E and 200W Areas is the result of disposal of liquids used in chemical processing activities. The potential sources of these tritium plumes were identified by comparing data on each of the plumes with data presented in the Draft Phase I Installation Assessment of Inactive Waste-Disposal Sites at Hanford^(a). This comparison suggested that process condensate liquid wastes from the PUREX Plant (in the 200W Area) and from past operations at the REDOX Plant (in the 200W Area) represent the major sources of tritium. (Process condensate is water that is condensed from closed systems that are in direct contact with radioactive material.) At both the PUREX and REDOX plants, process condensates resulted from the initial dissolution of the nuclear fuel. A widespread plume situated between the 200E Area and the Columbia River (Figure 3.12) is primarily a result of operations at the PUREX Plant during 1956 to 1972. The historical movement of tritium along ground-water flow paths from PUREX to the Columbia River was also observed at individual monitoring wells. The tritium concentration history at well 6-41-23 (Figure 3.13), located midway between

(a) U. S. Department of Energy, 1986, Draft Phase I Installation Assessment of Inactive Waste-Disposal Sites at Hanford, Richland, Washington.

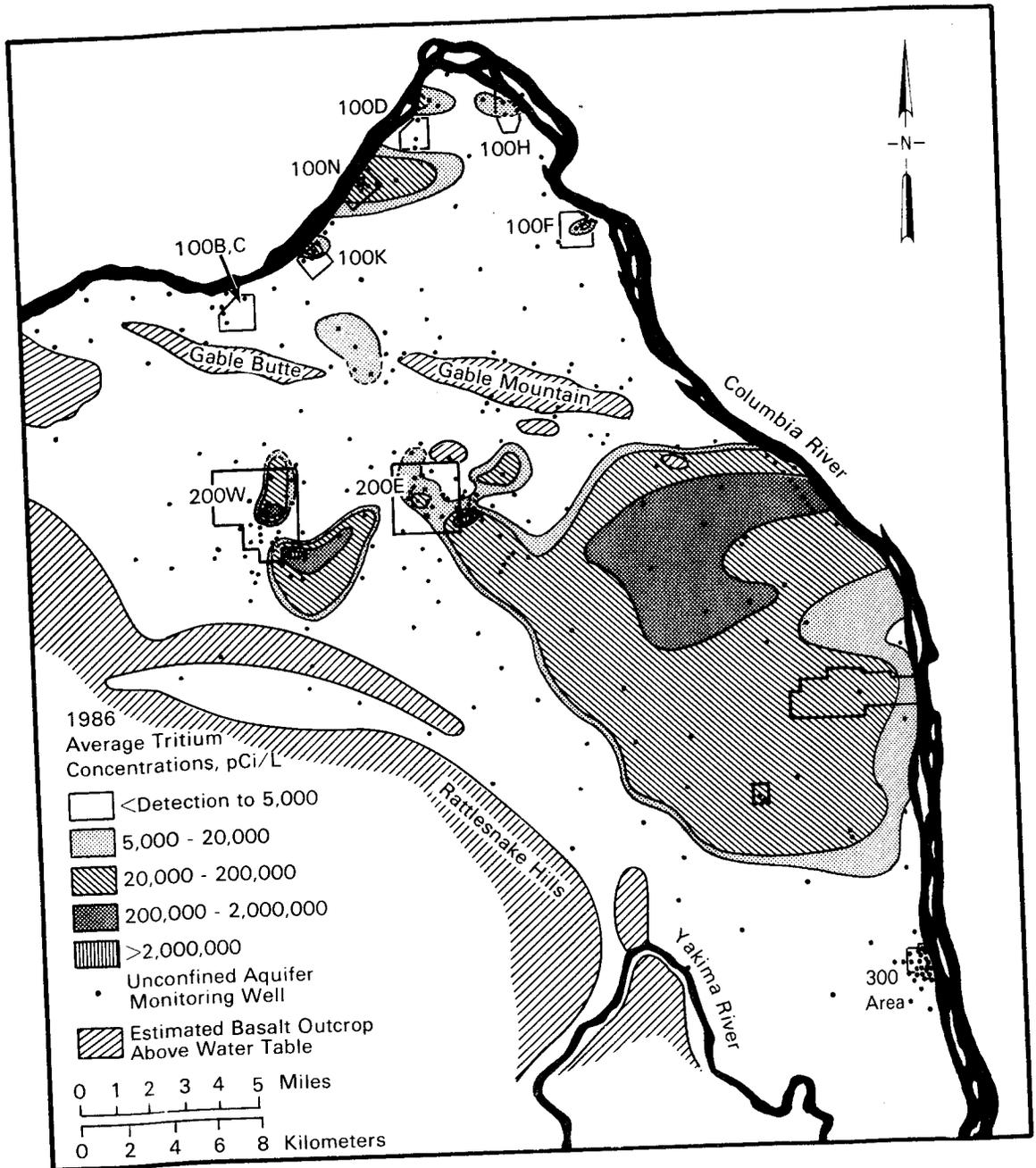


FIGURE 3.12. Tritium Concentrations in Ground Water for 1986

TABLE 3.6. Major Constituents Linked to Site Operation Activities

Facilities Type	Area	Constituents
Reactor Operations	100	Tritium, ⁶⁰ Co, ⁹⁰ Sr, Cr
Irradiated Fuel Processing	200	Tritium, nitrate, ¹³⁷ Cs, ¹²⁹ I
Fuel Fabrication	300	Uranium, Cr

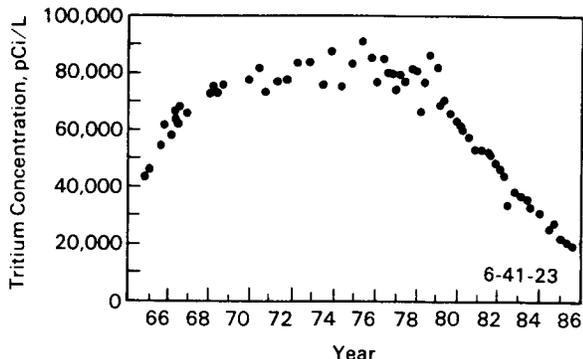


FIGURE 3.13. Tritium Concentrations in Well 6-41-23, 1966 Through 1986

the 200E Area and the Columbia River (Figure 3.10), showed increases (until about 1977) and decreases (from 1977 to the present) in concentrations as tritium flowed past the well. The decrease in concentrations at this well resulted from the discontinuation of PUREX operations in 1972, when ground water with a lower tritium concentration began flowing past the well. Tritium concentration histories at three other locations [wells 6-40-1 and 6-42-2 near the Columbia River (Figure 3.14) and well 6-42-12A located farther inland (Figure 3.15)] also showed increases in tritium during the 1970s. Concentrations have not yet begun to decrease at these wells as shown by their location in the plume (within the contour of 200,000 pCi/L; see Figure 3.12). It is expected that concentrations in these three wells will decrease (as they have in well 6-41-23) when the cleaner ground water reaches the wells. The variations in concentrations at wells 6-40-1 and 6-42-2 can be partially attributed to the mixing of surface water in the aquifer as the Columbia River stage changes.

Recent increases in tritium concentrations were observed close to the 200E Area in wells 6-32-43 and 6-33-42 (located in Figure 3.10). These

two wells, which were drilled in 1977, showed decreasing tritium concentrations during the time the PUREX Plant was shut down, and then increasing concentrations in 1985 as a result of increased liquid waste disposal in early 1984 (Figure 3.16). These increased concentrations indicated the presence of a second, smaller area of tritium concentrations that were above 200,000 pCi/L in the region near the PUREX Plant (south-east corner of the 200E Area) (Figure 3.12).

Another major tritium plume, in the southern portion of the 200W Area, emanated from the REDOX Plant, which processed fuel from 1951 until 1967. This plume was less widespread and had higher concentrations than the first plume produced by the PUREX Plant. The lower hydraulic conductivity of the geologic media resulted in slower ground-water flow rates near the 200W Area.

Figure 3.12 shows 1986 tritium concentrations that were above 5000 pCi/L in the northern region of the 200W Area, in the region east of the 200E Area (near B Pond), and between Gable Butte and Gable Mountain. These plumes are the result of past Hanford operations. The waste disposal practices that created these plumes were not identified.

A comparison of the average tritium concentrations in each well for 1986 (Figure 3.12) showed one plume near REDOX at levels above the DCG (2,000,000 pCi/L). Several locations showed tritium concentrations above the DWS (20,000 pCi/L). These locations included 1) isolated portions of the 100B, 100F, 100K and 100N Areas, 2) the 200W Area, and 3) the large plume located between the 200E Area and the Columbia River.

During 1986, samples from ten wells were analyzed for gross alpha activity in the area of the highest tritium concentrations to the south of and along the Columbia River and just south of the midpoint between the 200W and 200E

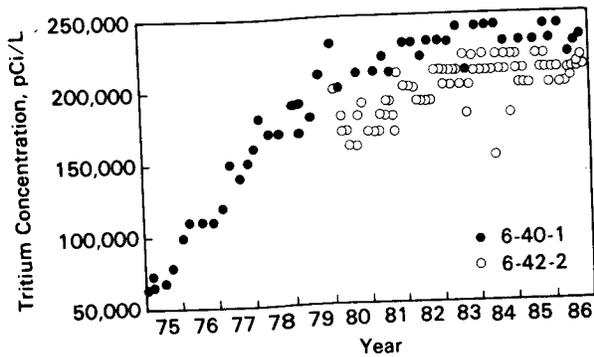


FIGURE 3.14 Tritium Concentrations in Wells 6-40-1 and 6-42-2, 1975 Through 1986

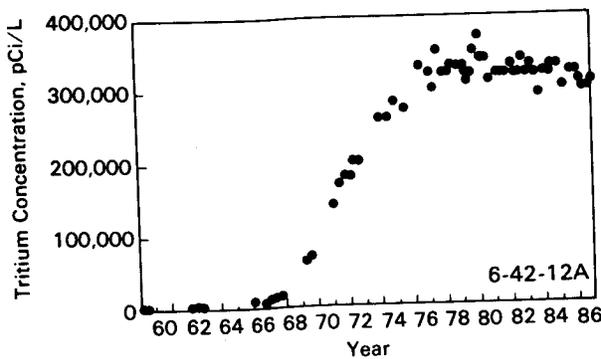


FIGURE 3.15. Tritium Concentrations in Well 6-42-12A, 1960 Through 1986

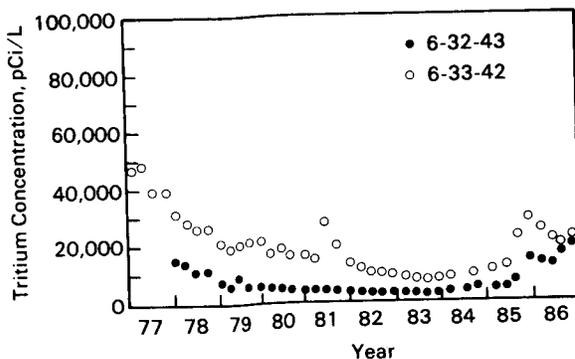


FIGURE 3.16. Tritium Concentrations in Wells 6-32-43 and 6-33-42, 1977 Through 1986

Areas. Gross alpha analyses were used to indicate the possible presence of uranium or plutonium in a sample, although plutonium was not expected to migrate to these locations. Results for all wells were less than 6 pCi/L (the detection limit is 4 pCi/L). (The DWS for gross alpha radiation is 15 pCi/L, not including uranium.) A summary of the gross alpha analytical results are listed in Appendix A, Table A.14. Uranium and plutonium results described below indicated that uranium was the alpha emitter in samples from wells near the Columbia River.

Samples from wells in the 100H, 100K, 300, and 400 Areas, and in 600-Area wells (the same 600-Area wells as those sampled for gross alpha analysis) were analyzed for gross beta activity. Gross beta activity indicated the possible presence of ^{106}Ru , ^{137}Cs , ^{90}Sr , ^{125}Sb , or ^{60}Co . The results are summarized in Appendix A, Table A.14. In all cases, concentrations were equal to or lower than those measured in 1985. Wells I-H4-3 and I-H4-4 showed average concentrations of 500 and 210 pCi/L, respectively, which was significantly above the DWS (50 pCi/L) for gross beta activity. All wells in the 300 and 400 Areas had average concentrations that were below the DWS, although most of the results were above the detection level (16 pCi/L). Average gross beta concentrations for samples from the 600-Area wells, located in the major tritium plume area, ranged from 32 to 82 pCi/L.

Gamma scans were performed on samples from wells in 100, 200, 300, 400, and 600 Areas to obtain concentrations of constituents that emit gamma radiation. Summaries of ^{60}Co , ^{137}Cs , ^{103}Ru , ^{106}Ru , ^{125}Sb , and ^{131}I concentrations are presented in Appendix A, Tables A.15 through A.20, respectively. Results for each of these radionuclides are discussed below.

All ^{60}Co results were consistent with 1985 results, except for well 6-50-53, where there was an increase from a maximum value of 50 pCi/L in 1985 to an average value of 260 pCi/L in 1986. Measurements were below the detection limit (20 pCi/L) at many wells. (The DWS for ^{60}Co is 100 pCi/L; the DCG is 5000 pCi/L.) Notable levels of ^{60}Co (72 to 190 pCi/L) were present in wells around the 1325N LWDF.

Samples from wells listed in Table A.15 were tested for gamma-emitting radionuclides. Only

those wells with detectable amounts of ^{137}Cs , ^{103}Ru , ^{106}Ru , ^{125}Sb , or ^{131}I were listed in Tables A.16 through A.20. Cesium-137 was detected in only a few wells because of its low mobility in the ground water. All concentrations of ^{137}Cs were below the DWS (200 pCi/L) and DCG (3000 pCi/L). (See Appendix A, Table A.16, for a summary of ^{137}Cs results.)

Ruthenium-103 was detected in 100N-Area wells only. This constituent was not expected to be found beyond areas immediately adjacent to the 100N Area because of its short half-life (39.4 days). All concentrations in these wells were below the DCG (50,000 pCi/L). Results are summarized in Appendix A, Table A.17.

Ruthenium-106 is a mobile, short-lived gamma-emitter. In some instances, ^{106}Ru and ^{125}Sb made up a significant portion of the gross beta activity. Wells in the 100N Area near the 1325N LWDF showed average ^{106}Ru concentrations of 150 to 970 pCi/L, which is above the DWS (30 pCi/L) and below the DCG (6000 pCi/L). One 600-Area well (6-38-65, located between the 200E and 200W Areas) had a concentration of 560 ± 210 pCi/L. Results are summarized in Appendix A, Table A.18.

Antimony-125, an easily detected gamma-emitter, was measured in well I-K-27 and in the 100N-Area wells near the 1325N LWDF. Results ranged from 140 to 410 pCi/L, which is far below the DCG of 60,000 pCi/L (see Appendix A, Table A.19).

Because ^{131}I has a short half-life, it was also detected only in 100N-Area wells. The highest concentrations existed near the 1325N LWDF (17,000 to 330,000 pCi/L), which is significantly above the DWS (3 pCi/L) and the DCG (3000 pCi/L). (All wells analyzed for gamma emitters are listed in Table A.16.) Results are summarized in Appendix A, Table A.20.

The presence of ^{129}I in ground water is significant primarily because of its relatively long half-life (16 million years) and its potential for accumulation in the environment as a result of long-term releases from nuclear fuel reprocessing facilities (Soldat 1976). On the Hanford Site, the main contributor of ^{129}I to the ground water has been liquid discharges to cribs in the 200 Areas. Samples from six wells in the 200E Area

and 12 wells in the 600 Area were analyzed for ^{129}I . Eight wells showed concentrations above the DWS for ^{129}I (1 pCi/L). (The DCG is 500 pCi/L.) Results of the ^{129}I analyses are listed in Appendix A, Table A.21.

Sources of uranium found in the ground water as a result of Site operations were liquid effluents placed in disposal cribs in the 200 Areas and in trenches in the 300 Area (ERDA 1975). Uranium may also occur naturally in soils, rock, ground water, and surface water (Fairbridge 1972). Uranium concentrations were measured in the unconfined aquifer in the vicinity of both the uranium fuel fabrication facilities and those inactive waste sites in the 300 Area known to have received uranium waste. As shown in Figure 3.17, a measurable uranium plume exists beneath the 300 Area. The extent of the uranium plume was limited to a fairly well-defined area downgradient from the active and inactive waste sites. Average annual uranium concentrations in the 300 Area ranged from 5 to 31 pCi/L (see Appendix A, Table A.22). These concentrations are similar to average concentrations measured in 1985.

Uranium concentrations in the 100H Area varied from extremely low levels (3.6 pCi/L) to an annual average of 460 pCi/L at well 1-H4-3. All 400- and 600-Area ground-water samples showed only background levels of uranium (less than 10 pCi/L) (Appendix A, Table A.23). Samples from six wells (6-39-0, 6-41-1, 6-42-2, 6-43-3, 6-46-4, and 6-47-5) along the Columbia River (in the area where tritium concentrations were highest) were analyzed for isotopic uranium (see Appendix A, Table A.23). The concentrations ranged from 1.8 to 2.2 pCi/L for ^{234}U , 0.035 to 0.057 pCi/L for ^{235}U , and from 1.2 to 1.6 pCi/L for ^{238}U . These levels were consistent with the gross alpha measurements taken in wells near the Columbia River and indicated that uranium was the dominant alpha-emitter in the six wells. The DCG for these three uranium isotopes are 500, 600, and 600 pCi/L, respectively.

Samples from the same six wells were analyzed for isotopic plutonium. Results are summarized in Appendix A, Table A.23. No detectable plutonium was observed, which is a further indication that the gross alpha activity predominantly resulted from uranium.

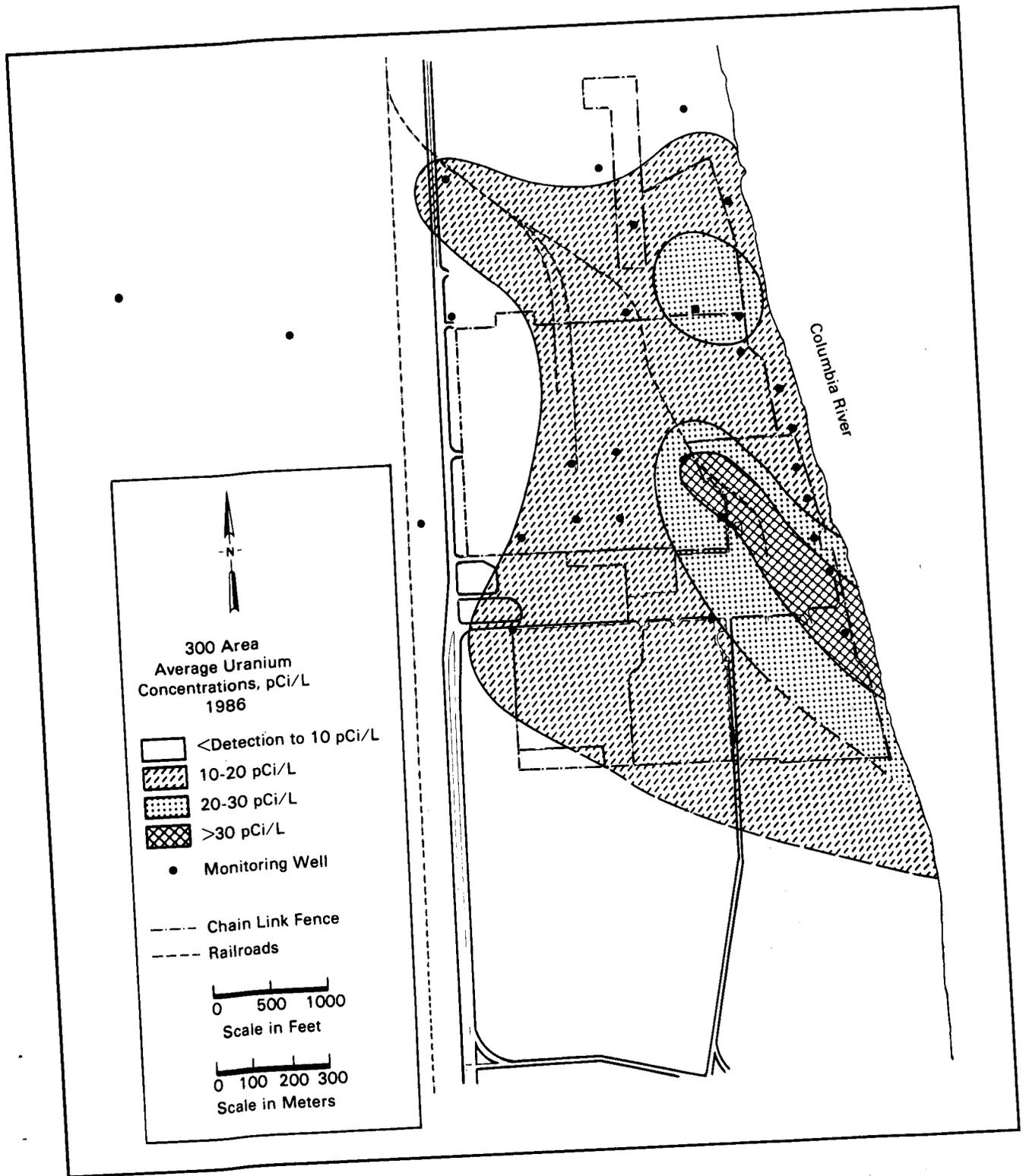


FIGURE 3.17. Uranium Concentrations in Ground Water Beneath the 300 Area for 1986
(see 300-Area location in Figure 3.10)

Strontium-89 and ⁹⁰Sr were measured in ground-water samples from the six wells to assess the contribution of these radionuclides to gross beta activity. Results indicated that these two strontium isotopes comprised less than 1 pCi/L of the gross beta activity. The results of the isotopic strontium analyses (see Appendix A, Tables A.23 and A.24) showed concentrations at or below the detection level (0.6 pCi/L). Strontium-90 was also measured in wells in the 100N and 300 Areas, in well 2-W22-10, and in three 600-Area wells inland from the river. Only in the 100N Area were ⁹⁰Sr concentrations above the DWS (8 pCi/L) and the DCG (1,000 pCi/L), with wells showing concentrations between the detection level and 2700 pCi/L.

CHEMICAL MONITORING RESULTS FOR THE UNCONFINED AQUIFER

This subsection describes the chemical impact of Site operations. Nitrate, chromium, and fluoride, historically monitored in the ground water, are discussed below. Additional chemicals described in this subsection were analyzed in 1985 and early 1986 as part of an expanded chemical monitoring effort.

Although nitrate is associated with process condensate liquid wastes, other liquids discharged to the ground also contain nitrate. The extent of nitrate contamination in the unconfined aquifer reflects the extensive use of nitric acid in chemical reprocessing and decontamination operations. Nitrate, like tritium, can be used to help define the extent of contamination, because nitrate is present in many waste streams and is mobile in the ground water.

The nitrate plumes (Figure 3.18) are shaped differently from the tritium plumes (Figure 3.12), primarily because nitrate concentrations are not reduced with time by radioactive decay, as are tritium concentrations. The nitrate plumes are more complicated than the tritium plumes because they derive from a variety of sources, both natural and manmade. As a result, nitrate is not as easily traced back to isolated sources. A summary of nitrate (as nitrate ion) concentrations, as determined by the ion chromatography method during the second half of the year, is given in Appendix A, Table A.25.(a)

The nitrate plumes differ greatly from the tritium plumes in the 300 Area, the 100B/C Area, east and south of the 100F Area, and east of the 200W Area. It is suspected that both past and present waste management activities contributed to the 300-Area nitrate concentrations. Past practices (including those at currently inactive waste sites) probably contributed nitrate to the ground water near the 100B/C Area, and east and south of the 100F Area. Past operations in the 200W Area contributed to the plume covering that site. Natural or agricultural activities from an offsite area may have contributed up to 1 or 2 mg/L to the nitrate plumes. Nitrate concentrations exceeded the DWS (45 mg/L for nitrate as nitrate ion) in the 100, 200E and 200W, and 300 Areas and the 600 Area to the southwest of the old Hanford townsite. Maximum nitrate concentrations measured in these areas were 53 mg/L (100B Area), 83 mg/L (100D Area), 140 mg/L (100F Area), 61 mg/L (100H Area), 63 mg/L (100K Area), 84 mg/L (100N Area), 340 mg/L (near the 200E Area), 240 mg/L (near the 200W Area), 57 mg/L (300 Area), and 64 mg/L (600 Area).

Chromium was measured in wells located in the 100H, 300, and 400 Areas in 1986. The results, which are consistent with the previous year's results, are summarized in Appendix A, Table A.26. All average Cr concentrations were below the DWS of 0.05 mg/L, except in the 100H Area, where annual averages at three wells were significantly higher. Average concentrations at these three wells ranged from 0.30 to 0.39 mg/L.

Fluoride was measured in samples from wells in the 100H, 300, and 400 Areas. All results for wells sampling the unconfined aquifer in these areas were below the DWS of 2 mg/L (Appendix A, Table A.26).

The expanded monitoring of chemical constituents in 1985 and early 1986 provided analyses of ground-water samples from 90 wells located throughout the Site. The results were reviewed to determine if noticeable levels of selected con-

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- (a) The ion chromatography method is more accurate than the specific ion probe procedure used to measure nitrate during 1985 and the first half of 1986. Specific ion probe results are not reported because of analytical uncertainties.

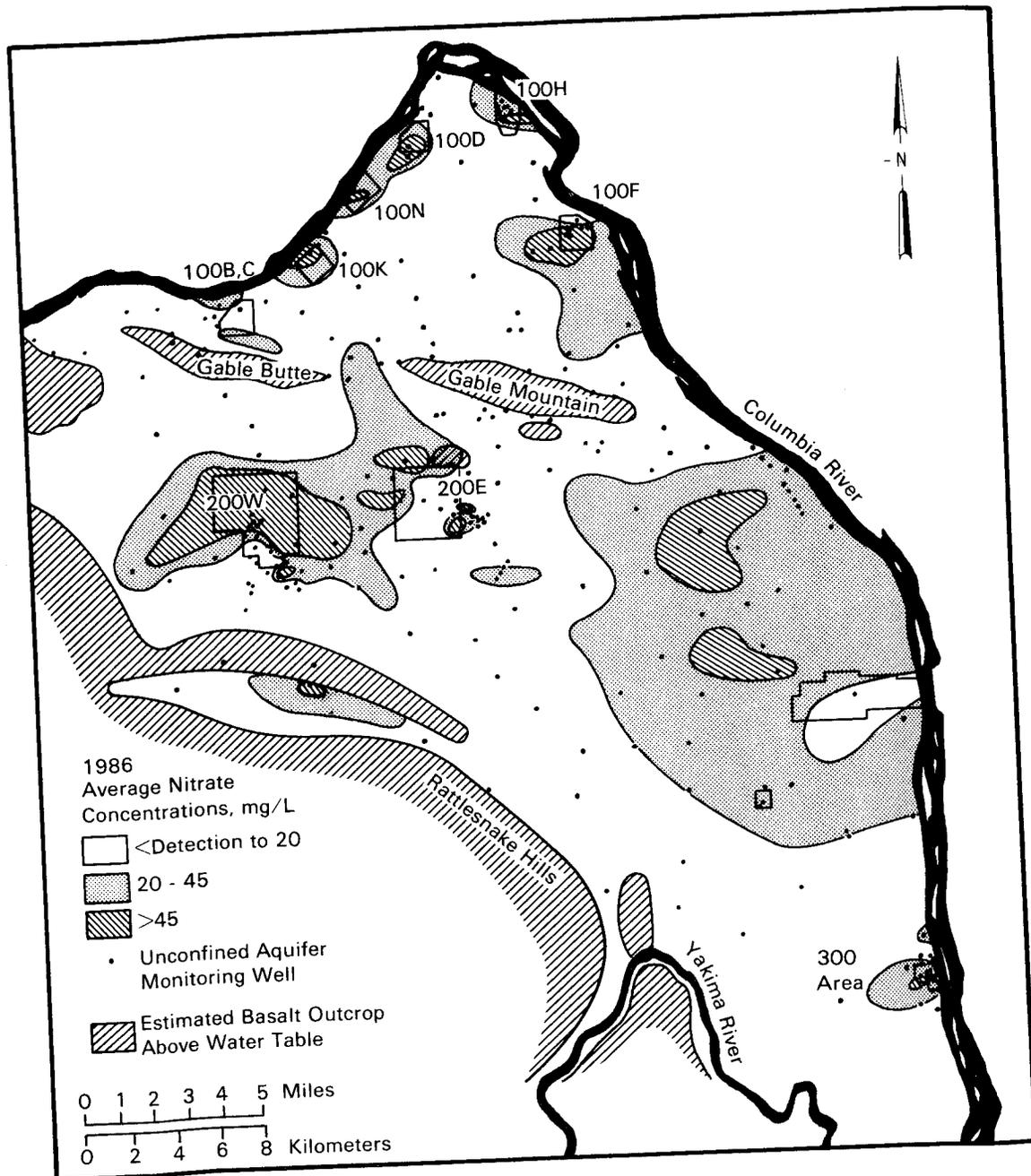


FIGURE 3.18. Nitrate Concentrations in Ground Water for 1986

stituents were present. The constituents most frequently reported at elevated concentrations in the 100 Areas were Cd, Cr, nitrate, and TOC. The same constituents, plus gross alpha, Zn, and Cu, were most frequently detected for the 200 Areas. Constituents with concentrations above the detection limit appeared to contain particulate material in the unfiltered samples. The analysis of unfiltered samples is required by EPA for compliance with RCRA monitoring (USEPA 1983). These particulates may have been the result of sediments in the well or of well-casing corrosion. The effect of the particulates was most pronounced for Ba, Cd, Zn, and Cu. Samples from wells in the 100 and 600 Areas that were high in Cr also appeared to contain particulate material. Samples high in particulates were also high in Al, which is a good indicator of particulates.

Constituents detected in a few wells appeared to be the result of Site operations; these included Cr, nitrate, and carbon tetrachloride. Two wells in the 100D area (1-D5-12 and 1-D8-3) showed high Cr levels that were not associated with high Al or other indicators of particulate material. Carbon tetrachloride was detected in two wells at the eastern and western boundaries of the 200W Area; measured levels of 28 µg/L in well 6-39-79 and 41 µg/L in well 6-38-70 were 6 and 8 times the DWS (Appendix C). Constituents that were below the detection limit included As, Hg, Se, Ag, Sb, Be, Os, Tl, phosphate, pesticides, herbicides, polychlorinated biphenyls, total organic halogen, and a large number of organic compounds. The number of analyses and measurements yielding results below the detection limit for each constituent analyzed are listed in Appendix A, Table A.28.

The expanded monitoring effort also provided information on the background levels of several constituents resulting from natural and offsite sources. Results from monitoring for levels of contamination were then compared to these background levels. Thirty-eight of the 90 site-wide wells were used to determine background levels; these wells were unlikely to be affected by past or present Site operations for most constituents. A summary of the estimated background levels of chemicals in the ground-water samples obtained from the 38 wells is given in Table 3.7. Because of its widespread distribution, nitrate is not included in Table 3.7.

The background concentration of nitrate was estimated to be 0.5 to 2 mg/L in areas unaffected by nitrate contamination. Estimates of the background concentrations of constituents were complicated by the presence of particulate matter in the ground-water samples. Constituents that appeared to be affected when samples were not filtered include Ba, Cr, Mn, Ni, Zn, Pb, Na, Al, K, Cu, V, and Ra. Some subjectivity was used in determining the background levels of these constituents. These levels should be considered to be estimates only.

Samples from five wells (6-42-40A, 6-47-43, 6-38-71, 6-34-51, and 6-32-77) adjacent to the 200 Areas (shown in Figure 3.11) were analyzed for a large set of constituents, including organics, regulated by RCRA and the State of Washington (WDOE 1986). Less than detectable concentrations were obtained for all constituents considered. A complete listing of the constituents is given in Appendix D (Table D.3).

Samples from 43 wells were analyzed by HEHF once during the year for water-quality parameters that included pH, conductance, Ca, Mg, Na, CO₃, HCO₃, K, B, NO₃, Cl, SO₄, and total dissolved solids (TDS). These results provided additional sitewide information on the chemical characteristics of the ground water (Appendix A, Table A.29). Five wells had levels of TDS above the DWS (500 mg/L). Two wells were above the DWS (250 mg/L) for SO₄, and five were above the DWS (10 mg/L) for nitrate as nitrogen. These wells are in areas affected by Site operations; none of the wells supplied drinking water.

RADIOLOGICAL AND CHEMICAL MONITORING RESULTS FOR THE CONFINED AQUIFER

The confined aquifer was monitored to help determine the extent of ground-water flow between the confined and unconfined aquifers. This aquifer intercommunication was identified by Graham et al. (1984). Ground-water samples from the uppermost (Rattlesnake Ridge) confined aquifer were analyzed for tritium, nitrate, gamma-emitting radionuclides, and fluoride. The results are summarized in Appendix A, Tables A.12, A.13, A.16 through A.20, and A.27. Wells that were constructed in the confined (or a composite of the confined and

TABLE 3.7. Estimated Background Levels for Selected Constituents in Hanford Ground Water

<u>Constituent</u>	<u>Detection Limit (µg/L)</u>	<u>Background Concentration^(a) (mg/L)</u>
Ag	10	<10
Al	150	<150
As	5	<5
Ba	6	38 ± 15
Be	5	<5
Ca	50	38,000 ± 12,000
Cd	2	<5
Cl	500	9,400 ± 5,100
Cr	10	10-20
Cu	10	<10
F	500	<500 - 1,500
Hg	0.1	<0.1
K	100	5,000 ± 1,400
Mn	5	<5-700
Na	100	18,000 ± 5,900
NH ₄	50	110 ± 50
Na	10	<10
Pb	5	<10
PO ₄	1,000	<1,000
SO ₄	500	33,000 ± 18,000
V	5	15 ± 8

(a) Stated as an average, an average ± the standard deviation, or a range.

unconfined) aquifer are indicated by footnotes in each table. In most cases, only background levels of constituents were detected in these wells. An exception was well 2-E33-12, which was contaminated 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 et al.1984). Contaminant concentrations have decreased by dilution as ground water with lower tritium concentrations flowed past the well.

The measured concentrations of radionuclides in well 6-47-50 indicated that intercommunication has occurred between the Rattlesnake

Ridge confined aquifer and the unconfined aquifer north of the 200E Area. This well is located near an erosional window (i.e., near an area where the confining layer is absent) in the Elephant Mountain basalt (Graham et al. 1984). Ground water in the uppermost confined aquifer in that area will discharge to the unconfined aquifer near West Lake (Graham et al. 1984).

Fluoride was detected in well 6-S18-51, which samples the confined aquifer in Rattlesnake Hills. An average concentration of 8 mg/L (above the DWS of 2 mg/L) could be attributed to the chemistry of the basalt formations.

3.3 SURFACE-WATER MONITORING

R. L. Dirkes

The Columbia River was identified as the primary environmental exposure pathway to the public as a result of radioactivity in liquid effluents entering the river, either as direct discharges or indirect ground-water seepage. Radionuclides in the river have decreased significantly since the shutdown of the plutonium production reactors with single-pass cooling systems and the installation of improved liquid effluent control systems at the N Reactor. However, radionuclides associated with Hanford operations continued to be routinely identified in the river water during 1986. In general, water quality parameters (radiological and nonradiological) measured during 1986 were in compliance with applicable standards, and no significant deterioration of the water quality attributable to Hanford was evident.

Four onsite ponds were also sampled periodically 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 any contaminants that may be in pond water and sediments.

COLUMBIA RIVER

Pollutants, both radiological and nonradiological, are known to enter the Columbia River along the Hanford Site. In addition to direct discharges from Hanford facilities, pollutants in the ground water, as a result of past effluent disposals, are known to seep into the river. Effluents from each direct discharge point were routinely monitored and reported by the appropriate operating contractor. Each discharge was identified and regulated for nonradiological constituents under the NPDES. The NPDES-permitted discharge locations and parameters routinely measured are listed in Table 3.8. Potential sources of nonra-

diological pollutants not associated with Hanford include irrigation return water canals and significant seepage associated with the extensive irrigation practices north and east of the river.

The water quality of the Columbia River was monitored routinely during 1986 at sample locations upstream and downstream of the Hanford Site. Monitoring was conducted to identify influences on the water quality, should they exist, that may have been attributable to operations at Hanford. In addition, monitoring results were used to demonstrate compliance with water quality standards associated with the

TABLE 3.8. Measurements for NPDES-Permitted Discharges at Hanford (a)

Measurement	Location		
	100K Area (2 Discharges)	100N 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	--(b)	X	--
Heat Discharged	--	X	--
Settleable Solids	--	--	X
Iron	--	X	--
Ammonia	--	X	--
Chromium	--	X	--

(a) NPDES Permit No. WA-000374-3 (USEPA 1983b).

(b) Dashed line indicates no measurement required.

Class A water designation for this stretch of the Columbia River. Because these criteria do not include specific limits for radionuclides, concentrations observed at the Site were compared to State of Washington and EPA drinking water limits.

Sample Collection and Analysis

Samples of Columbia River water were collected throughout 1986 at the locations shown in Figure 3.19. Samples were collected at Priest Rapids Dam, the 300-Area Water Intake, and the Richland Pumphouse for analysis of selected radionuclides at frequencies appropriate to their half-lives and their importance as indicators of potential environmental impacts. Gross alpha and gross beta measurements provided a general indication of the radioactive contamination present. Specific radionuclides of primary significance in the river were ^3H , ^{60}Co , ^{89}Sr ,

^{90}Sr , ^{131}I , ^{129}I , ^{137}Cs , $^{239,240}\text{Pu}$, ^{234}U , ^{235}U , and ^{238}U .

The Priest Rapids Dam sampler, located approximately midstream within the dam, collected samples as water passed through the dam. Priest Rapids Dam is located approximately 5 miles upstream of the Hanford Site boundary. At the 300-Area sampling location, near the southern boundary of the Site, water was collected from the intake forebay along the shoreline. The Richland Pumphouse sampler, located about 2 miles downstream of the Site boundary, collected water from a single point approximately 30 ft into the river from the shoreline.

In most instances, two types of samplers were used for the collection of radiological samples: a composite system that collected a fixed volume of water at set intervals at each location during

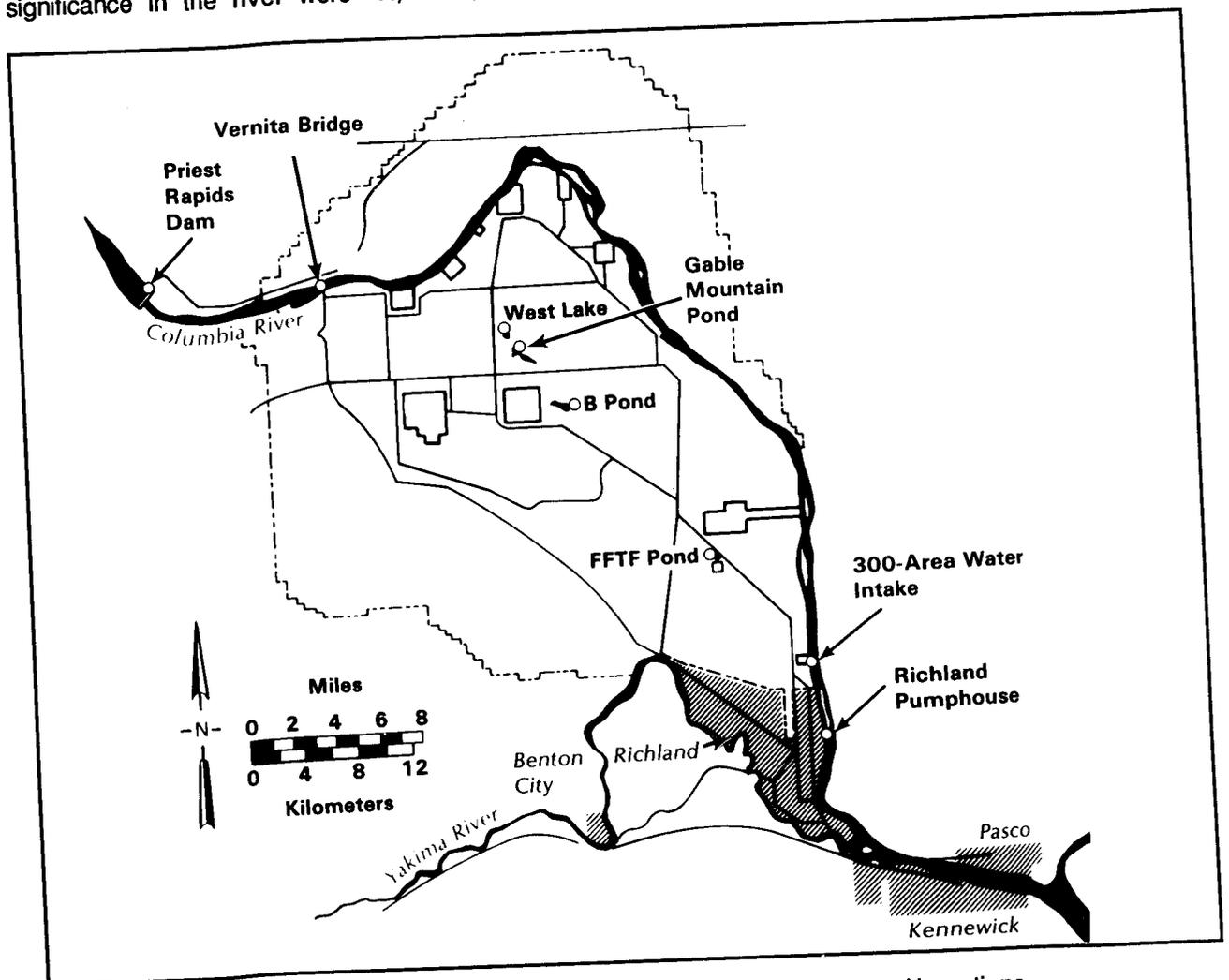


FIGURE 3.19. Columbia River Water Sampling and Onsite Pond Locations

each sample period, and a specially designed system that continuously collected waterborne radionuclides from the river water on a series of filters and ion-exchange resins. Grab samples were used in a few special cases when routine equipment was inoperable.

The composite sampler consisted of a timer-activated solenoid valve that periodically diverted a continuously flowing substream of Columbia River water into a 10-L container. This cycle repeated itself throughout the 1-week sample period, such that approximately 30 mL of water was collected every 30 min. The 10-L sample container was changed every week and the sample was taken to the laboratory, where the water from a single location was composited over a 4-week period before analysis, resulting in a total sample size of approximately 40 L. Gross alpha, gross beta, ^3H , ^{89}Sr , ^{90}Sr , ^{234}U , ^{235}U , and ^{238}U analyses were performed on the samples collected with the composite sampling system. Composite sampling systems were located at Priest Rapids Dam and the Richland Pumphouse during 1986.

A special, continuously flowing system was used to separate other radionuclides from river water before analysis. A large volume of water was required to allow the extremely small concentrations of these radionuclides in the river water 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 about 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 ^3H , were collected on a mixed-bed, ion-exchange resin column. The filters and ion-exchange resin were exchanged every 2 weeks and analyzed for gamma-emitting radionuclides (see Appendix D). The filters and resin from each location were then composited separately by quarter year for analyses of ^{129}I , ^{238}Pu , and $^{239,240}\text{Pu}$. The continuous sampling systems were located at Priest Rapids Dam and the 300-Area water intake during 1986.

Samples were collected from shoreline sites near the Vernita Bridge and near the Richland Pumphouse for analysis of various nonradiological water quality parameters. Monthly grab samples were collected at both sample locations. 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 HEHF laboratory where processing was initiated as appropriate to ensure the integrity of the sample. Water quality analyses performed by HEHF included pH, nitrate, total coliform and fecal coliform bacteria, and the biological oxygen demand. All of these parameters are indicators of the nonradiological quality of Columbia River water.

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

Results

The results of the radiological analysis of Columbia River water samples collected during 1986 are summarized in Tables A.30 and A.31, Appendix A. Significant results are discussed and illustrated below, with comparisons to previous years' results provided. Radionuclides consistently observed in measurable quantities in river water during 1986 were ^3H , ^{90}Sr , ^{129}I , ^{234}U , ^{238}U , and $^{239,240}\text{Pu}$. All of these radionuclides exist in worldwide fallout and are also present in effluents from Hanford facilities. Tritium and uranium occur naturally in the environment.

Gross alpha and gross beta measurements are useful as indicators of the general radiological quality of the river water and provide an early indication of changes in the levels of radioactive contamination that may warrant further investigation. The 1986 average gross alpha and gross beta concentrations observed in Columbia River water at Priest Rapids Dam and the Richland Pumphouse were well below applicable drinking water standards, 15 pCi/L and 50 pCi/L, respectively. Figures 3.20 and 3.21 illustrate

the gross alpha and gross beta concentrations observed at both locations during the past 6 years. As is apparent in the figures, 1986 concentrations were consistent with those of previous years, with no significant increases or decreases observed.

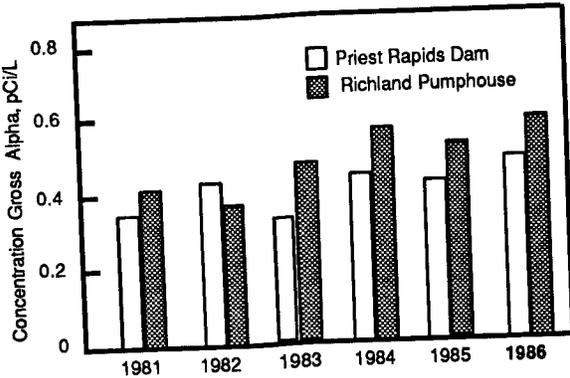


FIGURE 3.20. Gross Alpha Concentrations Observed in Columbia River Water, 1981 Through 1986

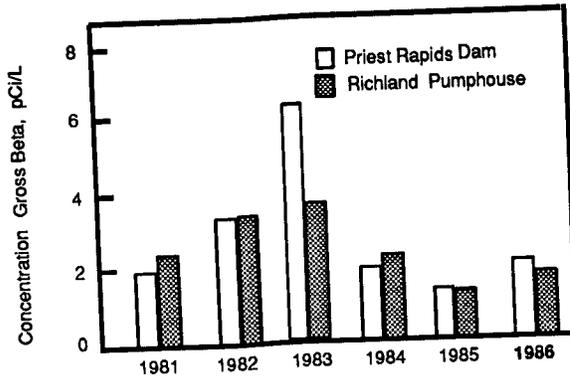


FIGURE 3.21. Gross Beta Concentrations Observed in Columbia River Water, 1981 Through 1986

Annual average concentrations of ^3H measured at Priest Rapids Dam and the Richland Pumphouse during 1986 were 100 pCi/L and 150 pCi/L, respectively. Figure 3.22 provides a comparison of the annual average concentrations of ^3H observed at Priest Rapids Dam and the Richland Pumphouse for the period 1981 through 1986. The concentrations of ^3H observed in the river during 1986 were similar to those observed during recent years and were comparable to measurements reported by the State of Washington (DSHS 1986). Figure 3.23

provides a comparison of monthly ^3H concentrations observed in river water, showing that concentrations at the Richland Pumphouse were generally higher during the year than those at Priest Rapids Dam. The variability observed in the monthly ^3H concentrations during 1986 was comparable to that experienced during previous years (Price 1986). Statistical tests indicated that the difference between the concentrations observed at these locations was significant.^(a) Sources of ^3H entering the river were effluent releases from N Reactor and ground water entering the river along the Site (see "Effluents, Waste Disposal, and Unusual Occurrences" and "Ground-Water Monitoring"). All observed tritium concentrations were well below the State of Washington and EPA standards of 20,000 pCi/L for drinking water.

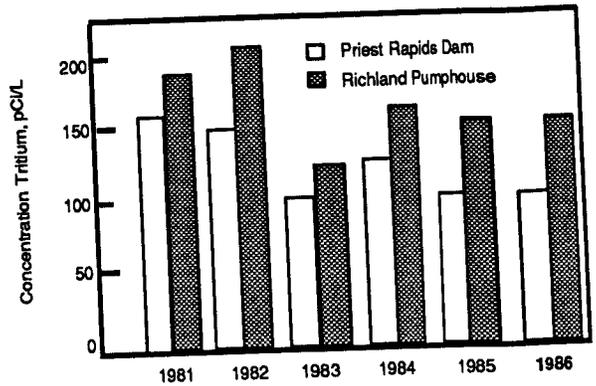


FIGURE 3.22. Annual Average ^3H Concentrations Observed in Columbia River Water, 1981 Through 1986

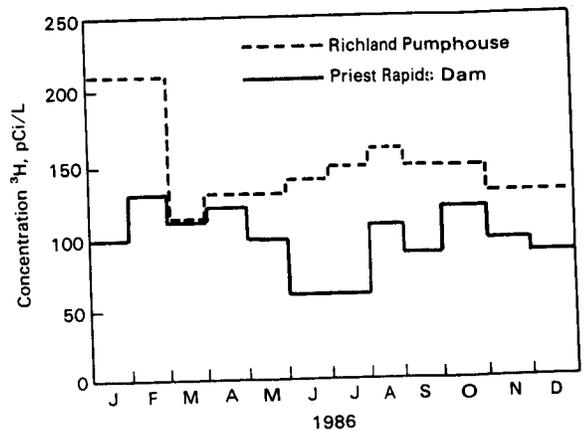


FIGURE 3.23. Monthly ^3H Concentrations Observed in Columbia River Water During 1986

(a) Paired sample comparison, t-test of differences (Snedecor and Cochran 1980).

The annual average ^{90}Sr concentrations measured at Priest Rapids Dam and the Richland Pumphouse during 1986 were essentially the same (0.15 pCi/L and 0.16 pCi/L, respectively). Figure 3.24 shows the annual average ^{90}Sr concentrations observed at these locations from 1981 through 1986. Although the Richland Pumphouse annual average concentrations were generally slightly higher than those observed at Priest Rapids Dam, the differences observed since 1981 were very slight, especially when the uncertainty associated with the averages was considered. Figure 3.25 presents the monthly ^{90}Sr concentrations observed during the year at both locations, demonstrating the closeness of ^{90}Sr concentrations observed at the two locations. Statistical tests indicated that the difference between the ^{90}Sr concentrations observed throughout the year at these locations was insignificant. The only known source of ^{90}Sr entering the Columbia River was the liquid-waste disposal facility in the 100N Area, which discharged 8 Ci to the river during 1986. All ^{90}Sr concentrations observed during 1986 in Columbia River water were well below the State of Washington and EPA standard of 8 pCi/L for drinking water.

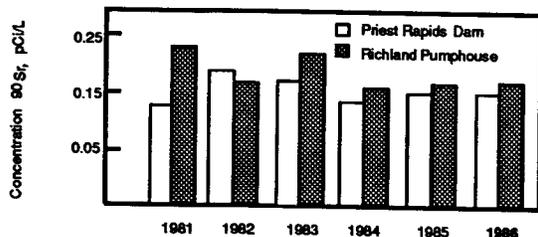


FIGURE 3.24. Annual Average ^{90}Sr Concentrations Observed in Columbia River Water, 1981 Through 1986.

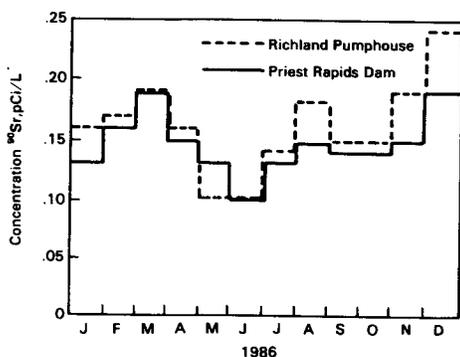


FIGURE 3.25. Monthly ^{90}Sr Concentrations Measured in Columbia River Water During 1986

Strontium-89 concentrations in Columbia River water during 1986 were generally below the detection level. As in past years, 1986 average concentrations of ^{89}Sr were essentially the same at both locations (0.005 pCi/L) and well below the State of Washington and EPA drinking water standard of 20 pCi/L.

Annual average uranium concentrations in 1986 continued to be slightly higher in samples of Columbia River water collected at the Richland Pumphouse than in those collected at Priest Rapids Dam, as shown in Figure 3.26. The observed difference in the annual averages (0.46 pCi/L and 0.50 pCi/L) is very slight, and monthly values observed during the year were not consistently higher at any one location, as Figure 3.27 shows. As in the case of ^{90}Sr , these figures indicate that there is not a significant difference between nor a significant contribution to Columbia River water uranium concentrations attributable to Hanford Operations. Although there is no direct discharge of uranium to the river, it is known to be present in the ground water beneath the 300 Area (see "Ground-Water Monitoring") and has been detected at elevated levels in riverbank springs entering the river in this area (McCormack and Carlile 1984).

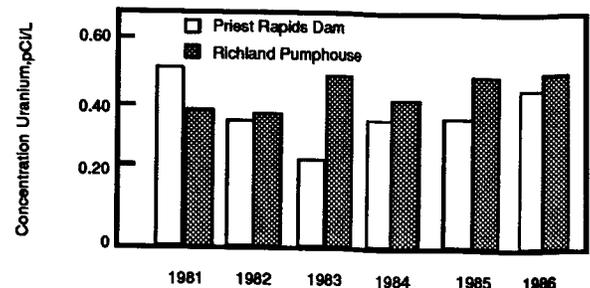


FIGURE 3.26. Annual Average Uranium Concentrations Observed in Columbia River Water, 1981 Through 1986

As in the past several years, ^{129}I concentrations continue to be higher in river water collected at the 300-Area Water Intake than at Priest Rapids Dam. The average Priest Rapids Dam and 300-Area river water concentrations of ^{129}I during 1986 were 9 aCi/L and 100 aCi/L, respectively. Iodine-129 in the river is attributable to the flow of ground water from the unconfined aquifer into the river (see "Ground-Water Monitoring"). Figure 3.28 provides the quarterly ^{129}I results for the two locations and also shows the average quarterly flow rate of the Columbia River for 1986

and the previous 5 years. As the figure shows, the differences observed during 1986 between the Priest Rapids and 300-Area concentrations were similar to the differences observed in past years. The figure also illustrates the influence of the river flow rate on the downstream ^{129}I concentrations, as higher flow rates are associated with reduced concentrations, and vice versa. As has been the case for other radionuclides, the concentrations of ^{129}I observed in Columbia River water during 1986 were well below those concentrations that would result in doses exceeding the State of Washington and EPA standard for drinking water of 4 mrem/yr.

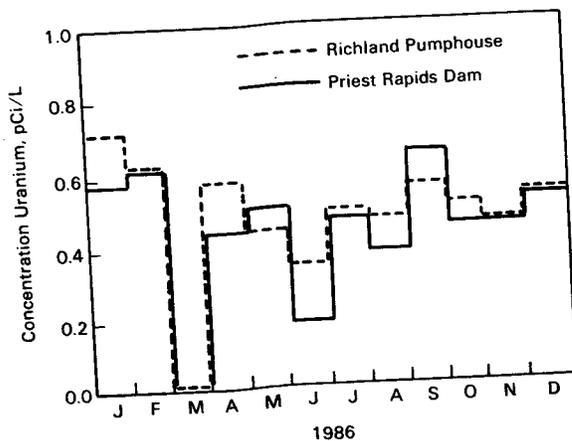


FIGURE 3.27. Monthly Uranium Concentrations Observed in Columbia River Water During 1986

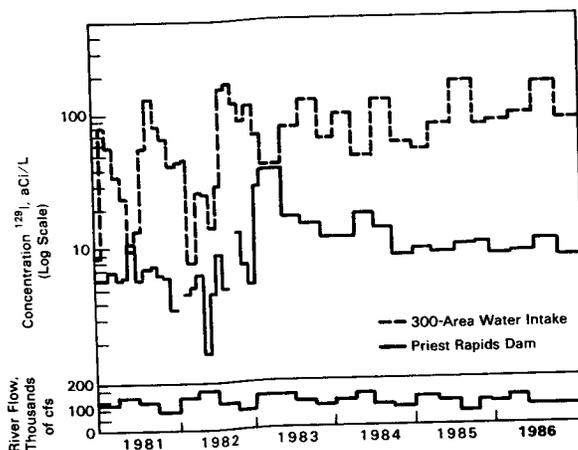


FIGURE 3.28. Iodine-129 Concentrations Observed in Columbia River Water, 1981 Through 1986

In general, ^{131}I concentrations in Columbia River water were below the detection level during 1986. A notable exception to this was the 2- to 3-month period immediately following the Chernobyl incident, during which ^{131}I was identified in river water collected at both locations. By July, ^{131}I levels had dropped back to levels typical of past years. All ^{131}I concentrations observed in Columbia River water during 1986 were well below the EPA and State of Washington drinking water standard of 3 pCi/L.

During 1986, ^{60}Co was not consistently observed in measurable quantities in Columbia River water at Priest Rapids Dam, the 300-Area Water Intake, or the Richland Pumphouse. Likewise, ^{134}Cs and ^{137}Cs were generally below the detection level during the year. As in the case of ^{131}I , both ^{134}Cs and ^{137}Cs were identified at very low levels that are probably attributable to fallout from the Chernobyl accident. All ^{60}Co , ^{134}Cs , and ^{137}Cs concentrations observed during the year were below EPA and State of Washington drinking water standards.

Table A.32, Appendix A, summarizes the non-radiological water quality data compiled by both PNL and the USGS during 1986. These data include a number of parameters for which no regulatory limit exists, but which are useful as indicators of water quality. Pacific Northwest Laboratory and USGS results, where duplicated, were in general agreement with each other and were comparable to levels observed in recent years. With the few exceptions noted below, applicable standards for water designated Class A were met at both sampling locations. There was no indication during 1986 of any significant deterioration of the water quality along this stretch of the Columbia River resulting from Hanford operations.

Figure 3.29 illustrates 1986 sampling results for several water quality parameters with respect to the applicable standard and previous year's results. The pH measurements taken throughout the year, above and below the Site, were generally in close agreement and, with three exceptions, were within the acceptable range for Class A waters. On two occasions, the upstream pH values were measured below the 6.5 limit while the downstream pH measurement was observed below the limit once. The median fecal coliform concentrations observed at both

locations during 1986 were below Class A requirements. Average dissolved oxygen and turbidity levels were similar upstream and downstream, consistent with previous years' results, and did not violate applicable standards.

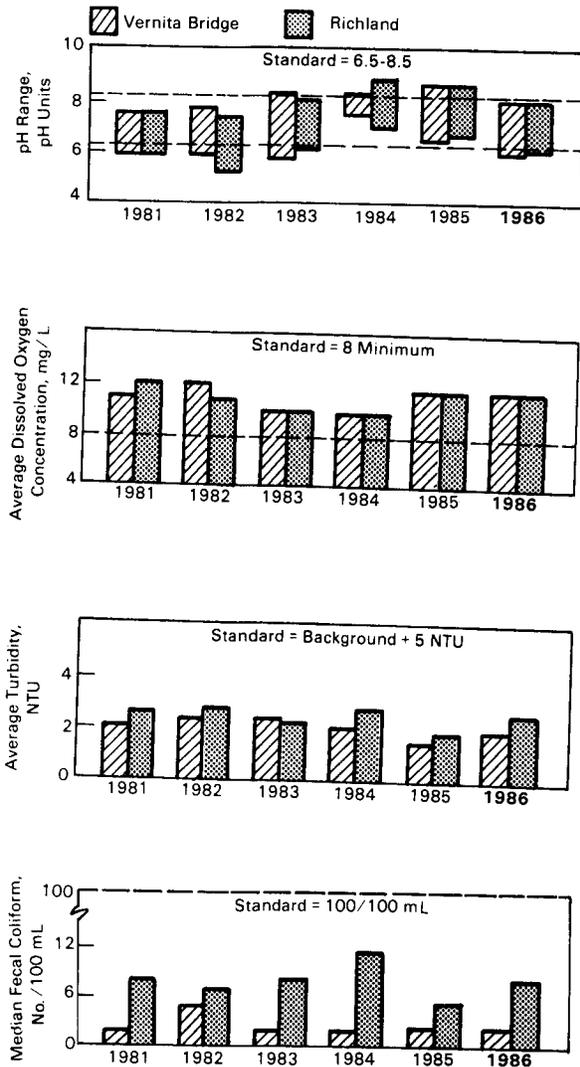


FIGURE 3.29. Columbia River Water Quality Measurements, 1981 Through 1986

Average monthly Columbia River water temperatures at Priest Rapids Dam and the Richland Pumphouse are illustrated in Figure 3.30. Also plotted in this figure are the monthly average river flow rates. The periods of time during which N Reactor was operating are also identified. River temperatures and the differences observed between Priest Rapids

Dam and Richland Pumphouse temperatures during 1986 were similar to those observed in the past (Price 1986). Increases and decreases in river temperature during the year were similar at both locations. The major source of heat to the Columbia River in the Hanford Reach is solar radiation. Thermal discharges from N Reactor operations are also defineable sources of heat to the river; however, incremental increases occurred by reactor operations are largely dissipated and marked by temperature fluctuations that result from solar radiation and convection cooling.

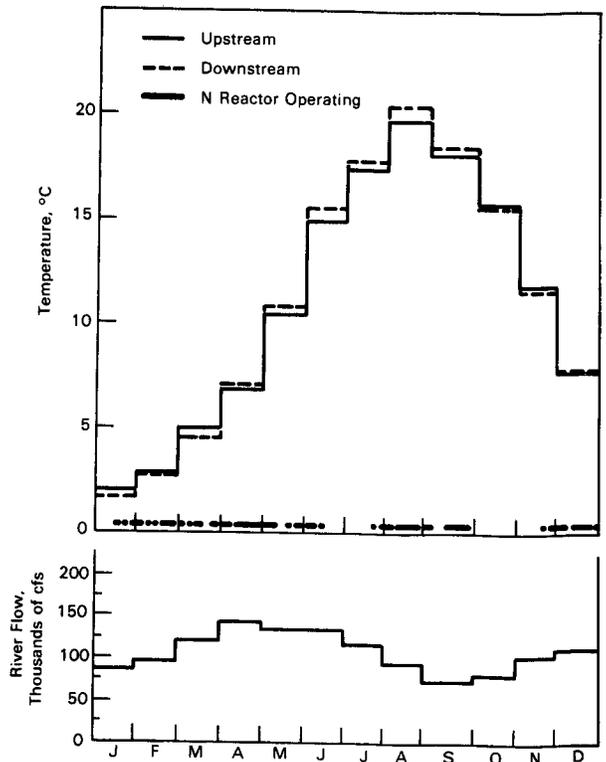


FIGURE 3.30. Columbia River Temperature and Flow Rates Measured During 1986

ONSITE PONDS

Four onsite ponds located near operating areas shown in Figure 3.19 were sampled periodically during 1986. Two of the ponds located near the 200E Area, Gable Mountain Pond and B Pond, were excavated in the mid-1950s for disposal of process cooling water and other liquid wastes occasionally containing low levels of radionuclide

contamination. A third pond, West Lake, also located near the 200E Area, is a natural body of water interconnected with the ground water. This pond did not receive direct effluent discharges from Site facilities during the year. The fourth onsite pond, FFTF Pond, located near the 400 Area, was excavated in 1978 for the disposal of cooling water from various facilities within the 400 Area.

Operating contractors are responsible for monitoring effluents discharged to the ponds and for operational surveillance of the ponds. During 1986, decommissioning activities continued on Gable Mountain Pond, further reducing its volume and subsequently increasing the volume of B Pond as a result of the diversion of water from Gable Mountain to B Pond.

Although the ponds were inaccessible to the public and did not constitute a direct offsite environmental impact during 1986, they were accessible to migratory waterfowl, creating a potential biological pathway for the dispersion of contaminants. Periodic sampling of the ponds also provided a secondary check on effluent control and monitoring systems.

Sample Collection and Analysis

During 1986, 10-L grab samples were collected every 3 months from each of the ponds. Care was taken to avoid surface debris and the re-suspension and inadvertent collection of bottom sediments during the sampling process. Unfiltered aliquots of the samples were analyzed for gross alpha and gross beta activities, gamma-emitting radionuclides, ^3H , and ^{90}Sr . Sodium-22 analyses were performed on the FFTF pond samples to detect indications of process failure.

Results

The analytical results from pond samples collected during 1986 are summarized in Table A.33, Appendix A. The maximum, minimum, and average values are provided for the various radionuclides of interest at each pond. Further discussion of individual constituents and comparisons with results observed during previous years are provided below for each of the ponds.

Radionuclide concentrations observed in Gable Mountain Pond water during 1986 were similar to those observed in recent years, as illustrated in Figure 3.31. Figure 3.32 illustrates the aver-

age concentrations of various radionuclides observed in B Pond water during the years 1981 through 1986. The concentrations of gross beta and ^{90}Sr have decreased since 1984. The gross alpha, ^{137}Cs , and ^3H concentrations remained in the range previously observed at this pond.

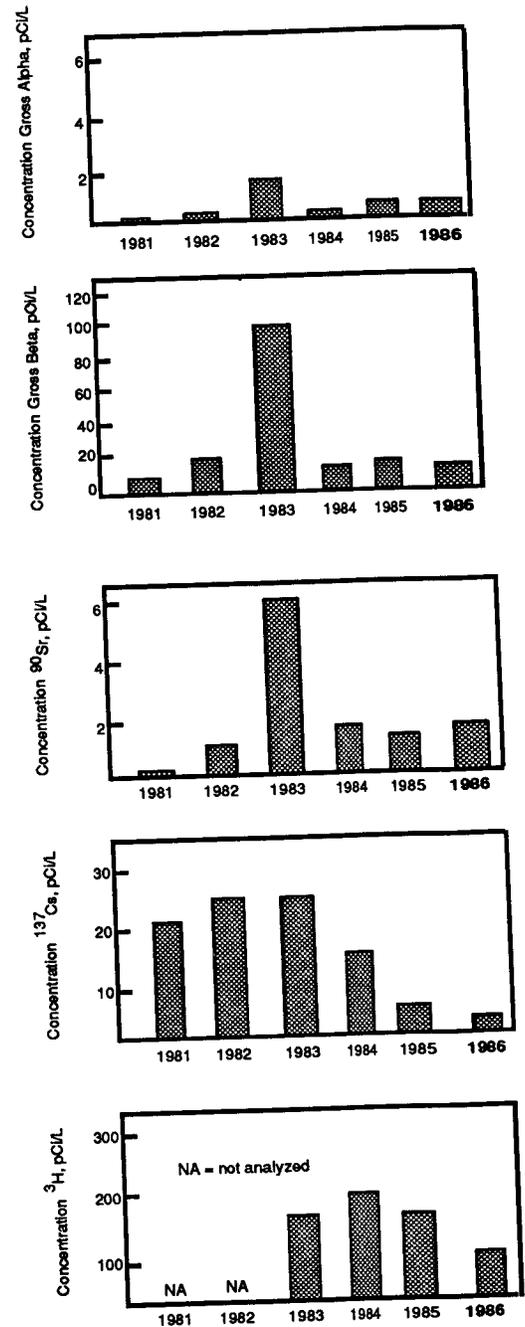


FIGURE 3.31. Annual Radionuclide Concentrations Observed in Gable Mountain Pond, 1981 Through 1986.

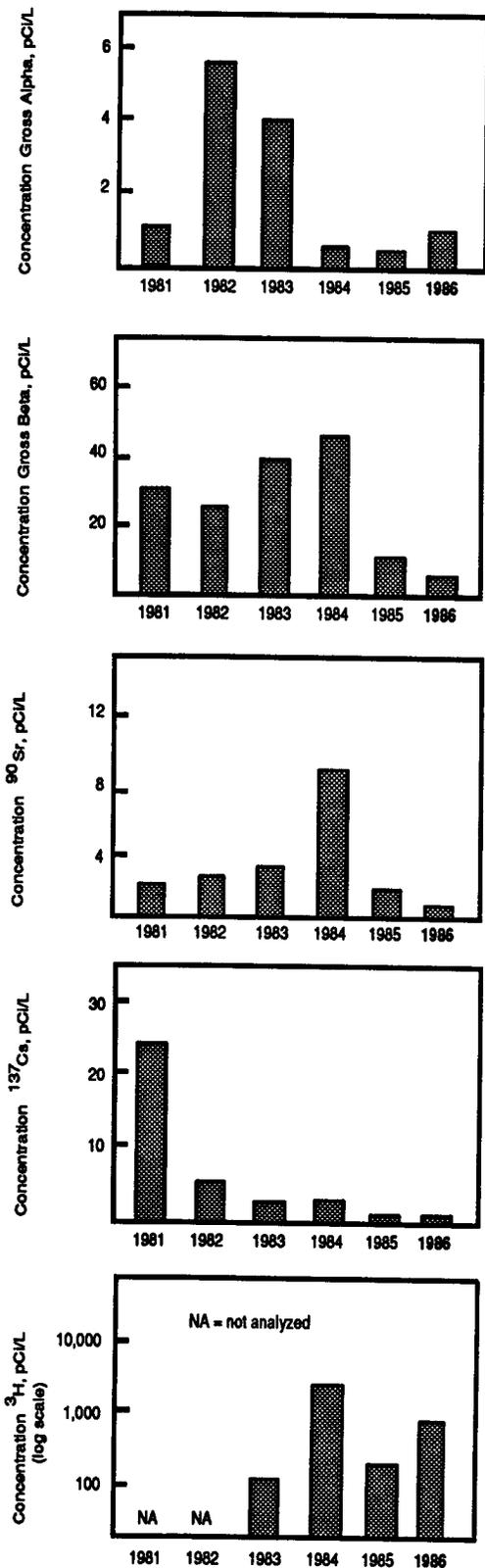


FIGURE 3.32. Annual Average Radionuclide Concentrations Observed in B Pond, 1981 Through 1986

The radionuclide concentrations observed in water collected from the FFTF Pond remained relatively stable over the years (Figure 3.33), with the exception of ³H, which decreased significantly during 1986. This decrease is attributable to a change in the source of the water supply serving the 400 Area. A new well, completed in a deeper aquifer with significantly lower ³H concentrations, was put into service during February 1986. Gross alpha, ⁹⁰Sr, and ²²Na were generally below the detection level during 1986 and thus were omitted from the figure.

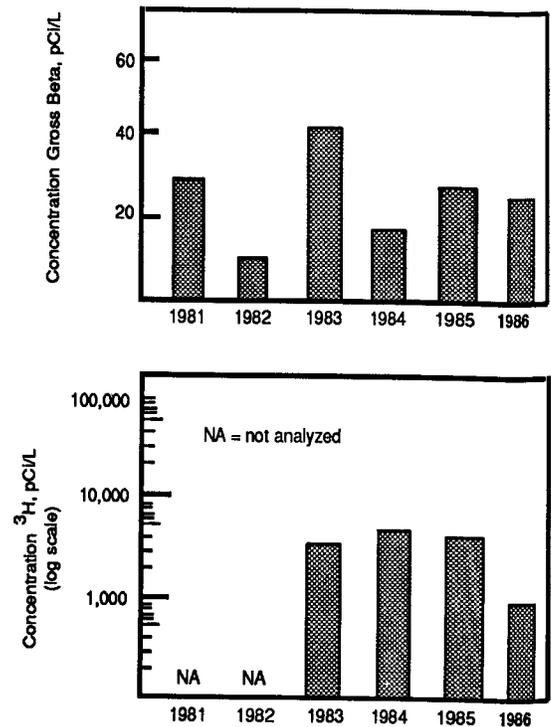


FIGURE 3.33. Annual Average Radionuclide Concentrations Observed in FFTF Pond, 1981 Through 1986

Radionuclide concentrations observed in West Lake during 1986 were comparable to those reported in past years (Figure 3.34). As in past years, gross alpha and gross beta concentrations observed in West Lake, which is recharged from the ground water (Gephart et al. 1976), were higher than gross alpha and gross beta levels observed in other onsite ponds. This has been reported to be a result of high concentrations of naturally occurring uranium (Speer et al. 1976). Strontium-90 concentrations remained relatively stable over the past 6 years. Tritium

concentrations, which appeared to decrease since 1983, were similar to those in the unconfined aquifer beneath West Lake (see "Ground-Water Monitoring").

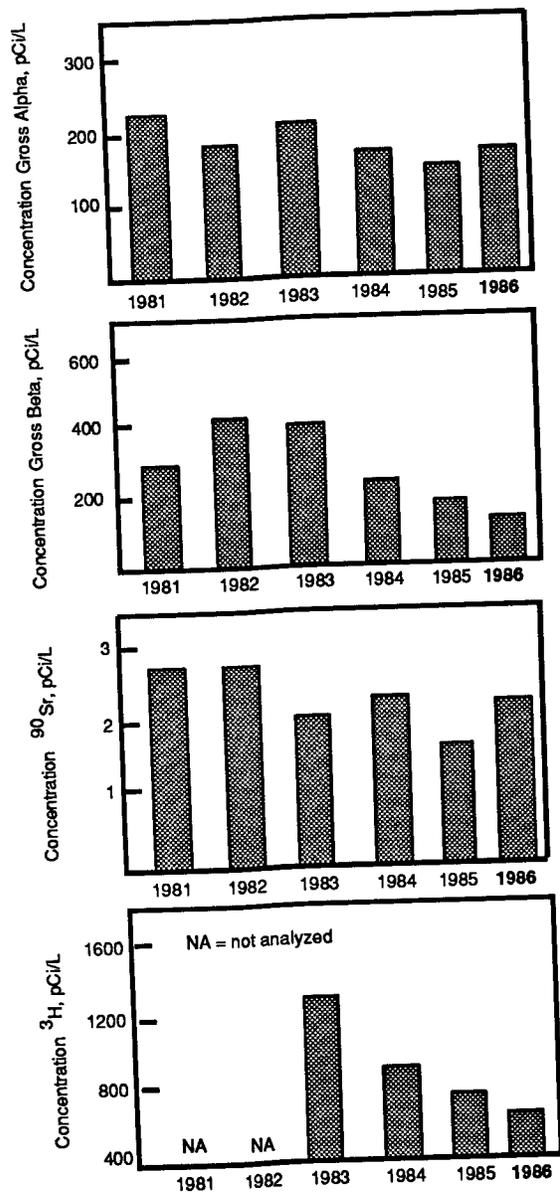


FIGURE 3.34. Annual Average Radionuclide Concentrations Observed in West Lake, 1981 Through 1986

3.4 FOOD AND FARM PRODUCT MONITORING

K. R. Price

Alfalfa and several types of foodstuffs, including milk, vegetables, fruits, beef, chickens, eggs, and wheat, were collected at several locations in the Hanford Site environs during 1986 (Figure 3.35). Samples were collected primarily from locations in the prevailing downwind directions (i.e., to the south and east of the Site). Samples were also collected in generally upwind directions somewhat distant from the Site to provide information on radioactivity levels that could be attributed to worldwide fallout, which included debris from the Chernobyl incident. Foodstuffs collected in the Riverview Area (see Figure 3.35) were irrigated with water pumped from the Columbia River downstream of the Site. All samples were analyzed for ^{90}Sr and ^{137}Cs . Milk samples were also analyzed for ^{129}I , ^{131}I , ^{89}Sr , and ^3H . Fruit samples were analyzed for ^3H as well as ^{90}Sr and ^{137}Cs .

Tritium, ^{90}Sr , ^{131}I , and ^{137}Cs were found in a number of foodstuff samples collected during 1986; however, the concentrations measured in samples collected near the

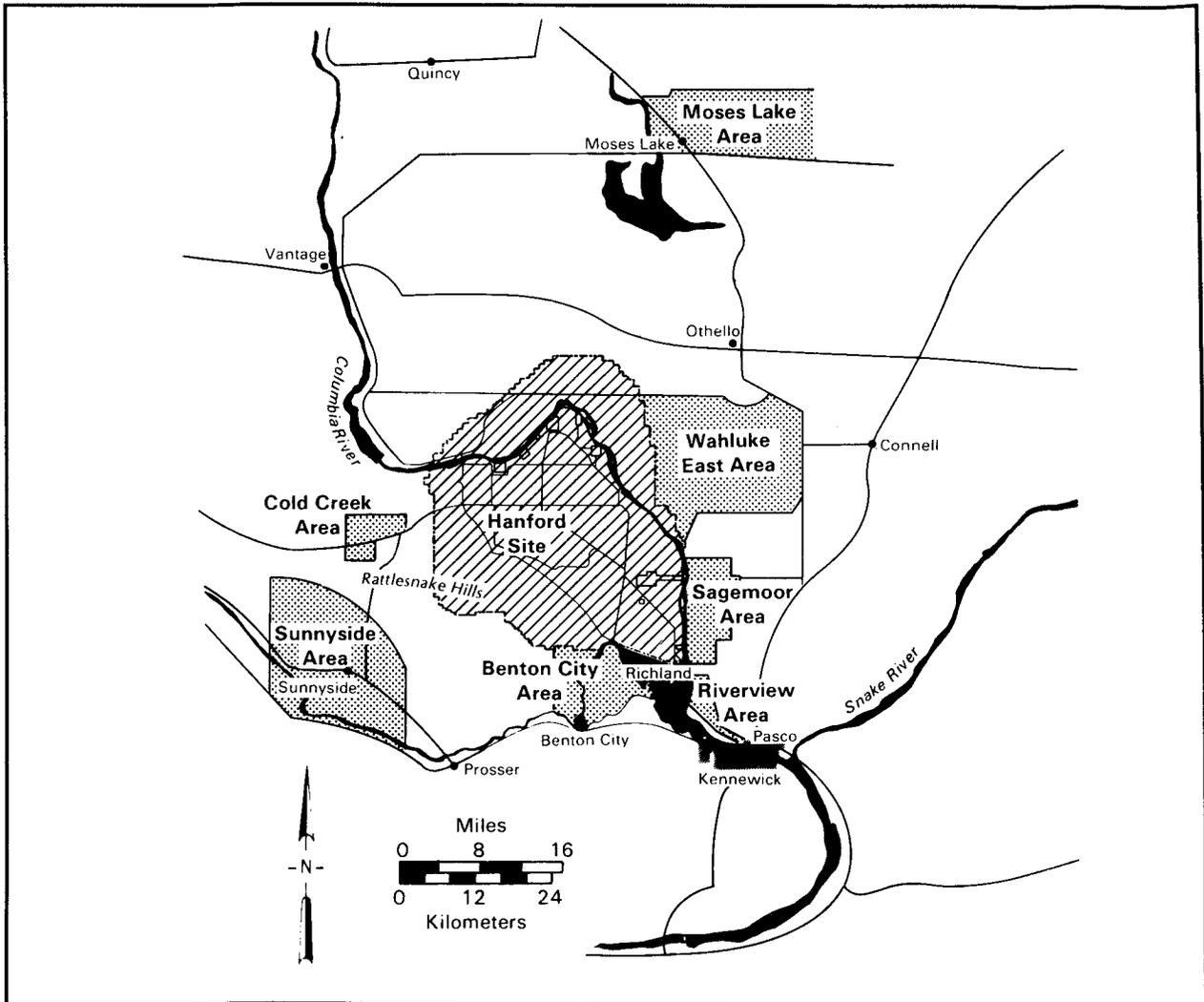


FIGURE 3.35. Foodstuffs Sampling Areas

Hanford Site were similar to those measured in samples collected away from the Site. No measurable effect from the use of Columbia River water for irrigation was detected. Iodine-131 was detected briefly in milk samples collected after the Chernobyl incident. 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 1986 Hanford Operations").

MILK

Samples of raw, whole milk were collected from several dairy farms near the Site perimeter and in the prevailing 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, which included debris from the Chernobyl incident. The general sampling locations are shown as stippled areas in Figure 3.35, and results are listed in Table A.34, Appendix A. Samples were routinely collected every other week throughout the year from the Sagemoor and Sunnyside areas, and monthly from other areas. Special samples were collected daily at Riverview to monitor the concentration of ^{131}I in milk following the Chernobyl incident.

The ^{131}I present in all milk samples collected between the second week of May and the second week of June was a result of fallout from Chernobyl. Figure 3.36 shows how the levels of ^{131}I in milk collected from the Riverview area quickly reached a maximum concentration soon after the arrival of fallout on May 5, 1986. All evidence of ^{131}I disappeared from milk samples via radioactive decay by mid-July.

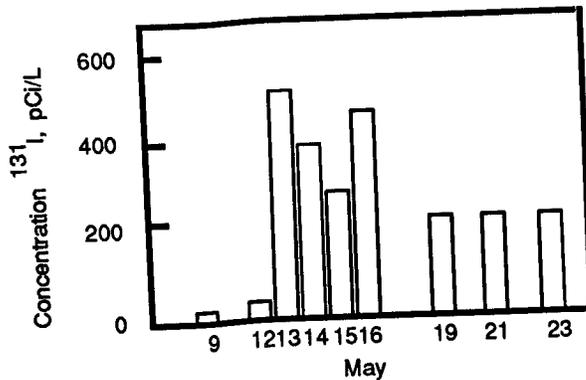


FIGURE 3.36. Iodine-131 Concentrations in Milk at Riverview Following the Chernobyl Incident

Cesium-137 was measured at slightly elevated concentrations in milk samples when compared to normal levels. Peak concentrations from Chernobyl fallout occurred at different dairy farms at different times, depending on when the farmers used hay that had been contaminated. Most samples showed elevated concentrations toward the end of the year, when dairy cows were fed hay cut during the previous summer.

Strontium-90 and ^{89}Sr were not present in Chernobyl fallout in measurable amounts, and the concentrations in milk samples collected in 1986 were similar to those noted in 1985. Average ^{90}Sr and ^{137}Cs concentrations in milk for 1986 and the previous 5 years are shown in Figure 3.37.

Analyses for ^3H and ^{129}I were performed on selected milk samples in 1986. Tritium was identified in a few of the samples, and ^{129}I in all of the samples. Concentrations were low, however, and no differences were apparent between near-Site and distant sampling locations. Tritium and ^{129}I were not present in sufficient amounts in Chernobyl fallout to permit it to be distinguished from other worldwide fallout.

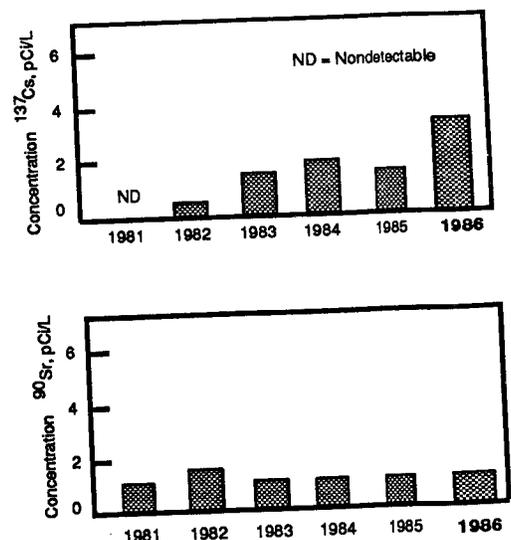


FIGURE 3.37. Annual Average ^{137}Cs and ^{90}Sr Concentrations Measured in Milk, 1981 Through 1986

VEGETABLES

Samples of leafy vegetables (i.e., spinach, leaf lettuce, or cabbage) were obtained once during the summer from gardens located within the sampling areas listed in Table A.35, Appendix A. The leafy vegetables provided an indication of radionuclides present in locally grown produce. Three replicate samples, each composed of mixtures of the edible portions of the various leafy vegetables grown at the sampling locations, were obtained. Samples were analyzed for ^{90}Sr and ^{137}Cs , and results are provided in Table A.35, Appendix A. Strontium-90 and ^{137}Cs were identified in most samples but with no apparent difference between distant and nearby locations. The concentrations of ^{90}Sr and ^{137}Cs at all locations are comparable to those of recent years, as shown in Figure 3.38. Samples of leafy vegetables were collected during the first two weeks of July, too late to be influenced by fallout from Chernobyl.

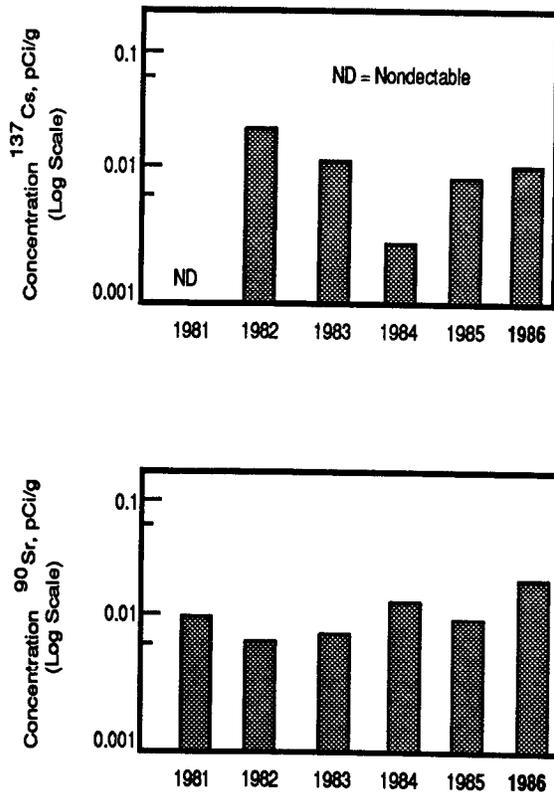


FIGURE 3.38. Annual Average ^{137}Cs and ^{90}Sr Concentrations Measured in Leafy Vegetables, 1981 Through 1986

The potential radiation dose to the hypothetical maximally exposed individual was calculated for an individual who was a long-term resident of the Riverview area (see "Potential Radiological Doses from 1986 Hanford Operations"). A major contributor to the estimated dose was ^{90}Sr from Columbia River water used to irrigate foodstuffs grown in the Riverview area.

A variety of vegetables were collected from the Riverview area in 1986. Potatoes, carrots, and tomatoes were for ^{90}Sr , ^3H , and gamma-emitting radionuclides. Results were similar to concentrations found in foodstuffs from other sampling areas, and no effect from the use of Columbia River water for irrigation could be detected. No influence from Chernobyl was detected. Results are shown in Table A.36, Appendix A.

FRUIT

Samples of apples, cherries, grapes, and melons were collected during harvest from the areas listed in Table A.37, Appendix A. Three replicate samples were collected at each sampling location, and the edible portions were analyzed for ^3H , ^{90}Sr , and ^{137}Cs . Results are provided in Table A.37.

Tritium was identified in about one-fourth of the samples analyzed, ^{90}Sr in nearly all of the samples, and ^{137}Cs in a few samples. There were no apparent differences between fruit types or sampling locations. The concentrations of ^{90}Sr and ^{137}Cs were attributed to worldwide fallout. The ^3H identified was attributed to worldwide fallout and natural sources.

WHEAT AND ALFALFA

Samples of ripened wheat and mature alfalfa were collected from the areas listed in Table A.38, Appendix A. Three replicate samples of wheat and alfalfa were collected at each location and analyzed for ^{90}Sr and ^{137}Cs . Results of the analysis are shown in Table A.38, Appendix A.

In 1986, as in 1985, ^{90}Sr was identified in nearly all of the samples. Cesium-137 from Chernobyl and worldwide fallout was also identified in nearly all samples. No distinct difference in radionuclide concentrations was apparent between samples collected near the Site and those collected at a distance.

BEEF, CHICKEN, AND EGGS

Samples of locally produced chickens, eggs, and beef were collected from the areas listed in Table A.39, Appendix A. Table A.39 provides results of analyses of the samples for ^{137}Cs and ^{90}Sr . Results were all very low and generally near detection levels. No influence from Chernobyl fallout was detected in these samples. Cesium-137 and ^{90}Sr concentrations in beef for 1986 and the previous 5 years are shown in Figure 3.39.

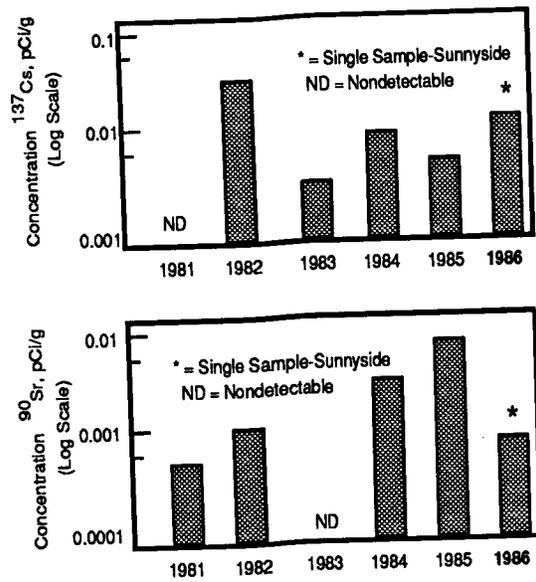


FIGURE 3.39. Annual Average ^{137}Cs and ^{90}Sr Concentrations Measured in Beef, 1981 Through 1986

3.5 WILDLIFE MONITORING

K. R. Price

The Hanford Site serves as a refuge for waterfowl, upland game birds, and a variety of other animals. Wildlife have access to several areas near Site facilities that contain low levels of radionuclides attributable to Site operations (e.g., waste-water ponds). Sampling was performed in areas where the potential existed for wildlife to ingest radionuclides (see Figure 3.40). The number of animals that visited these areas was small compared to the total wildlife population in the region, and, as a result, human consumption of animals from the sampling locations was unlikely.

Fish were collected from the Hanford reach of the Columbia River. The analyses of the fish provided an indication of the radionuclide concentrations in local game fish and were used to evaluate the potential dose to humans from this pathway. These fish showed no important differences in radionuclide concentrations in muscle tissue compared to upstream samples.

Analytical results of terrestrial wildlife samples collected during 1986 were similar to those observed in recent years. The dose that a person who consumed any of the wildlife sampled could have received, even at the maximum radionuclide concentrations measured in 1986, was well below applicable DOE standards.

DEER

Samples taken from road-killed deer (Figure 3.40) 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 $^{239,240}\text{Pu}$ in liver. Results indicated the presence of detectable levels of ^{137}Cs (0.03 pCi/g) in two deer. The liver of one animal contained detectable quantities of $^{239,240}\text{Pu}$ at 0.0002 pCi/g. These concentrations were in the range generally attributed to worldwide fallout, and the median values were consistent with those observed in previous years, as shown in Figure 3.41. Individual results for 1986 are shown in Table A.40, Appendix A.

FISH

Fish were collected at various locations along the Columbia River (see Figure 3.40), and boneless filets were analyzed for ^{60}Co , ^{90}Sr , and ^{137}Cs . The remaining carcasses were analyzed to estimate ^{90}Sr in bone. Median concentrations for ^{60}Co and ^{137}Cs in whitefish and bass in 1986 and recent years are shown in Figure 3.42. Whitefish were collected both upstream of Hanford near Priest Rapids Dam and within the Site

near the 100D Area. Bass were collected near the 100F Area. Individual results for ^{60}Co , ^{90}Sr , and ^{137}Cs for 1986 are shown in Table A.41, Appendix A.

Cesium-137, ^{90}Sr , and ^{60}Co were detected in a few of the whitefish muscle samples collected along the Hanford reach of the river near the 100D Area, as well as upstream of the Site near Priest Rapids Dam, but there were no quantifiable differences between the two locations. Strontium-90 in whitefish carcasses, however, was measurably higher in samples collected from the 100D Area than in samples collected upstream of the Site. Samples of bass muscle and carcass collected from the slough near the 100F Area showed concentrations similar to those measured in whitefish collected near the 100D Area.

UPLAND GAME BIRDS

Pheasants were collected from the 100, 200, and 300 Areas (Figure 3.40). Samples of breast meat from each bird were analyzed for ^{60}Co and ^{137}Cs . A slightly greater number of the birds showed detectable concentrations of ^{137}Cs than of ^{60}Co . The median concentrations for ^{137}Cs in the 100 and 200 Areas are shown in

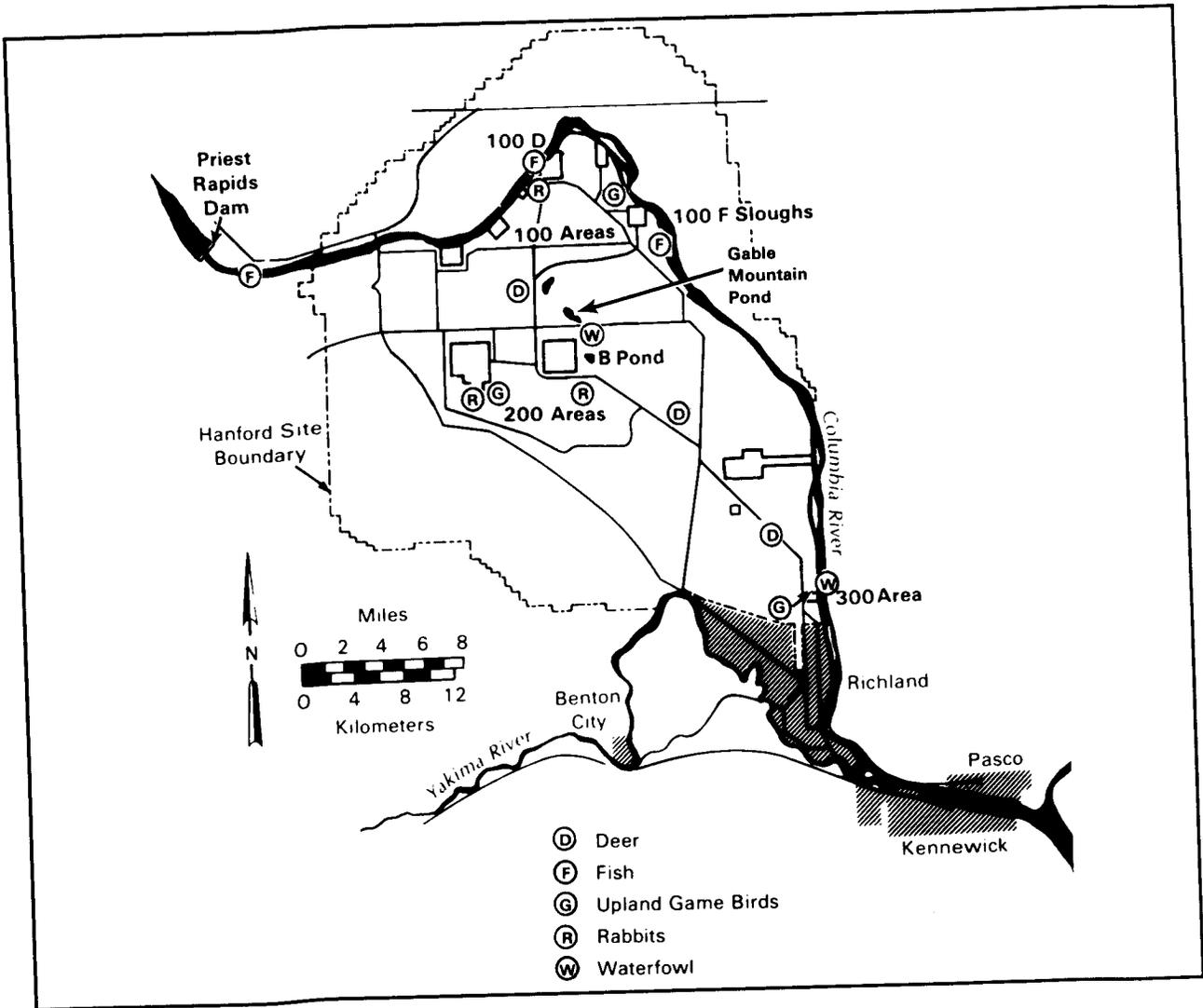


FIGURE 3.40. Wildlife Sampling Areas

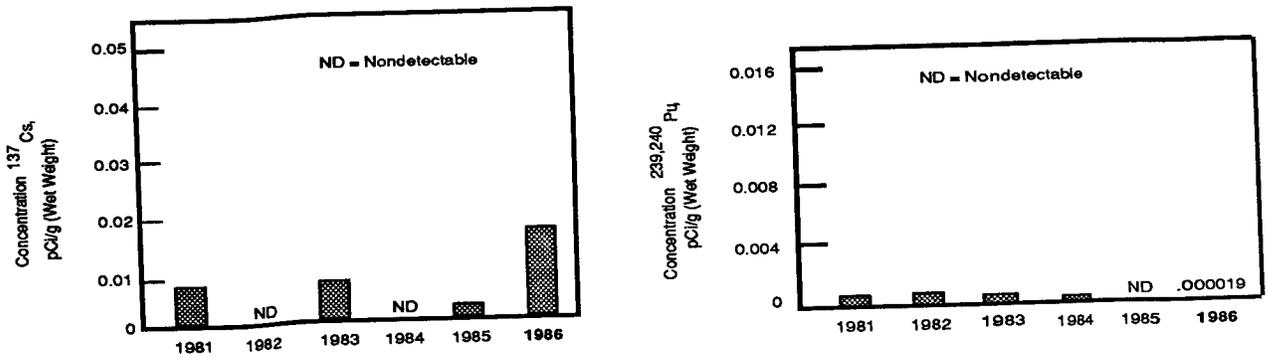


FIGURE 3.41. Median Concentrations of ¹³⁷Cs and ^{239,240}Pu Measured in Deer Muscle and Liver, 1981 Through 1986

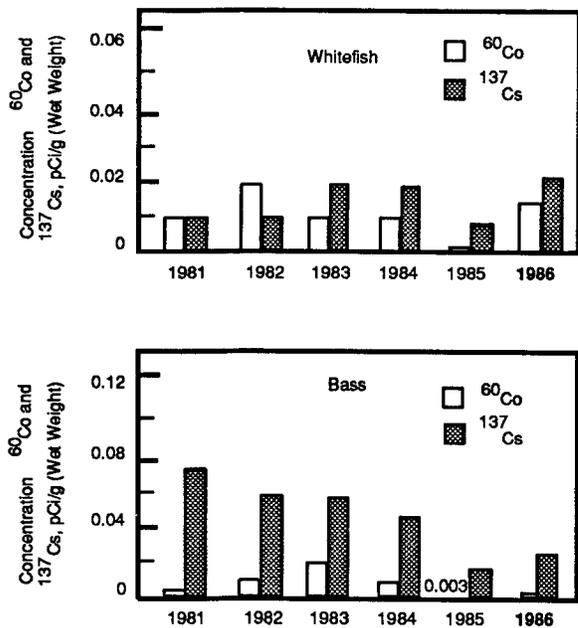


FIGURE 3.42. Median Concentrations of ^{60}Co and ^{137}Cs Measured in Whitefish and Bass, 1981 Through 1986

Figure 3.43 and are within the ranges observed during previous years. Cobalt-60 and ^{137}Cs were not detectable in the single bird collected from the 300 Area. Maximum and average concentrations for 1986 for both nuclides are shown in Table A.42, Appendix A.

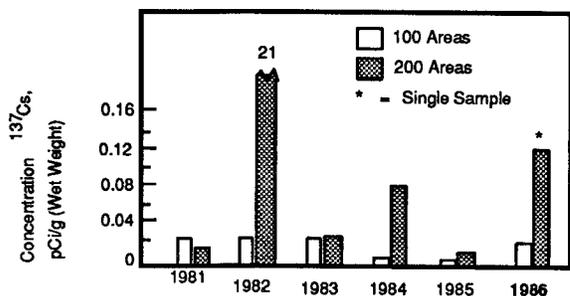


FIGURE 3.43. Median Concentrations of ^{137}Cs Measured in Mallard Ducks from B Pond, 1981 Through 1986

WATERFOWL

Mallard ducks were collected from B Pond and Gable Mountain Pond in the 200 Area and from the 300-Area trench (Figure 3.40). An approximately 0.5-kg sample of breast meat from each

bird was analyzed for ^{137}Cs . The results illustrated in Figure 3.44 show decreasing concentrations in ducks collected from B Pond over the last several years. Concentrations in samples collected from the 300-Area trench in 1986 were about one-fifth those in the 200 Area, as shown in Table A.43, Appendix A. Continued decommissioning of Gable Mountain Pond in 1986 reduced waterfowl use of it, but four ducks were collected, as noted in Table A.43, Appendix A. Cesium-137 concentrations in these ducks were less than concentrations in B Pond ducks but greater than the concentrations in 300-Area trench ducks.

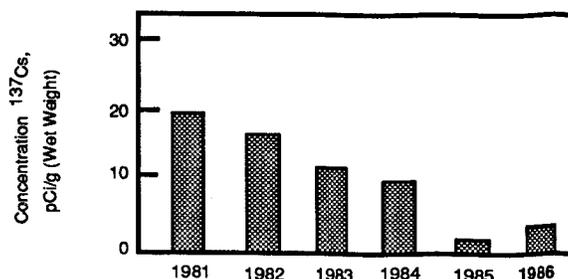


FIGURE 3.44. Median Concentrations of ^{137}Cs Measured in Mallard Ducks from B Pond, 1981 Through 1986

RABBITS

Cottontail and black-tailed jack rabbits were collected near the 100 and 200 Areas during 1986. The samples were analyzed for gamma-emitting radionuclides in muscle, ^{90}Sr in bone, and $^{239,240}\text{Pu}$ in liver. Median concentrations for ^{90}Sr in bone and ^{137}Cs in muscle for the last several years are shown in Figures 3.45 and 3.46. Median concentrations in 1986 were within the range of previous years. Maximum and average concentrations for 1986 are shown in Table A.44, Appendix A.

No other gamma-emitting radionuclides of possible Hanford origin were detected in any samples at levels greater than expected from worldwide fallout. Concentrations of $^{239,240}\text{Pu}$ in liver samples ranged from values near the detection limit (0.0006 pCi/g) to 0.001 pCi/g for one sample.

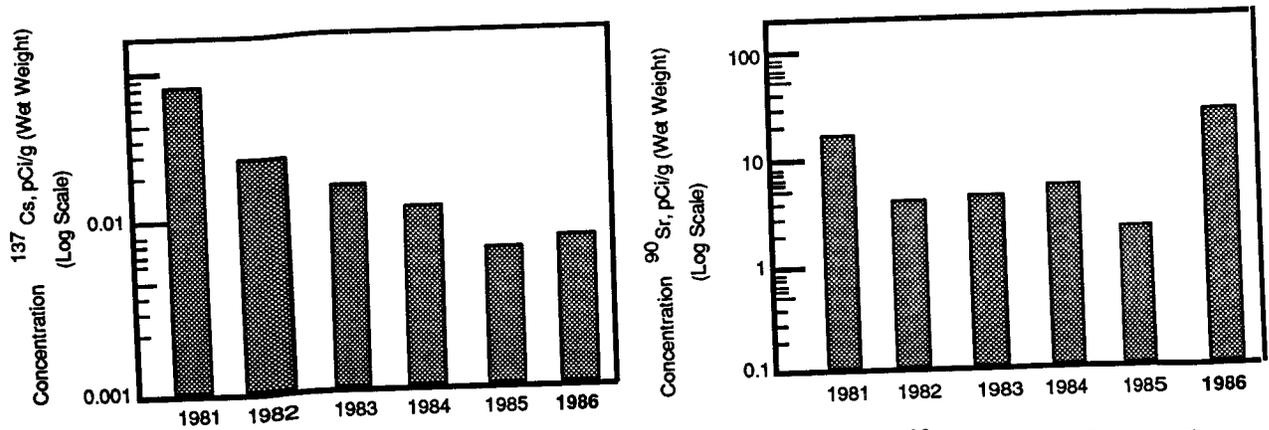


FIGURE 3.45. Median Concentrations of ^{137}Cs Measured in Muscle and ^{90}Sr in Bone of Cottontail Rabbits in the 100 Area, 1981 Through 1986

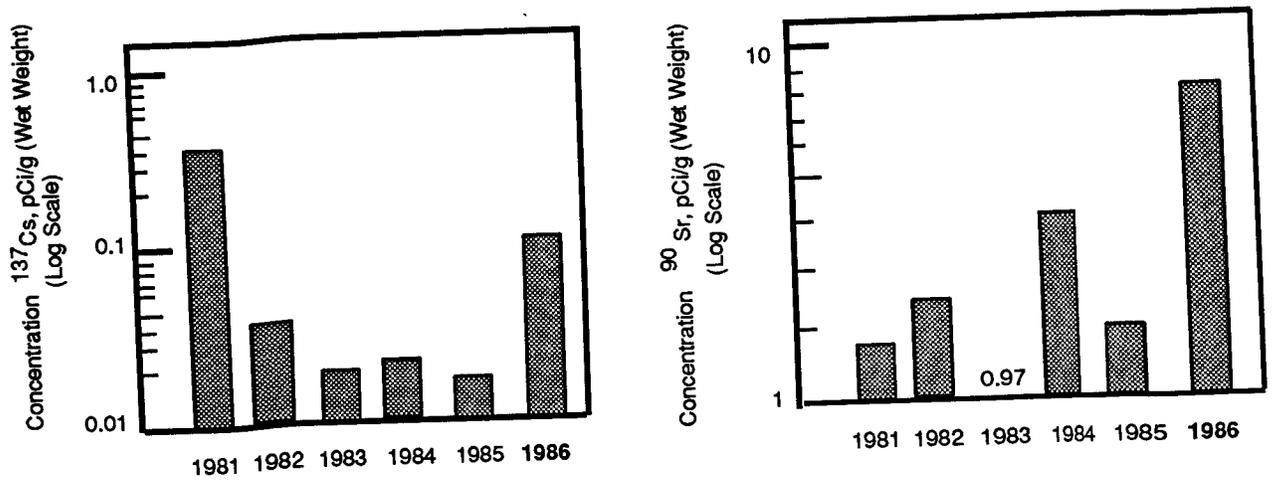


FIGURE 3.46. Median Concentrations of ^{137}Cs Measured in Muscle and ^{90}Sr Measured in Bone of Jack Rabbits in the 200 Areas, 1981 Through 1986

3.6 SOIL AND VEGETATION MONITORING

K. R. Price

Surface soil and rangeland vegetation samples were collected at a number of locations during 1986, both on the Site and off. The purpose of sampling was to detect the buildup of radionuclides from the deposition of airborne effluents released from Hanford facilities. Samples were collected at nonagricultural, undisturbed sites so that natural deposition and buildup processes would be represented. Because the radionuclides of interest were present in worldwide fallout or occurred both naturally and in Hanford effluents, their presence, to some extent, was expected in all samples. A major complicating factor for the 1986 monitoring was the deposition of radionuclides from the Chernobyl incident onto some soil and vegetation samples.

An assessment of radionuclide contribution from Hanford operations was made by comparing the 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, sample results obtained from each location in 1986 were compared to results obtained from the same location in previous years. Evaluations of 1986 sample results provided no indication of significant trends or important increases in the concentrations of radionuclides in the offsite environment that could be attributable to Hanford operations. Results from special soil samples collected downwind from Hanford did not indicate a measurable buildup of Hanford-derived radionuclides.

SAMPLE COLLECTION AND ANALYSIS

Soil and vegetation samples were collected at the 15 onsite and 16 offsite locations shown in Figure 3.47. In addition, five new soil sampling sites were established, at the communities of Moses Lake, Washtucna, Connell, Othello, and Yakima. Most of the onsite sampling locations were adjacent to major operating areas, where the contribution of radionuclides from operations could be readily assessed. The majority of the offsite samples were collected around the perimeter of the Site and in a generally downwind direction, where any Hanford contribution to radionuclide levels in soil and vegetation would be expected to be most easily detected. Samples were also collected in a generally upwind direction and at distant locations for comparison. The locations of the special soil samples collected downwind of Hanford are shown in Figure 3.48.

Single composite samples of surface soil were collected at each location. Each sample was made up of five "plugs" of soil, approximately 2.5 cm deep and 10 cm in diameter, obtained within a 100-m² area at the sampling site. The samples were dried, sieved through a 2-mm screen, and

thoroughly mixed. Aliquots of this well-mixed, composite sample were analyzed for gamma-emitting radionuclides, ⁹⁰Sr, ^{239,240}Pu, and uranium.

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

Soil Results

Analytical results from soil samples collected on the Site and off during 1986 are reported in Tables A.45 through A.48, Appendix A. Also included in these tables are the individual results observed during the previous 5 years for each specific location. For comparative purposes, the

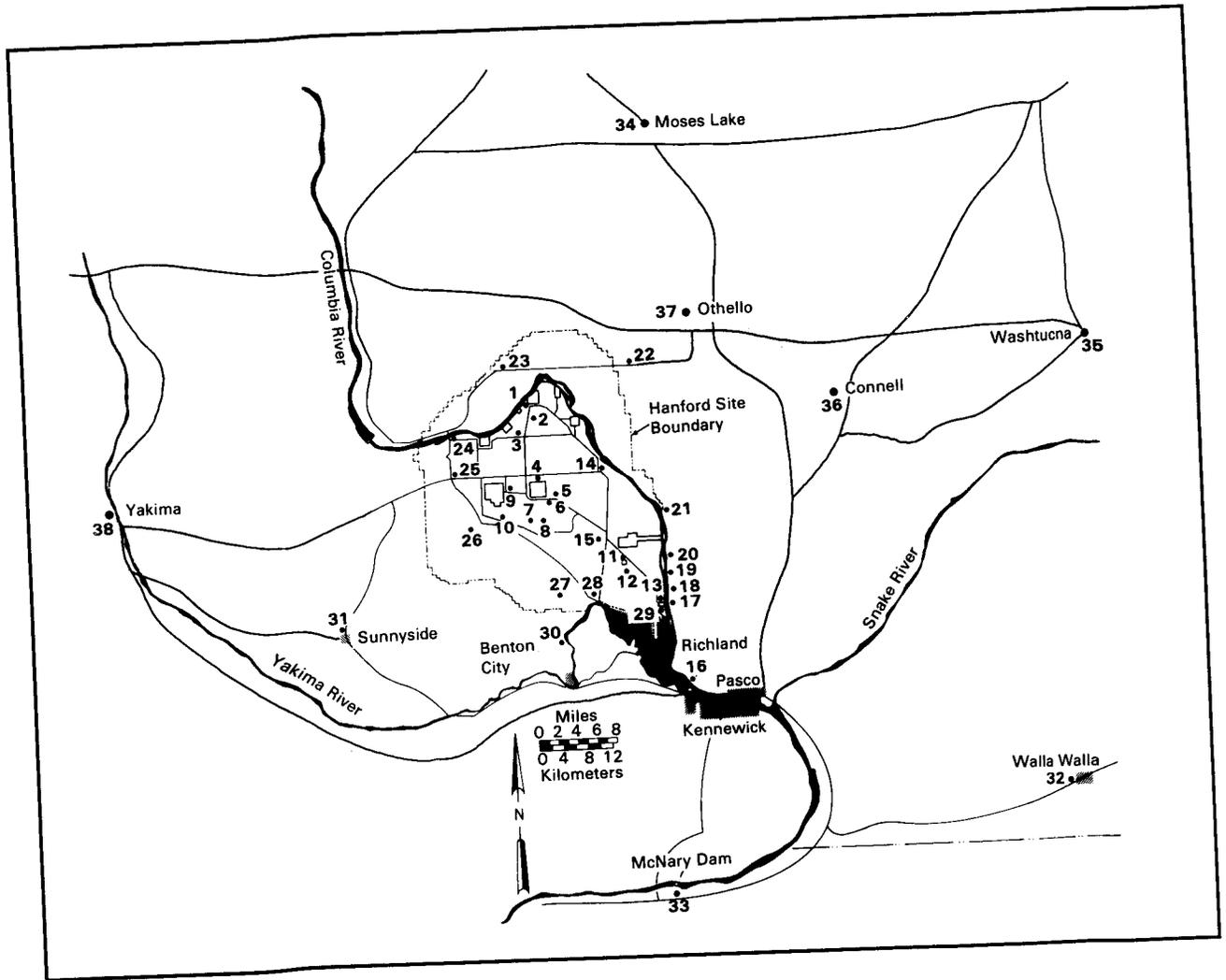


FIGURE 3.47. Onsite and Offsite Sampling Locations for Soil and Vegetation Samples

means of the results from all onsite locations and all offsite locations are provided. New sample locations were established in 1982, 1985, and 1986 as a result of program revisions and expansions.

Radionuclide concentrations observed in individual onsite soil samples during 1986 were similar to those observed in previous years. Although some variability was evident between sampling locations, the means of onsite soil sample results for specific radionuclides were similar to those observed during previous years. As expected, locations near operating areas, the 200 Area in particular, continued to show slightly elevated concentrations for a few radionuclides. Specifically, the 200E NC (Figure 3.47, Number 4) sample showed elevated levels of ^{90}Sr and ^{137}Cs , and the sample taken east of 200W (Figure 3.47,

Number 9) exhibited elevated levels of ^{239}Pu , ^{240}Pu , as has been the case in previous years.

The offsite soil sample results were similar to those collected during the past several years, as reflected in both the individual sample results and the mean of all offsite sample results. The histograms in Figure 3.49 display median values for ^{90}Sr , ^{137}Cs , $^{239,240}\text{Pu}$, and uranium for all samples collected at onsite and offsite locations during 1986. The median values rather than the means are plotted because of the small number of samples and the high degree of variability in the results. Radionuclide concentrations tended to be slightly higher at onsite locations than at offsite locations. In previous years, the offsite uranium concentrations in soil were slightly higher than those observed on the Site. Uranium was thought to occur naturally in the soil at

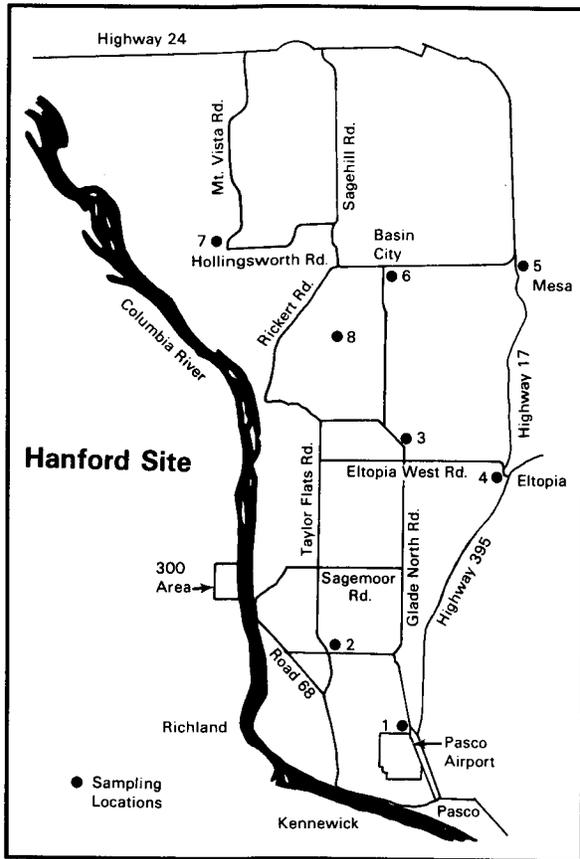


FIGURE 3.48. Locations of Special Soil Samples Collected Downwind of Hanford

several offsite sampling locations. Ten of the 21 offsite soil samples were collected after fallout from Chernobyl had arrived; these samples showed traces of ^{131}I (median=0.07 pCi/g). Iodine-131 is not normally observed in soil samples because it is not a major gaseous discharge from Hanford facilities, and because it has a half-life of only 8 days.

Further evaluation of the offsite sample results indicated that, with the exception of uranium, the radionuclide concentrations in soil collected at locations near the Hanford Site were similar to those collected at distant locations. Likewise, sample results from offsite locations generally downwind were similar to those from locations generally upwind. As has been observed in the past, radionuclide concentrations in soil were quite low and were in agreement with concentrations observed at other locations, although they appeared to be highly variable over time at a single location.

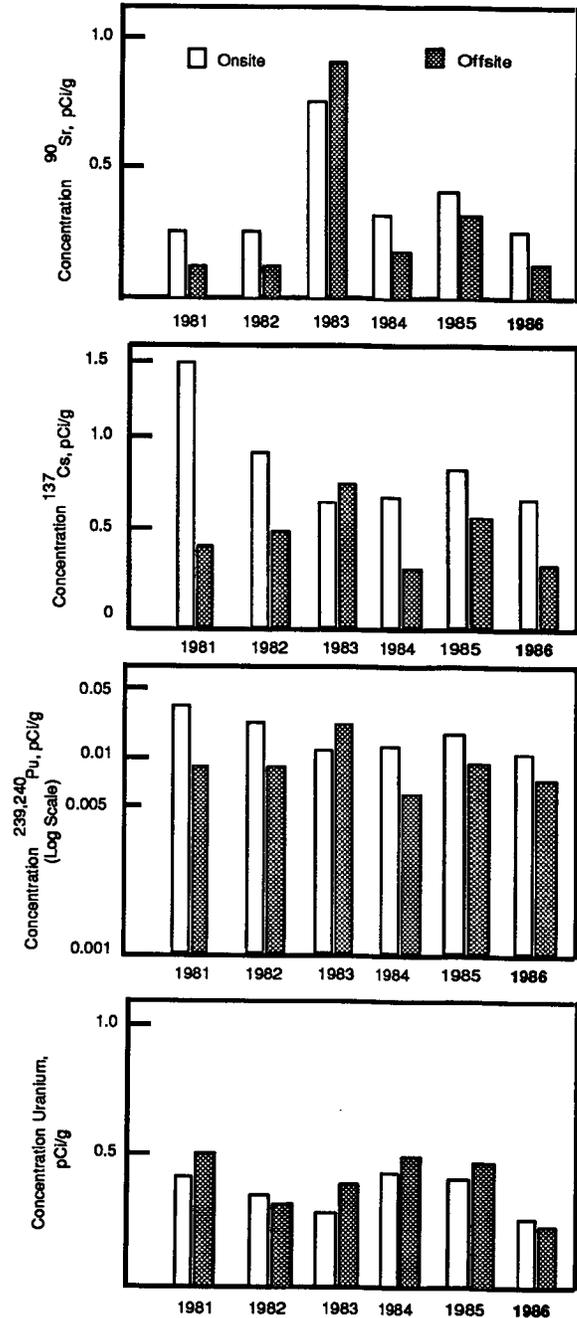


FIGURE 3.49. Median ^{90}Sr , ^{137}Cs , ^{239}Pu , and Uranium Concentrations Measured in Soil at All Onsite and Offsite Locations, 1981 Through 1986

SPECIAL DOWNWIND SOIL SAMPLES

Eight soil samples were collected at special downwind locations during 1986 to further assess the possible impacts of current and past releases of radioactive materials from Hanford operations. The samples were collected from an area extending from north of the Pasco airport to Basin City and from the Columbia River to the towns of Eltopia and Mesa. The specific locations are noted in Figure 3.48. Standard soil sampling and analytical techniques were used. Samples were analyzed for gamma-emitting radionuclides, ^{90}Sr , $^{239,240}\text{Pu}$, and uranium. Results are given in Table A.49, Appendix A. Individual results were similar to radionuclide concentrations noted for soil samples collected at other offsite locations during 1986.

VEGETATION RESULTS

Analytical results from samples of mature, perennial vegetation collected during 1986 are provided in Tables A.50 through A.53, Appendix A. As noted, samples from six locations were analyzed only for gamma-emitting radionuclides (i.e., ^{137}Cs) in 1986 and not for ^{90}Sr , ^{239}Pu - ^{240}Pu , or uranium. Six additional offsite sampling locations at distant communities were sampled in 1986 and analyzed for gamma-emitting radionuclides only. As with the soil-sample results, individual results observed during the previous 5 years at each location are given in the tables, along with the mean of the results for the same time period. The means of onsite and offsite sample results are also included for comparative purposes. New sample locations were added in 1982, 1985, and 1986.

Radionuclide concentrations observed in vegetation samples collected on the Site and off in 1986 were similar to those observed at the same locations during previous years, except where samples were collected after the arrival of fallout from the Chernobyl incident. Figure 3.50 provides histograms illustrating the median values of ^{90}Sr , ^{137}Cs , $^{239,240}\text{Pu}$, and uranium for all samples. Figure 3.51 is a histogram showing median values of gamma-emitting radionuclides in offsite samples collected after Chernobyl. Onsite samples were collected before the arrival of Chernobyl fallout. Cesium-137 was the only gamma-emitting radionuclide detected under normal conditions; the other radionuclides shown in Figure 3.51 were a result of Chernobyl

fallout. Traces of $^{239,240}\text{Pu}$ and uranium were not present in the fallout; therefore, they were not detected in vegetation samples. As with the soil data, concentrations of ^{90}Sr and $^{239,240}\text{Pu}$ in onsite vegetation were slightly elevated compared with offsite concentrations. Uranium

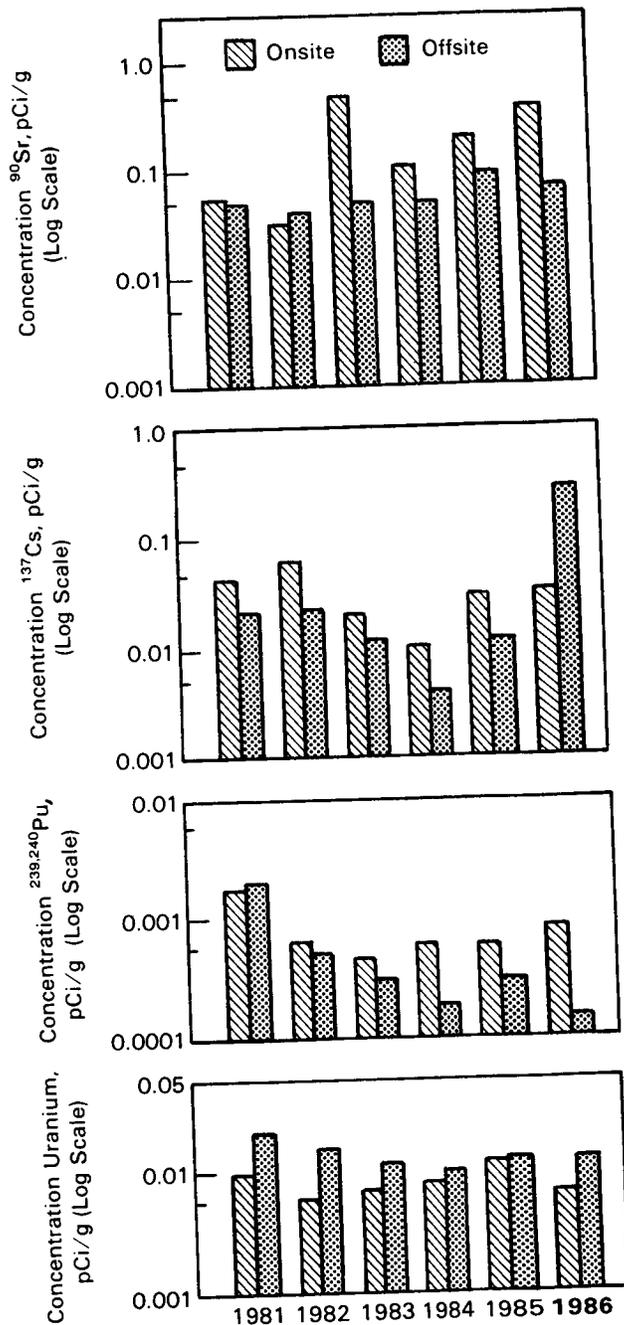


FIGURE 3.50. Median ^{90}Sr , ^{137}Cs , $^{239,240}\text{Pu}$, and Uranium Concentrations Measured in Vegetation at All Onsite and Offsite Locations, 1981 Through 1986

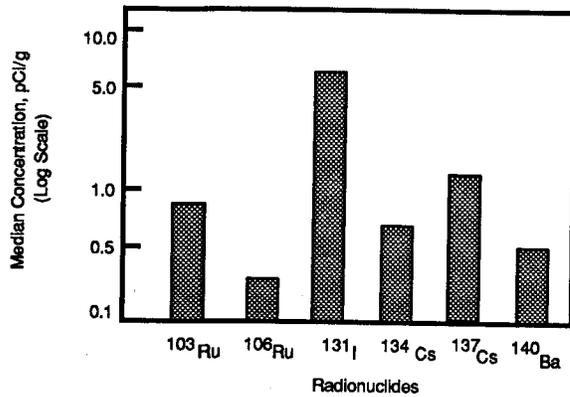


FIGURE 3.51. Median Concentrations of Radionuclides Measured in Vegetation After the Chernobyl Incident

concentrations in vegetation, however, were slightly higher at offsite locations than at onsite locations.

Ground water containing ^3H is widely dispersed in the unconfined aquifer beneath the

Hanford Site (see "Ground-Water Monitoring"). In most instances, the ground water is too deep for contact by plant roots. Trees are scarce on the Site, with only a few native trees near the river and some introduced trees growing near former homesites.

A group of black locust trees growing near the 100K Area were planted before the Hanford Site was established in 1943. The trees have not been irrigated since 1944, nevertheless, they have survived to date. It was thought that the roots had access to a source of ground water, enabling the trees to survive the hot, dry summer months. This was confirmed when a well was bored near the grove in April 1986. The water level was approximately 7.7 m below the ground surface.

The tritium concentration of the well water was 4500 pCi/L, which remained stable throughout the summer. The tritium concentrations in leaf water collected from a tree growing near the well were variable, with a peak value of 10,000 pCi/L in August 1986.

3.7 PENETRATING-RADIATION MONITORING

L. A. Rathbun

Dose rates from penetrating radiation (gamma-rays) were measured at a number of locations in the Hanford environs during 1986. The measurements were made using thermoluminescent dosimeters (TLDs) to provide estimates of the dose rates from external radiation sources. Naturally occurring sources, including cosmic radiation and natural radioactive materials in the air and ground, as well as worldwide fallout, resulted in penetrating radiation being recorded at all dosimeter locations. The dosimeters also measured dose rates from exposure to radioactive materials associated with activities at Hanford. Measurements made on the Site and off were similar to those of past years. As expected, dose rates near operating facilities were somewhat higher than natural background rates.

Radiation surveys were conducted at numerous locations on the Hanford Site. Onsite roads, railroads, and retired waste-disposal sites located outside of operating areas were routinely surveyed during 1986. These surveys were designed to identify areas where levels of radioactivity were abnormal. Survey results for 1986 were comparable to those of past years. No unexpected or abnormal conditions were observed on Site highways or railroads.

PENETRATING-RADIATION MEASUREMENTS

External radiation measurements were made using environmental TLDs at numerous locations on the Site, around the perimeter of the Site, in nearby and distant communities, and along the shoreline of the Columbia River. Environmental radiation dosimeters consisted of five $\text{CaF}_2:\text{Mn}$ thermoluminescent chips encased in a plastic capsule. The capsule contained a lead/tantalum filter to provide uniform dose response characteristics for penetrating radiation above 60 keV (Fix and Miller 1978). The 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^(a). The TLDs record radiation exposure

from natural and fallout sources, as well as any local contribution (NCRP 1975).

Dosimeters were placed at numerous locations in the vicinity of the Hanford Site and at several locations more distant from the Site, as shown in Figure 3.52. The dose rates measured at each location during 1986 are given in Table A.54, Appendix A. Offsite dosimeter locations were chosen to represent areas that could have been inhabited continuously. Dose measurements at these locations are reported in units of mrem/yr. Results were similar to those observed in previous years for the same locations. The background dose rate, calculated from the annual average dose rates observed at distant locations, was similar to that seen last year at 60 mrem/yr (0.007 mrem/h). Dose rates measured at Seattle and Spokane in 1985 by the Washington State Department of Social and Health Services (DSHS) were 56 mrem/yr and 88 mrem/yr, respectively (DSHS 1985). Figure 3.53 shows average annual dose rates measured at perimeter and distant locations during 1986 and the previous 5 years. The figure illustrates the natural year-to-year variability of penetrating radiation in the environs at both nearby and distant locations. The figure also shows that dose rates at perimeter stations generally averaged several mrem/yr higher than at the distant locations. The differences may have been caused by natural geographic variations in terrestrial radiation.

(a) Because the dosimeter is used in a multi-energy beta/gamma radiation field (the environment near Hanford) that differs considerably from calibration conditions (^{137}Cs photons in air), the conversion factor relating mrem to mR may not be exactly 1.0. Nonetheless it is assumed to be 1.0 throughout this report

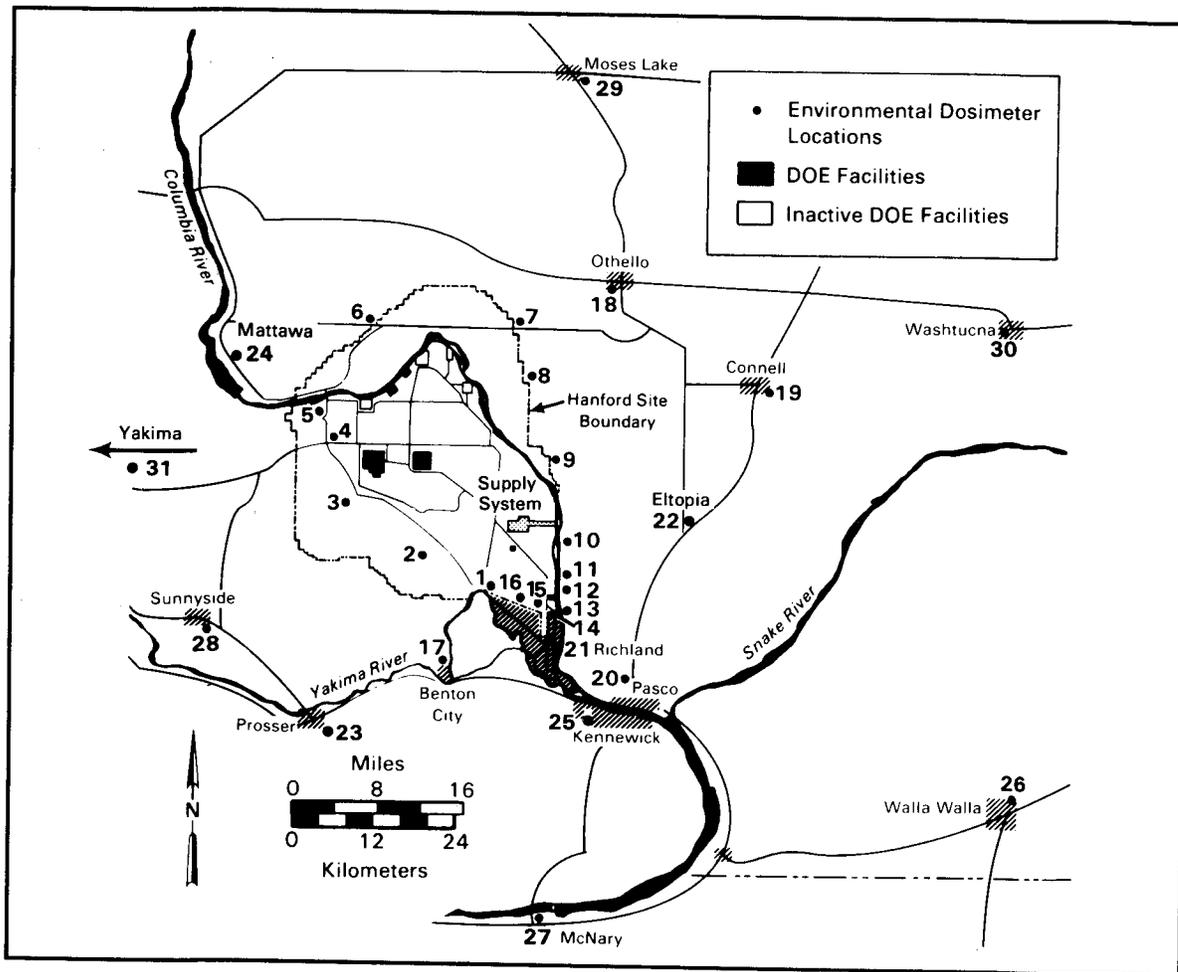


FIGURE 3.52. Environmental Dosimeter Locations at the Site Perimeter, Nearby Communities, and Distant Communities (see Table A.54, Appendix A for location number key)

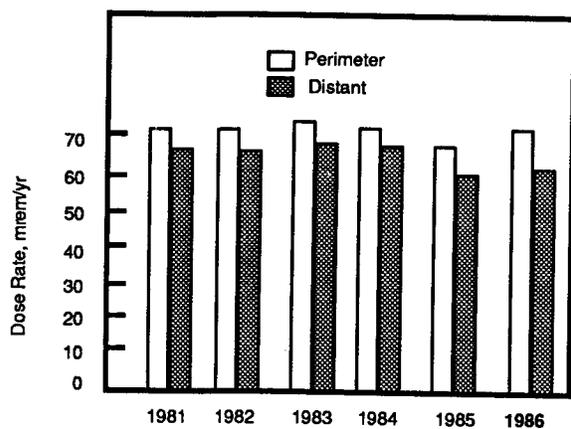


FIGURE 3.53. Annual Average External Dose Rates Measured at Perimeter and Distant Locations, 1981 Through 1986

Dosimeters were submerged in the Columbia River at Coyote Rapids and at the Richland Pumphouse (Figure 3.54) to provide an estimate of penetrating dose rates that could be received by a person immersed in the river. The measurements, shown in Table A.55, Appendix A, indicated a dose rate less than the background dose rate of 0.008 mrem/h measured on land. The average dose rates at the Coyote Rapids and Richland pumphouse locations were 0.005 and 0.004 mrem/h, respectively, during 1986. As expected, these dose rates have remained low and relatively constant over the years.

Dosimeters were placed at several publicly accessible locations near the perimeter of operating areas on the Hanford Site, as shown in Figure 3.55. These locations included the

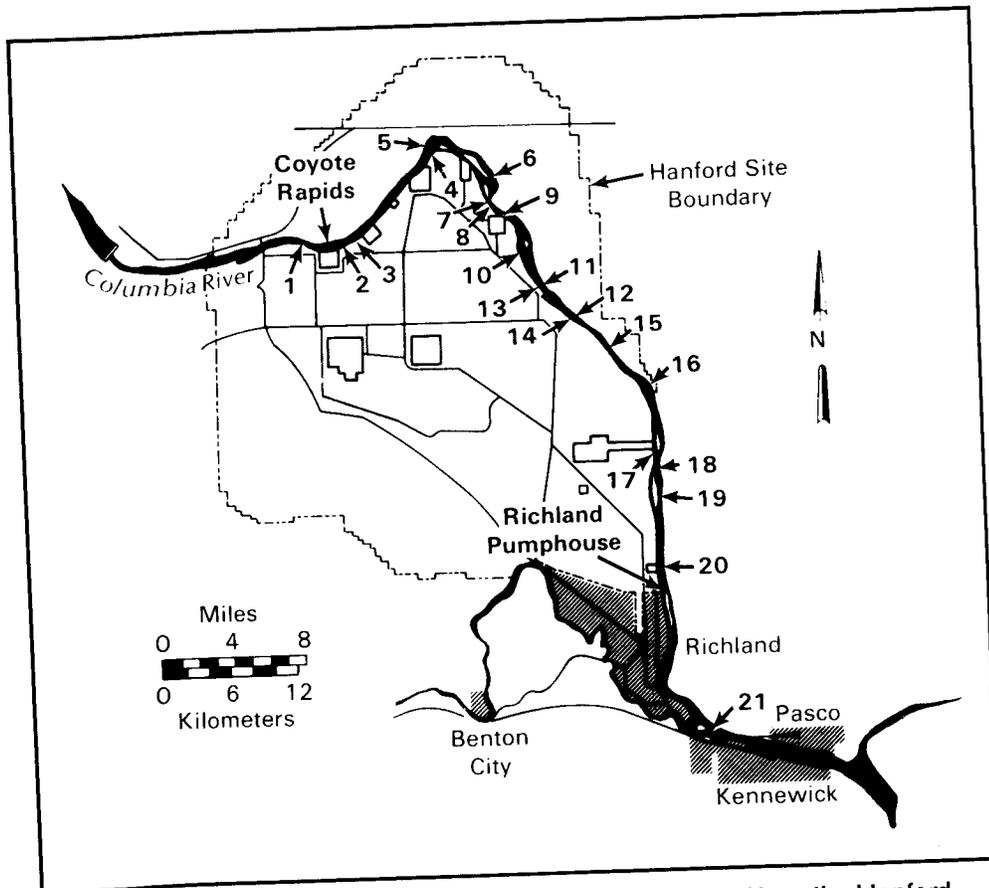


FIGURE 3.54. Environmental Dosimeter Locations Along the Hanford Reach of the Columbia River (see Table A.57, Appendix A for location number key)

shoreline of the Columbia River near the 100N Area, parking lots near the west perimeter of the 300 Area, and the parking lot near the Visitors' Center at the 400 Area (FFTF). Results of these measurements for 1986 are shown in Table A.56, Appendix A. Results are reported as mrem/h (instead of mrem/yr) because the locations are not continuously occupied by the same person. Dose rates near the 100N Area on the river shoreline were slightly elevated but similar to those observed in previous years. The maximum dose rate recorded near the 100N Area was 0.046 mrem/h, while the average varied between 0.023 and 0.035 mrem/h. Dose rates in this vicinity were attributed to waste-management activities within the 100N Area. Dose rates at publicly accessible locations along the west perimeter of the 300 Area were slightly elevated compared to normal background levels of 0.008 mrem/h. The highest dose rate measured along the west perimeter of the 300 Area was 0.023 mrem/h, recorded at a location near a

research facility housing a radioactive steam generator currently under study. The average dose rate at the other 300-Area perimeter location near a publicly accessible area was also higher than background levels (0.014 mrem/h). The dose rate near the Visitors' Center at the 400 Area (FFTF) was at the background level, indicating that the penetrating radiation at this location could not be attributed to FFTF activities during 1986.

Low levels of residual radioactivity (primarily ^{60}Co and ^{154}Eu) from past reactor operations in the 100 Areas were measured at several locations along the shorelines and on islands in the Hanford reach of the Columbia River. Radiation dose rates from these radionuclides were the subject of an extensive radiological survey in 1979 (Sula 1980). In 1980, based on findings of the survey, dosimeters were placed in areas along the river (see Figure 3.54) where dose rates were determined to be slightly elevated

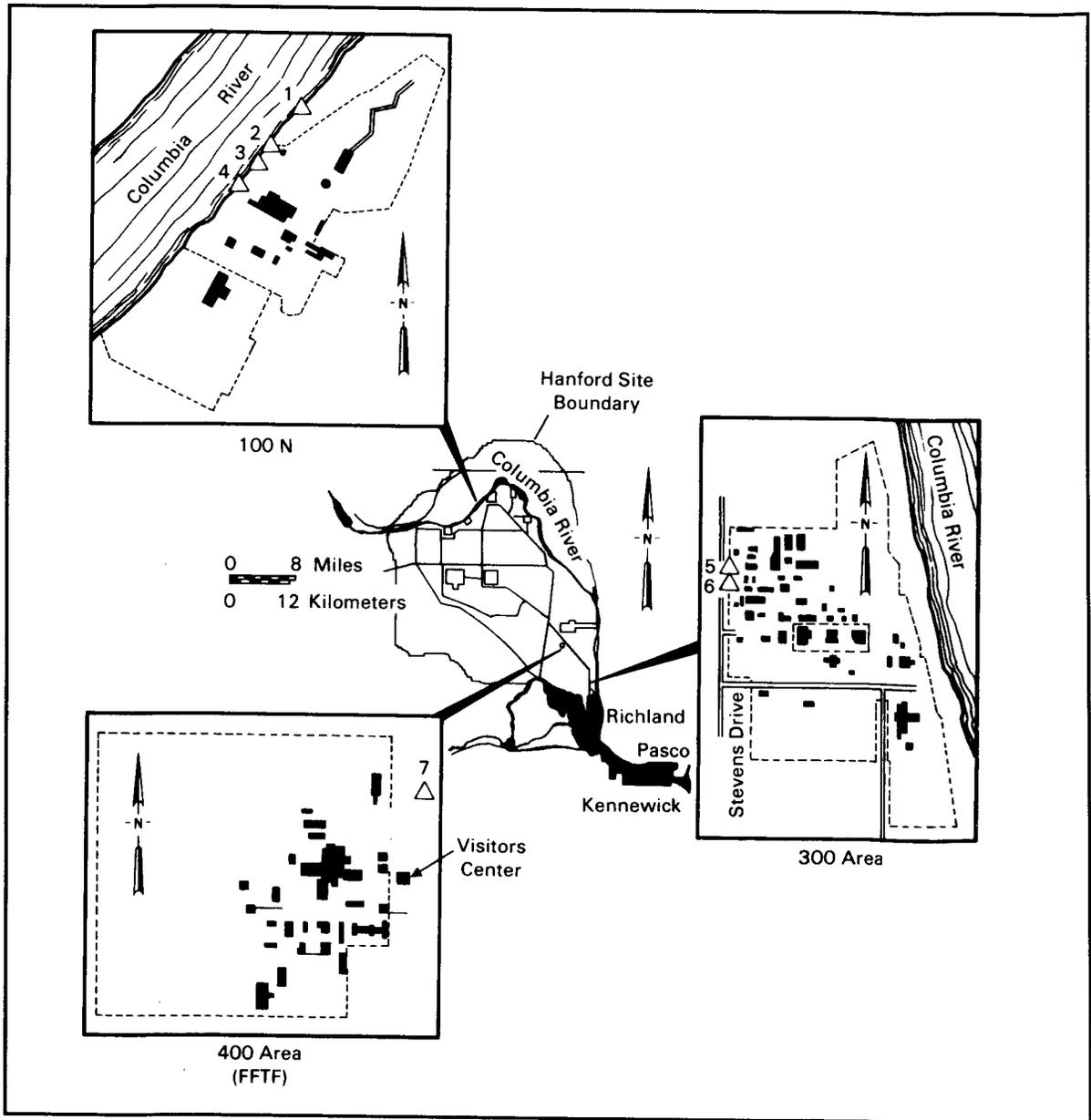


FIGURE 3.55. Environmental Dosimeter Locations at Publicly Accessible Onsite Locations (see Table A.56, Appendix A, for location number key)

with respect to background levels. Table A.57, Appendix A, provides results of measurements taken at these locations during 1986. Dose rates measured during 1986 were similar to those observed in recent years.

Onsite external penetrating radiation was measured at the locations shown in Figure 3.56. The results of these measurements are given in Table A.58, Appendix A. Dose rates above background levels were observed at several locations on the Site during 1986. The rate in excess of the background level observed near

the 100N Area was attributed to short-lived, airborne noble gases and direct radiation from reactor operations and waste-handling and storage facilities. Dose rates at two of the 300-Area locations (locations 15 and 16 of Figure 3.56) were higher than background levels during 1986. These locations were near the facility where the steam generator was being examined, which would account for the higher-than-background levels. Dose rates around the 200 and 400 Areas were within the expected background levels.

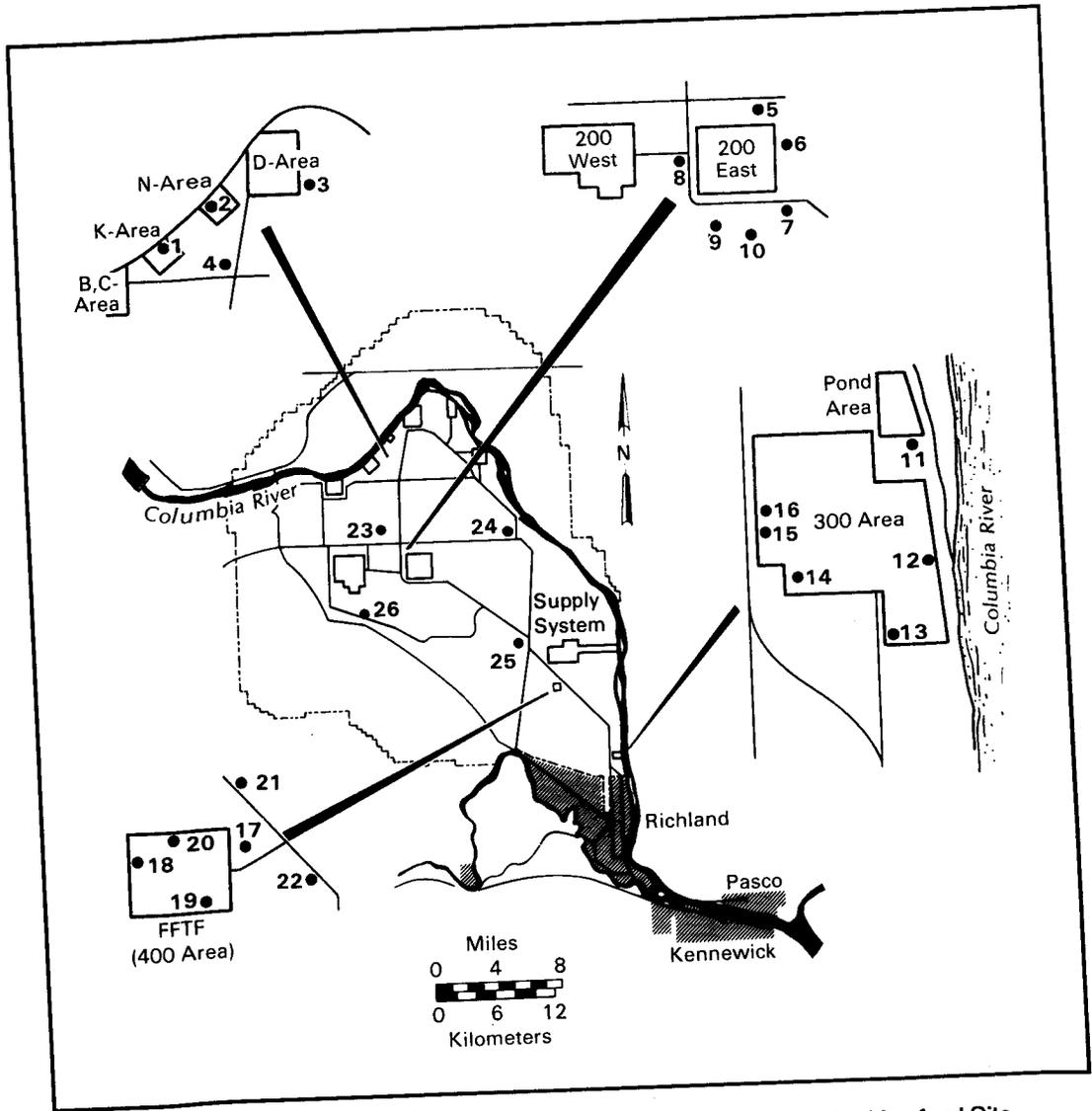


FIGURE 3.56. Environmental Dosimeter Locations on the Hanford Site (see Table A.58, Appendix A, for location number key)

RADIATION SURVEYS

Onsite roads, railroads, and inactive radioactive-waste disposal sites located outside of operating areas were routinely surveyed during 1986 to detect abnormal levels of radioactivity. The frequency of the surveys on specific routes for roads and railroads was based on their use and the potential for their contamination. The majority of the waste sites were surveyed twice during 1986. Specific routes and frequencies for surveys conducted during 1986 were defined in a master schedule.

The roads shown in Figure 3.57 were surveyed routinely using four scintillation detectors positioned approximately 0.5 m above the ground, evenly spaced across the width of a vehicle. No abnormal conditions were observed on the Site roadways surveyed during 1986. Railroad routes, also shown in Figure 3.57, were surveyed using a small railcar with two scintillation detectors mounted approximately 0.3 m directly above the tracks. Railroad surveys conducted during 1986 did not reveal any abnormal conditions on the Site railways.

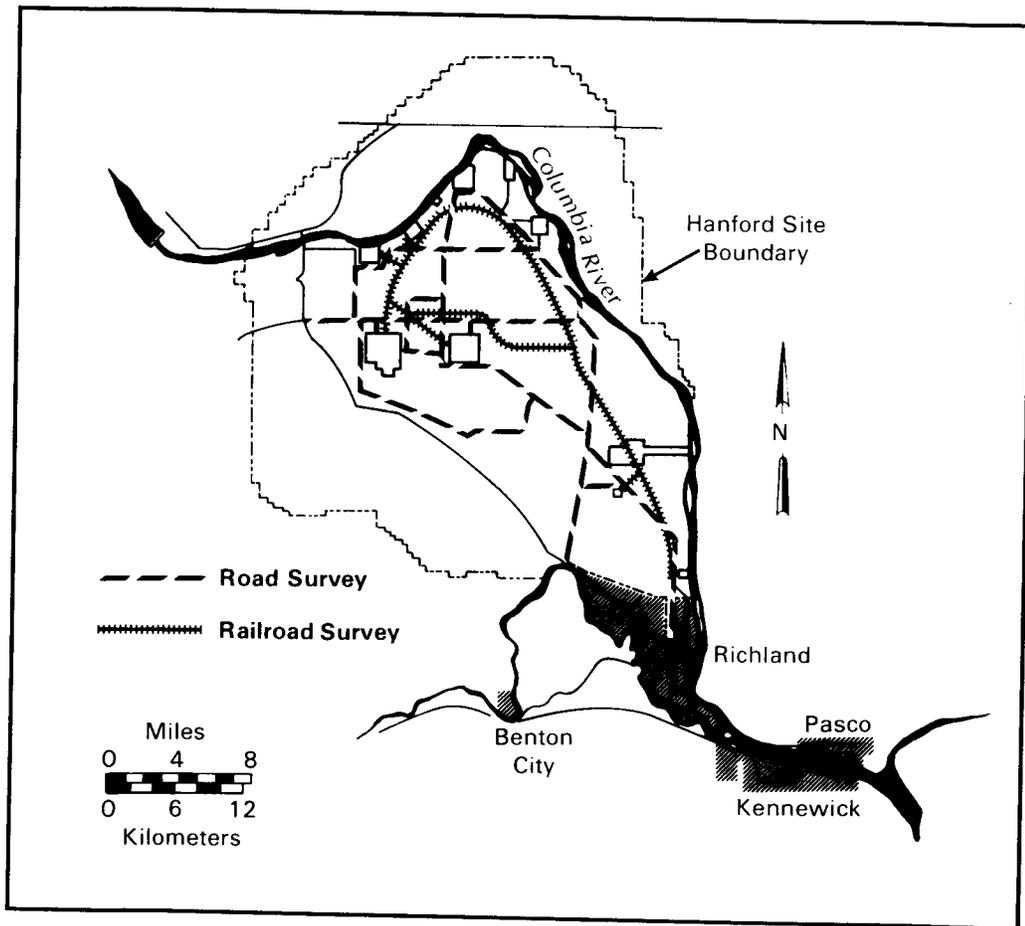


FIGURE 3.57. Road and Railroad Survey Routes

Inactive waste-disposal sites outside of the operating-area perimeter fences were surveyed during 1986 with portable instruments to detect changes in the levels of external radioactivity. The general physical conditions of the sites were also visually inspected. In general, radiation

surveys conducted during 1986 showed levels comparable to those observed in the past. Any problems with respect to the maintenance of the integrity of the Site were promptly reported to the responsible contractor for appropriate corrective action.

3.8 COMPARISON OF MEASURED AND CALCULATED RESULTS

R. E. Jaquish

Measurements of radiation levels and radionuclide concentrations in the environment were used to estimate the radiological impact of Hanford operations. However, the quantities of radionuclides released to the environment were usually small, and frequently it was not possible to measure radioactivity attributable to Hanford operations. For dose calculation purposes, environmental concentrations of radionuclides in air, water, and other media were calculated based on the quantities released in various effluents. To verify that the calculated environmental concentrations used in the dose models were reasonable, the concentrations of radionuclides that could be measured in air and water were compared with calculated values. The calculated concentrations used for radiological dose assessment were verified as reasonable estimates.

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

Table 3.9 lists the major nuclides contributing to the radiological dose impact of Hanford operations' monitored liquid effluents to the Columbia River. It also compares the calculated concentrations with the measured concentrations. The Richland Pumphouse was used as the downstream station for comparing concentrations. Measurements taken at Priest Rapids Dam were used as the background to be subtracted to obtain the net change in concentration. For ^{60}Co , ^{89}Sr , ^{131}I , ^{137}Cs , and $^{239,240}\text{Pu}$, the calculated concentrations were so low that no increase resulting from effluents could be detected. The calculated concentration correspond with the measured concentrations at the Richland Pumphouse, which show no significant increase in the concentrations of these nuclides. (A minus concentration indicates concentrations at the Richland Pumphouse were lower than at the background station.) For ^{90}Sr , the calculated concentration was low, but at a level that

could be detected by the measurement technique. However, the concentration measured was lower than that calculated. The only nuclide measured that had a statistically significant increase in concentration over the background station was ^3H . The calculated added concentration was 2.3 pCi/L, but the measured difference was 50 pCi/L. This difference indicates that there was an additional source of ^3H along the Hanford reach, presumably the ground water. (See "Ground-Water Monitoring".)

Surface-water monitoring results (see Tables A.13 and A.14) indicate increased concentrations of ^{129}I and uranium. These nuclides were not identified in monitored liquid effluents. The source of these was assumed to be from natural sources and ground-water seepage directly entering the River. (See "Ground-Water Monitoring".)

A similar comparison for airborne radionuclides was made by calculating the concentrations for the perimeter monitoring location nearest the Site (Ringold) and comparing these values with the average measured concentration at the perimeter. The average results for distant stations were used as the background level to be subtracted from the perimeter results to obtain the net concentration contributed by Hanford effluents. The 1986 average dispersion (X/Q) values were used for these calculations (see Tables F.5 to F.8, Appendix F). Table 3.10 lists the major airborne effluents from the 200 Area and shows the calculated and net measured concentrations at the perimeter location. For ^3H , ^{90}Sr , ^{131}I , ^{137}Cs , and $^{239,240}\text{Pu}$, the net measured perimeter concentration was very

TABLE 3.9. Measured and Calculated 1986 Annual Average Concentrations of Selected Radionuclides in the Columbia River (pCi/L)

Radionuclide	100 Area Releases, Ci (a)	Calculated Conc. Added Downstream	Measured Concentration at Richland Pumphouse Minus Background (b)
³ H	220	2.3	50
⁶⁰ Co	0.53	0.0055	0.004
⁸⁹ Sr	1.8	0.019	0.0
⁹⁰ Sr	0	0.083	0.01
¹³¹ I	0.13	0.0013	-0.013 (c)
¹³⁷ Cs	0.095	0.0010	-0.0002 (c)
^{239,240} Pu	0.0009	0.0000093	0.00007

(a) From Table G.5, Appendix G.

(b) From Tables A.13 and A.14, Appendix A.

(c) Negative concentration values indicate results less than the background value.

TABLE 3.10. Measured and Calculated 1986 Annual Average Air Concentrations of Selected Radionuclides (pCi/m³)

Radionuclide	200 Area Releases, Ci (a)	Calculated Perimeter Concentration	Average Measured Perimeter Concentration Minus Background (b)
³ H	60	0.028	-0.3 (c)
⁸⁵ Kr	500,000	230	63
⁹⁰ Sr	0.00071	3.3 x 10 ⁻⁷	-0.00003 (c)
¹³¹ I	0.2	0.0001	-0.01 (c)
¹³⁷ Cs	0.0087	4.0 x 10 ⁻⁶	0.0003
^{239,240} Pu	0.003	1.4 x 10 ⁻⁶	-3 x 10 ⁻⁷ (c)

(a) From Table G.1, Appendix G.

(b) From Tables A.3, Appendix A.

(c) Negative concentration values indicate results less than the background value.

low or negative, indicating no measured contribution from the Hanford effluent, which agreed with the calculated concentrations and indicated very low levels that would be below the detection levels of the measurement techniques. The calculated ⁸⁵Kr concentration was 230 pCi/m³ and the measured concentration was 63 pCi/m³. The measured concentration was the average for the perimeter stations while

the calculated concentration was for the nearest perimeter location; therefore, it would be expected that the calculated value would be higher.

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

4.0 POTENTIAL RADIOLOGICAL DOSES FROM 1986 HANFORD OPERATIONS

J. K. Soldat

An assessment was made of the radiological dose from Hanford operations during 1986. The calculated effective dose equivalent^(a) received by a hypothetical maximally exposed individual in 1986 was 0.09 mrem, compared to a value of 0.1 mrem estimated for 1985. The effective dose to the surrounding population (adding the doses to an average individual from all sources, and multiplying by the number of people in the area) was about 9 man-rem, the same value as estimated for 1985. The average per capita dose was estimated to be 0.03 mrem. The new DOE radiation standards for protection of the public are 100 mrem/yr for prolonged exposure and 500 mrem/yr for occasional annual exposures to a maximally exposed individual.^(b) All measured and calculated radiation doses were well below the applicable standards for radiation protection, and were substantially less than doses normally received from common sources of background radiation.

Radioactive materials were released into the environment as air and water effluents from Hanford operations during 1986. The potential radiation doses to the public that resulted from these releases were evaluated in detail, as required by DOE Order 5484.1 (USDOE 1981b), to determine compliance with pertinent regulations and standards.

The potential radiological impacts of 1986 Hanford operations were assessed in terms of the following:

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

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

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

- for continuity and for comparison with prior years' reports, the previously calculated cumulative doses are also reported in Appendix F.

To the extent possible, radiation dose assessments should be based on direct measurements of radiation exposure rates or radionuclide concentrations in the surrounding environment. However, the amounts of radioactive materials released during 1986 operations were usually too small to be measured directly once they were dispersed in the offsite environment. A few radionuclides could be detected in the Columbia River and in the air at sampling locations on the Site perimeter. For most radionuclides in environmental media, it was not possible to distinguish between concentrations resulting from either worldwide fallout or effluent releases from Hanford operations during 1986.

In most cases, the potential offsite radiation doses were estimated using computer models that predicted concentrations of radioactive materials in the environment from effluent releases. These models are described in Appendix F, and the reported Hanford effluents for 1986 are shown in Appendix G, Tables G.1 through G.6. The measured and estimated concentrations of selected radionuclides are compared in the section on "Environmental Monitoring Results."

The estimated potential offsite radiation doses to the public were very small. Although the uncertainty associated with the computed radiation dose calculations is not specified, it could be

relatively large because maximum parameter values (i.e., plant uptake and consumption factors) were selected for use in the models. Thus, the doses calculated using these models should be viewed as maximum estimates (made using maximizing assumptions) of the potential doses resulting from 1986 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 environmental dosimeters placed at locations of expected maximum dose rates. It does not represent the dose actually received by any member of the public but rather the radiation dose absorbed by the dosimeter. The reporting of maximum "fence-post" dose rates is required by DOE Order 5484.1.

"Fence-post" dose rates were measured in the vicinity of the 100N, 300, and 400 (FFTF) operating areas, as described in the "Penetrating Radiation Monitoring" section of this report. The 200 Area was not included because it was not accessible to the general public.

The Columbia River provides public access to an area within a few hundred meters of the 100-Area N Reactor and supporting facilities. Measurements made at the 100N Area shoreline (Table A.38, Appendix A) were consistently above background. The highest average dose rate observed along the shoreline during 1986 was 0.035 mrem/h (0.00035 mSv/h), or about five times the dose rate normally observed at offsite shoreline locations (0.007 mrem/h or 0.00007 mSv/h).

The FFTF Reactor Visitors' Center, located southeast of the FFTF Reactor building, provides public access to the 400 Area. Dose rate measurements during 1986 at this location (Table A.38, Appendix A) showed only normal background radiation levels (0.008 mrem/hr or 0.00008 mSv/h).

Dose rates along the perimeter of the 300 Area were above background levels at some locations accessible to the general public. The highest average dose rate measured was 0.017 mrem/h

(0.00017 mSv/h). The average dose rate for other 300 Area perimeter locations accessible to the public was 0.014 mrem/h (0.00014 mSv/h).

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

MAXIMALLY EXPOSED INDIVIDUAL DOSE

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

Based on 1986 environmental data, the following exposure pathways were included in the calculation of the hypothetical maximally exposed individual: inhalation and submersion in airborne effluents, consumption of foods contaminated by effluents deposited on the ground from airborne materials and by irrigation with Columbia River water, direct exposure to radionuclides deposited on the ground, use of drinking water originating from the Columbia River, consumption of fish taken from the Columbia River, and direct exposure to radionuclides while using the Columbia River for recreation. The hypothetical maximally exposed individual for 1986 was postulated to be an individual who:

- was a long-term resident in an area approximately 13 km south-southeast of the 300 Area
- consumed foodstuffs grown in the northwestern part of the Riverview district using Columbia River water for irrigation
- ingested drinking water obtained from the Pasco sanitary water system

- used the Columbia River extensively for boating, swimming, and fishing, and consumed the fish that were caught.

The doses to the hypothetical maximally exposed individual were calculated using the effluent data listed in Tables G.1 and G.5, Appendix G. The maximally exposed individual was assumed to be a long-term resident because several long-lived radionuclide effluents persist in the environment in small quantities for many years.

The calculated committed doses to specific organs and the effective doses for the maximally exposed individual are summarized in Table 4.1. These values include the doses received from exposure to liquid and airborne effluents during 1986 as well as potential exposure beyond 1986 from radionuclides deposited in the body during 1986 via inhalation and ingestion of drinking water, fish, and farm products.

The total effective dose to the hypothetical maximally exposed individual in 1986 was calculated

to be 0.09 mrem (0.0009 mSv). The primary pathways contributing to the 1986 effective dose to the maximally exposed individual were

- consumption of food irrigated with Columbia River water (35%)
- consumption of food containing radionuclides deposited from the air (29%)
- consumption of fish from the Columbia River (21%).

The effective dose limits for any member of the general public from all routine DOE operations are 500 mrem/yr (5 mSv/yr) for occasional exposures and 100 mrem/yr (1 mSv/yr) for prolonged exposure periods. The calculated effective dose for the hypothetical maximally exposed individual was 0.1% of the prolonged exposure limit. The dose limit for any individual organ is 5000 mrem/yr (50 mSv/yr). In the maximally exposed individual, the organ calculated to receive the highest dose was the thyroid (0.02% of the limit).

TABLE 4.1. Calculated Committed Doses and the Effective Dose to the Hypothetical Maximally Exposed Individual from 1986 Hanford Operations (mrem)

Pathway	50-Year Committed Dose					Effective Dose (f)
	Red Marrow	Bone Surfaces	Lung	GI (a)	Thyroid	
Air - Direct (b)	0.009	0.04	0.02	0.006	0.01	0.01
- Food (c)	0.0004	0.0008	0.0006	0.001	0.9	0.03
Water - Foods(d)	0.2	0.4	0.0003	0.004	0.005	0.03
- Drinking Water	0.009	0.02	0.0001	0.002	0.002	0.002
- River Recreation(e)	0.07	0.2	0.004	0.03	0.006	0.02
Total	0.3	0.6	0.03	0.04	0.9	0.09

(a) Gastrointestinal tract (lower large intestine).

(b) Includes inhalation, submersion, and direct exposure to ground deposition.

(c) Includes consumption of all foodstuffs contaminated via dry deposition.

(d) Includes consumption of all foodstuffs contaminated via irrigation water.

(e) Includes consumption of fish taken from the Columbia River.

(f) Effective dose compiled from the product of each organ's dose and its weighting factor. 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: 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 1986 emissions resulted in doses that were 0.04% of the whole-body dose limit and 1% of the organ dose limit. Thus, the calculated maximum hypothetical annual doses for 1986 Hanford releases were well below all applicable standards.

A comparison of the effective dose for the maximally exposed individual from 1986 Hanford operations and the doses for 1985 are shown in Figure 4.1. The effective doses for 1985 and 1986 are given in Table 4.2.

POPULATION DOSE

The regional dose from 1986 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 man-rem. The results are shown in Table 4.3, in terms of the committed organ dose and the effective dose. Site-specific population distribution characteristics, food pathway and dietary parameters,

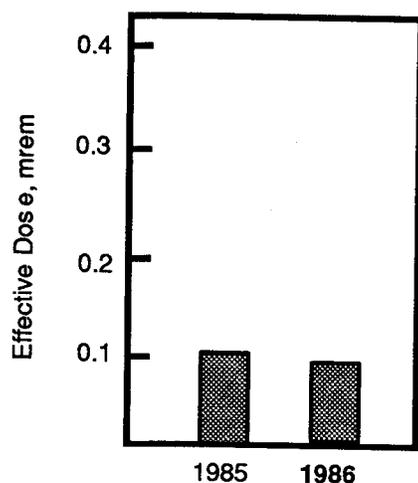


FIGURE 4.1. Calculated Effective Doses to the Maximally Exposed Individual, 1985 and 1986

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 for the population was calculated to be 9 man-rem (0.09 man-Sv) in 1986, the same as in 1985. This dose corresponds to an average per capita effective dose of 0.03 mrem (0.0003 mSv) for individuals living in the 80-km radius of Hanford.

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

The primary pathways contributing to the 1986 effective dose to the population were

- air submersion in the short-lived noble gases from the N Reactor (44%)
- consumption of foodstuffs contaminated with radionuclides released with gaseous effluents from the PUREX Plant stack (40%).

The air submersion and inhalation pathways were the primary sources of 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 1986 Hanford operations, based on the population of 340,000 within 80 km, was 0.03 mrem. 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, worldwide fallout, and a round-trip coast-to-coast airline trip. The average radiation doses from these sources and the per capita effective dose equivalent from Hanford emissions are compared in Figure 4.3. The estimated average per capita dose for individual members of the public is only a small fraction of the average per capita whole-body dose from natural background and medical sources of radiation (about 100 mrem/yr in the Tri-Cities area of Washington State).

TABLE 4.2. Calculated Committed Organ Doses and Effective Dose to the Hypothetical Maximally Exposed Individual from Hanford Operations, 1985 and 1986 (mrem)

<u>Committed Dose (a)</u>	<u>1985</u>	<u>1986</u>
Red Marrow	0.3	0.3
Bone Surfaces	0.7	0.6
Lung	0.07	0.03
GI (b)	0.09	0.04
Thyroid	1.0	0.9
Effective Dose (c)	<u>0.1</u>	<u>0.09</u>

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

TABLE 4.3. Calculated Committed Organ Doses and the Effective Doses for the 80-km Population from 1986 Hanford Operations (man-rem)

<u>Pathway</u>	<u>50-yr Committed Dose</u>					<u>Effective Dose (g)</u>
	<u>Red Marrow</u>	<u>Bone Surfaces</u>	<u>Lung</u>	<u>GI (a)</u>	<u>Thyroid</u>	
Air - Direct(b)	5	11	7	4	6	5
- Foods (c)	0.07	0.09	0.06	0.1	110	4
Water - Foods(d)	0.2	0.3	0.0004	0.003	0.005	0.03
- Drinking Water	0.4	0.8	0.006	0.004	0.06	0.08
- River Recreation (e)	0.03	0.06	0.003	0.01	0.004	0.009
Total	<u>5</u>	<u>12</u>	<u>7</u>	<u>4</u>	<u>120(f)</u>	<u>9</u>

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

TABLE 4.4. Calculated Committed Organ Doses and Effective Dose to the 80-km Population from Hanford Operations, 1985 and 1986 (man-rem)

<u>Committed Dose (a)</u>	<u>1985</u>	<u>1986</u>
Red Marrow	6	5
Bone Surfaces	31	12
Lung	13	7
GI (b)	4	4
Thyroid	98	120
Effective Dose (c)	<u>9</u>	<u>9</u>

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

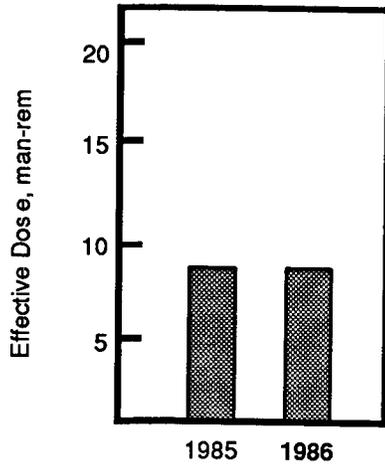


FIGURE 4.2. Calculated Effective Dose to the 80-km Population

RADIOLOGICAL IMPACT FROM PAST OPERATIONS

Columbia River

Measured levels of certain radionuclides in the Columbia River have been attributed to past operations at Hanford. (See "Surface Water Monitoring.") 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 and islands were studied by Sula (1980). Dose rates along the river were found to be slightly above normal background levels, except at a few locations where dose rates were observed to be several times background levels. (See "Penetrating Radiation Monitoring.")

Concentrations of ^3H and ^{129}I were detected in the river in 1986. Iodine-129 was detected by using extremely sensitive sampling and analytical techniques (see Tables A.30 and A.31, Appendix A). The dose from these radionuclides entering the river, based on measured differences in concentrations at Priest Rapids Dam and Richland for 1986 (see "Surface Water Monitoring"), was calculated to be an effective dose of only 0.008 mrem to a maximally exposed individual and 1.2 man-rem to the population of 340,000 people within 80 km.

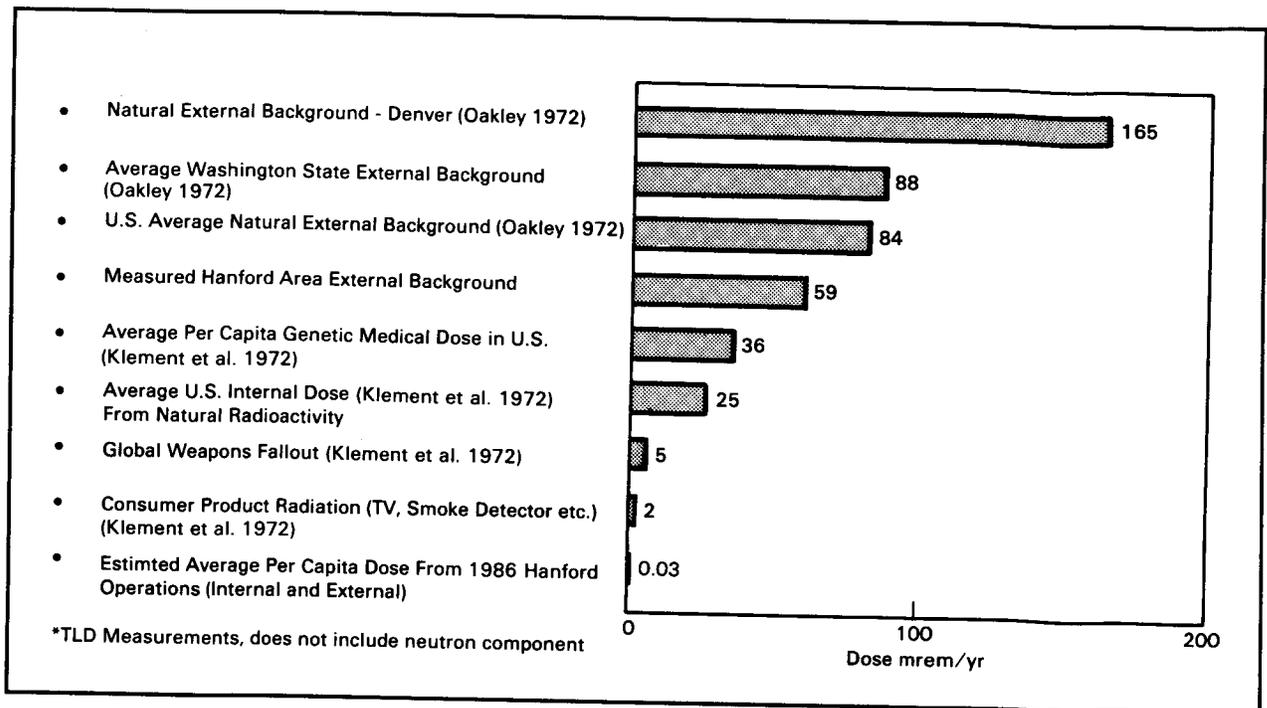


FIGURE 4.3. Annual Radiation Doses from Various Sources

The per capita dose was calculated to be 0.004 mrem (0.00004 mSv).

RADIOLOGICAL IMPACT FROM PUREX PLANT OPERATIONS

The PUREX Plant restarted operations in November 1983 and continued operations through September 1986. In addition to the dose contributions identified earlier from PUREX Plant operations, other minor dose contributions of interest are discussed here. The greatest percentage of airborne emission from the PUREX Plant in 1986 was 500,000 Ci of ^{85}Kr (see Table G.1, Appendix G). Krypton-85 is an inert gas and is not retained in environmental media or the human body. The dose from inhaling ^{85}Kr is small compared with doses from other radionuclides. Even though the curie quantity of this radionuclide was large, it was a minor contributor to the radiation dose. The average concentration of ^{85}Kr measured in 1986 at the perimeter monitoring stations was 100 pCi/m³, which was calculated to produce a potential effective dose of 0.002 mrem to an individual who was at that location 100% of the time.

In 1986, there was also 0.003 Ci of $^{239,240}\text{Pu}$ in airborne emissions from the PUREX Plant (see Table G.1, Appendix G), compared to 0.01 Ci in 1985. Plutonium-239,240 was also a minor contributor to the dose from 1986 Hanford operations, with a maximum potential effective dose of 0.002 mrem (0.00002 mSv).

RADIOLOGICAL IMPACT ON DRINKING WATER FROM WELLS

During 1986, ground water was used as the source of drinking water for the 400 Area (FFTF), the Yakima Barricade Guardhouse, and the Hanford Patrol Training Academy. Samples were collected from these systems throughout the year in accordance with applicable drinking water regulations. With the exception of tritium concentrations measured in the drinking water at the FFTF, 1986 results were similar to those observed during previous years. Tritium concentrations in the drinking water at the FFTF decreased from an average of 22,000 pCi/L in 1985 to 8,500 pCi/L in 1986 as a result of drilling a new, deeper well for the drinking water source.

The effective dose to a worker at FFTF consuming 250 L of such water during 1986 was estimated to be 0.13 mrem or 3% of the Washington State Drinking Water Standard of 4 mrem/yr. Radionuclide concentrations observed during 1986 were well below applicable drinking water limits in all cases. The monitoring results, non-radiological as well as radiological, from the Hanford Sanitary Water Quality Surveillance Program are discussed in more detail and reported annually by HEHF (Somers 1987).

5.0 QUALITY ASSURANCE

R. E. Jaquish

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

SAMPLE COLLECTION QUALITY ASSURANCE

Surface and ground-water samples were collected by trained Radiation Protection Technologists using documented procedures. The continuity of sampling locations was maintained through documentation in an environmental sampling locations manual.

Sample collection for chemical monitoring was performed according to specially developed written procedures. The samples were sealed with evidence tape to prevent tampering and were transported to the laboratory in accordance with the chain-of-custody procedures required by EPA for RCRA monitoring programs.

ANALYTICAL LABORATORY QUALITY ASSURANCE

The routine radiochemical analyses for environmental monitoring were performed by UST and PNL laboratories (water samples only). The U.S. Testing Company maintained an internal quality control program that involved routine calibration of counting instruments, frequent source and background counts, routine yield determinations of radiochemical procedures, replicate analyses

to check precision, and analyses of reagents to ensure purity of chemicals. Calibration standards traceable to the National Bureau of Standards (NBS) were used for radiochemical calibrations when available. Both laboratories continued to participate in the DOE Quality Assessment Program, and UST participated in the EPA Laboratory Intercomparison Studies Program. These programs provided standard samples of various environmental media (water, milk, air filters, soil, foodstuffs, and tissue ash) containing one or more radionuclides in known amounts. After the samples were analyzed, the results were forwarded to DOE and EPA for comparison with known values and with the results from other laboratories. Both EPA and DOE have established criteria for evaluating the accuracy of results (Jarvis and Sui 1981; Sanderson 1985). These programs provided a regular means for accurate evaluation of results and for indications of where corrective actions were needed. Summaries of the 1986 UST results for both programs are provided in Tables 5.1 and 5.2. Most of the results during the year were within 3-sigma control limits. The results from the PNL participation in the Quality Assessment Program are shown in Table 5.3, showing all of the results were within control limits.

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

<u>Sample Media</u>	<u>Radionuclides</u>	<u>Number Analyzed</u>	<u>Number of Analyses Within Control Limits^(a)</u>
Air filters	^7Be , ^{54}Mn , ^{60}Co , ^{90}Sr , ^{125}Sb ^{137}Cs , ^{234}U , ^{238}U , ^{239}Pu , ^{241}Am	20	18
Soil	^{40}K , ^{90}Sr , ^{137}Cs , ^{226}Ra , ^{238}Pu , ^{234}U , ^{238}U , ^{239}Pu , ^{241}Am	15	13
Vegetation	^{40}K , ^{90}Sr , ^{137}Cs , ^{239}Pu ^{241}Am , U(total)	15	11
Tissue	^{40}K , ^{90}Sr , ^{137}Cs , ^{234}U , ^{238}U , ^{226}Ra , ^{239}Pu	12	11
Water	^3H , ^{54}Mn , ^{60}Co , ^{90}Sr , ^{137}Cs ^{141}Ce , ^{234}U , ^{238}U , U(total) ^{239}Pu , ^{241}Am	21	20

(a) Control limits from Sanderson (1985).

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

<u>Sample Media</u>	<u>Radionuclides</u>	<u>Number Analyzed</u>	<u>Number of Analyses Within Control Limits^(a)</u>
Water	Gross Alpha, Gross Beta, ^{51}Cr , ^{65}Zn , ^{60}Co , ^{106}Ru ^{134}Cs , ^{137}Cs	31	31
Water	^{226}Ra , ^{239}Pu , ^{238}U , ^{228}Ra	10	9
Water	^{89}Sr , ^{90}Sr	6	6
Water	^3H	3	3
Milk	^{89}Sr , ^{90}Sr , ^{131}I , ^{137}C	5	5
Food	^{89}Sr , ^{90}Sr , ^{131}I , ^{137}C	4	3
Air filters	Gross Alpha, Gross Beta, ^{90}Sr , ^{137}Cs	8	8

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

TABLE 5.3. PNL Laboratory Performance on DOE Quality Assessment Program Samples

<u>Sample Media</u>	<u>Radionuclides</u>	<u>Number Analyzed</u>	<u>Number of Analyses Within Control Limits^(a)</u>
Water	³ H, ⁹⁰ Sr, ²³⁹ Pu, ²⁴¹ Am, ⁵⁴ Mn, ⁵⁹ Fe, ⁶⁰ Co, ¹²⁷ Cs, ¹⁴¹ Ce	10	10

(a) Control limits from Sanderson (1985).

Surface Monitoring

In addition to the 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 conduct special intercomparisons as necessary. All data were reviewed by a computerized, anomalous data system that checked each entry against established limits. An NBS standard reference sample of soil was submitted for blind analysis; the results are shown in Table A.59, Appendix A.

To check the precision of sampling and analysis, replicate samples were routinely collected. The replicate data provide an estimate of the variability that can be expected from the sampling and analysis process. The summary of the total precision for surface samples, based on replicate sampling, is shown in Table A.60, Appendix A. The results indicated the precision (or reproducibility) of results in terms of coefficient of variation, which was generally in the range of 20-50%. The expected analytical precision for samples above the minimum detectable concentration was in the range of 10-20%, indicating that there was additional uncertainty attributable to the sampling processes. The total precision values were within the expected range and were acceptable to assess the concentrations of radionuclides measured in the environment.

Each month three pairs of dosimeters were exposed to known levels of radiation and processed with the routine environmental dosimeters. A summary of the 1986 results is shown in

Table A.61, Appendix A. An average bias of approximately -1.7% was observed between the known and the measured exposures.

In 1986, PNL participated in the Eighth International Environmental Dosimeter Intercomparison Project. This project involved submitting PNL dosimeters to be exposed to known levels of radiation under carefully controlled field and laboratory conditions. The dosimeters were then returned to the project participants to be processed and to have the exposures determined. The frequency distribution of results for the participants for the two field sites and the laboratory exposure are shown in Figure 5.1. The PNL results, in all cases, were very close to the mean of the other participants' results and only slightly below the known exposure. In particular, the PNL result on the laboratory exposure, which was from ¹³⁷Cs gamma radiation, was very close to the known exposure. The shielded PNL dosimeter appeared to have a small, low bias for mixed energy radiation since gamma rays below 60 keV were excluded. The overall evaluation from this international intercomparison was that the PNL results were within the accuracy needed for environmental monitoring.

In 1985, PNL and DSHS expanded the number of shared environmental dosimeter locations from 7 to 21. The locations were on and around the Hanford Site, and around the U.S. Ecology site and the Washington Public Power Supply System WNP-2 Plant. Pacific Northwest Laboratory and DSHS dosimeters were put in place and collected at the same times. The results

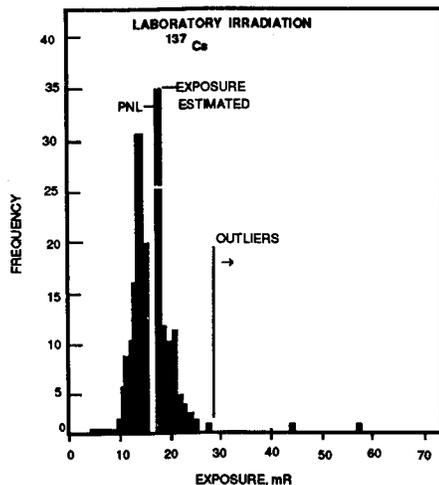
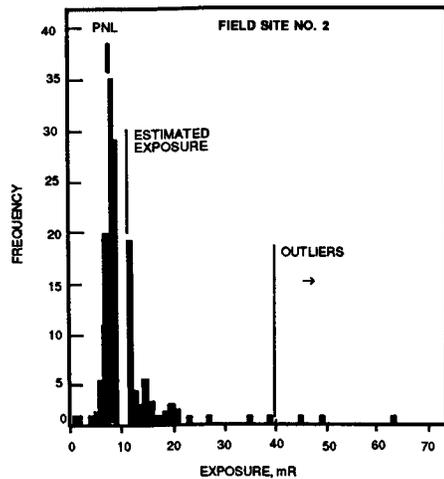
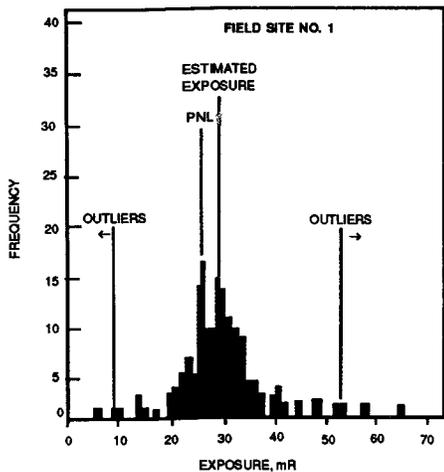


FIGURE 5.1. Participant Results in Eighth International Environmental Dosimeter Intercomparison Project

from the two organizations are shown in Table A.62, Appendix A. The DSHS results averaged 20% 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 DSHS dosimeter used an unshielded, less sensitive phosphor that over-responded somewhat to low-energy radiation.

Fruit and vegetable samples were collected from three farm areas east of Hanford. To provide a comparison with another laboratory, the samples were split with the Food and Drug Administration laboratory in Winchester, Massachusetts. The analyses performed and their results are shown in Table A.63, Appendix A. Results show very low levels of ^{90}Sr and tritium with no gamma emitters above detectable levels. The tritium results compared well for concentrations near the minimum detectable activity. The ^{90}Sr results showed the PNL results to be biased high. This problem was investigated and found to be attributable to failure to subtract the reagent blank value from the results.

Again in 1986 there was a special quality assurance effort involving sampling of the Columbia River and adjacent springs. In July 1986, the State of Washington, the State of Oregon, PNL (for the DOE), and Greenpeace Northwest conducted the joint sampling effort. The samples were shared among the participants; however, results were not available in time for incorporation into this report.

Radiological Ground-Water Monitoring

Duplicate field samples were periodically submitted by PNL and analyzed by the laboratory to ensure the quality of ground-water data. The duplicate samples consisted of one record sample and one blind sample. The record sample was labeled with the actual well number, and the blind sample was labeled with a fictitious well number. Analytical results for the duplicate samples for several constituents in 1986 are given in Table 5.4. The last column in this table gives the coefficient of variation for each pair of duplicate samples and an indication of the variability of

TABLE 5.4. Results of 1986 Routine Ground-Water Monitoring Audit Samples

Constituent (units)	Well Name	Sample Date	Record Sample	Blind Sample	Absolute Difference	Relative Difference ^(a)	Coefficient of Variation ^(b)
Gross Beta (pCi/L)	1-H4-3	28JUL86	720 ± 32	710 ± 32	10	1.4	2.6
60-Cobalt (pCi/L)	6-37-43	12JUN86	12 ± 21	-13 ± 17	25	-5000	-5000
	1-H4-3	28JUL86	8.8 ± 8.8	10 ± 10	1.2	12.8	51.4
	6-2-3	07OCT86	9.7 ± 10	11 ± 11	1.3	12.6	52.0
	6-28-40	11NOV86	16 ± 16	14 ± 14	2	13.3	51.5
	6-38-15	19JUN86	11 ± 12	20 ± 25	9	58.1	81.5
	6-27-8	12NOV86	14 ± 14	33 ± 33	19	80.9	89.7
	6-49-57	02JUN86	32 ± 20	33 ± 8	1	3.1	23.6
Tritium (pCi/L)	6-55-70	10JUN86	150 ± 290	-38 ± 290	188	336	394
	6-14-47	06SEP86	290 ± 290	-100 ± 280	390	411	393
	6-63-90	04MAR86	35 ± 500	160 ± 410	125	128	261
	6-55-70	02JAN87	192 ± 262	56.9 ± 259	135	109	142
	6-2-33A0	21FEB86	130 ± 410	550 ± 410	420	124	125
	6-45-69A	10JUN86	440 ± 300	270 ± 290	170	47.9	59.4
	6-S29-E12	11NOV86	340 ± 280	830 ± 290	490	83.8	78.1
	6-49-57	02JUN86	2,800 ± 330	2,500 ± 330	300	11.3	11.8
	1-B4-3	03FEB86	5,900 ± 470	6,000 ± 480	100	1.7	4.3
	6-28-40	11NOV86	11,400 ^(c)	11,700	300	2.6	2.3
	1-B4-3	09JAN86	23,000	23,000	0	0	0
	6-37-43	12JUN86	25,000	25,000	0	0	0
	6-2-3	07OCT86	106,000	104,000	2000	1.9	1.7
	6-2-3	30JUN86	110,000	110,000	0	0	0
	6-27-8	12NOV86	342,000	332,000	10000	3.0	2.6
	6-27-8	12NOV86	342,000	332,000	10000	3.0	2.6
	6-26-15A	24FEB86	360,000	360,000	0	0	0
6-38-15	19JUN86	530,000	530,000	0	0	0	
Uranium (pCi/L)	6-S29-E12	11NOV86	2.8 ± 5.1	8.8 ± 3.3	6	103	98.9
	1-H4-3	28JUL86	820 ± 23	840 ± 23	20	2.4	2.5
Chromium (mg/L)	1-H4-3	28JUL86	.56	.54	.02	3.6	3.2
Fluoride (mg/L)	1-H4-3	28JUL86	.24	.26	.02	8.0	7.1
Nitrate (µg/L)	6-55-70	02JAN87	<500	<500	0	0	0
	6-55-70	10JUN86	3,000	3,100	100	3.3	2.9
	6-28-40	11NOV86	13,500	13,600	100	0.7	0.7
	6-37-43	12JUN86	16,000	13,000	3000	20.7	18.3
	6-63-90	04MAR86	16,000	15,000	1000	6.5	5.7
	6-2-33A0	21FEB86	17,000	17,000	0	0	0
Nitrate (µg/L)	6-S29-E12	11NOV86	21,400	21,600	200	0.9	0.8
	6-41-23	30SEP86	24,300	24,300	0	0	0
	1-B4-3	03FEB86	33,000	25,000	8000	27.6	24.4
	6-2-3	07OCT86	31,800	32,100	300	0.9	0.8
	1-B4-1	08JAN86	48,000	46,000	2000	4.3	3.8
	6-27-8	12NOV86	47,000	47,000	0	0	0
	6-45-69A	10JUN86	52,000	48,000	4000	8.0	7.1
	6-2-3	30JUN86	52,000	50,000	2000	3.9	3.5
	6-26-15A	24FEB86	85,000	85,000	0	0	0
	6-38-15	19JUN86	89,000	85,000	4000	4.6	4.1
6-49-57	02JUN86	98,000	100,000	2000	2.0	1.8	

(a) Calculated as 100 times the absolute difference of the duplicates divided by their mean.

(b) Calculated as 100 times the standard deviation of the duplicates divided by their mean.

(c) The analytical laboratory did not report counting errors for ³H concentrations greater than 10,000 pCi/L.

the two samples relative to their average value. Unreliable estimates of the coefficient of variation occurred when both results for duplicate samples were not greater than twice the 2-sigma counting error. The coefficients of variation for duplicate samples greater than twice the 2-sigma counting error were less than 8% for the remaining audit samples, with a few exceptions, which generally indicates good internal agreement. In addition, Washington State University, as part of the QA for ground-water monitoring samples, selected Hanford wells, then split the samples with PNL for analysis. Analytical results for duplicate sample analysis for nitrate ions are given in Table 5.5. The Washington State University also submitted eight "spiked" nitrate samples to PNL for analysis. The results for both laboratories' analyses of the "spiked" nitrate samples (samples QA-1 to QA8) are also shown in

Table 5.5. The absolute and relative differences are small, with the absolute difference generally falling well below 10%.

Chemical Ground-Water Monitoring

The quality assurance effort for chemical monitoring included routine internal checks performed by the PNL laboratory as well as external checks conducted by the program to evaluate laboratory performance. Internal checks for both inorganic and organic analyses included extensive use of analytical standards, blank samples, and spiked samples.

The external effort conducted by PNL to evaluate the performance of the primary analytical laboratory included interlaboratory comparisons

TABLE 5.5. Concentrations of Nitrate in Ground-Water Samples from the Hanford Site (expressed in mg/L as nitrate)

Date	Sample (a)	WSU Analysis NO ₃	PNL (UST) Analysis NO ₃	Absolute Difference (mg/L)	% ^(b) Difference
10-9-86	6-29-4	30.24	32.4	2.16	6.9
	6-40-1	38.60	42.2	3.60	8.9
	6-26-15A	37.54	41.0	3.46	8.8
	6-47-5	28.07	30.0	1.93	6.6
	6-42-2	37.85	41.3	3.45	8.7
	6-20-20	38.60	42.3	3.70	9.1
11-18-86	6-S3-E12	23.86	24.6	0.74	3.1
	6-S6-E14	7.35	7.28	0.07	1.0
	6-S6-E4B	16.07	17.5	1.43	8.5
	6-S4-E4D	24.45	25.7	0.25	1.0
	6-S11-E12AP	<0.18	0.5	—	—
	6-S19-E13	19.74	21.3	1.56	7.6
	6-2-3	30.10	29.4	0.70	2.3
12-4-86	6-66-23	41.92	45.4	3.48	8.0
	6-77-36	73.71	75.1	1.39	1.9
	6-71-52	6.20	6.43	0.23	3.6
	6-89-35	8.59	9.31	0.72	8.0
	6-64-27	40.15	43.2	3.05	7.3
12-22-86	QA8	31.16	34.4	3.24	9.9
	QA7	9.69	10.6	0.91	9.0
	QA6	26.61	29.1	2.49	8.9
	QA3	105.45	109.0	3.55	3.3
	QA2	88.18	99.2	11.02	11.8
	QA1	50.64	53.4	2.76	5.3
	QA5	<0.18	<0.5	—	—
	QA4	17.62	19.8	2.18	11.7

(a) Well locations are shown in Figure 3.10.

(b) Calculated as 100 times the absolute difference between the WSU and PNL analyses divided by their mean.

of replicate samples, and the submission of blind standards and blanks. In addition, UST participated in EPA-sponsored performance evaluations for both water supply (drinking water) and water pollution (waste-water) samples.

Interlaboratory comparisons using field samples to date showed that results from UST were comparable to those from other laboratories. Comparisons were conducted for anions, volatile organics, and metals. The anions were analyzed by HEHF and WHC, volatile organics by PNL, and metals by HEHF.

Blind standards, including numerous organic and inorganic constituents, were submitted quarterly to UST. In general, the performance of UST was good. Occasionally, results of the analyses caused the laboratory to reevaluate methods or performance.

Environmental Protection Agency-sponsored evaluations covered a wide range of water-borne

pollutants, including metals, ions, pesticides and herbicides, and various organic compounds. Performance by UST in these evaluations has been very good.

DOSE CALCULATIONS QUALITY ASSURANCE

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



REFERENCES

Corley, J. P., et al. 1981. **A Guide for Environmental Radiological Surveillance at U.S. Department of Energy Installations.** DOE/EP-0023, U.S. Department of Energy, Washington, D.C.

Department of Social and Health Services (DSHS) (Washington State). 1985. **Twenty-Second Annual Report, July 1982 through December 1983.** Environmental Radiation Program, Olympia, Washington.

Department of Social and Health Services (DSHS) (Washington State). 1986. **State of Washington Environmental Protection Section Interim Environmental Radiation Data Report for 1985.** Environmental Radiation Program, Olympia, Washington.

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

Energy Research and Development Administration (ERDA). 1975. **Alternative for Long-Term Management of Defense High-Level Radiation Waste.** ERDA-77-44, Energy Research and Development Administration, Richland, Washington.

Fairbridge, R. W., ed. 1972. **The Encyclopedia of Geochemistry and Environmental Sciences.** Van Nostrand Reinhold Company, New York.

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

Feely, H. W., R. Larsen and C. Sanderson. 1987. **Annual Report of the Surface Air Sampling Program.** In press, Environmental Measurements Laboratory, U.S. Department of Energy, New York.

Fix, J. J., and M. L. Miller. 1978. **The Hanford Environmental $\text{CaF}_2\text{:MN}$ Thermoluminescent Dosimeter.** PNL-2489, Pacific Northwest Laboratory, Richland, Washington.

Gephart, R. E., et al. 1976. **Geohydrologic Study of the West Lake Basin.** ARH-CD-775, Atlantic Richfield Hanford Company, Richland, Washington.

Gephart, R. E., et al. 1979. **Hydrologic Studies Within the Columbia Plateau, Washington: An Integration of Current Knowledge.** RHO-BWI-ST-5, Rockwell Hanford Operations, Richland, Washington.

Graham, M. J., et al. 1981. **Hydrology of the Separations Area.** RHO-ST-42, Rockwell Hanford Operations, Richland, Washington.

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

Healy, J. W., et al. 1958. "Radiation Exposure to People in the Environs of a Major Production Atomic Energy Plant." In **Proceedings of the Second United Nations International Conference on the Peaceful Uses of Atomic Energy**, pp. 309-318. United Nations, Geneva.

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

International Commission on Radiological Protection (ICRP). 1977. **Recommendations of the International Commission on Radiological Protection.** ICRP Publication 26, Pergamon Press, New York.

International Commission on Radiological Protection (ICRP). 1979-1982. **Limits for Intakes of Radionuclides by Workers.** ICRP Publication 30, Part 1 (and subsequent parts and supplements), Vol. 2, No. 3/4, through Vol. 8, No. 4, Pergamon Press, New York.

Jarvis, A. N., and L. Sui. 1981. **Environmental Radioactivity Laboratory Intercomparison Studies Program.** EPA-600/4-81-004, U.S. Environmental Protection Agency, Las Vegas, Nevada.

Jacques, I. D. 1987. **UNC Environmental Surveillance Report for the 100 Areas-FY 1986.** UNI-4065, UNC Nuclear Industries, Richland, Washington.

Klement, A. W., Jr., et al. 1972. **Estimates of Ionizing Radiation Doses in the United States 1960-2000.** ORP/CSD 72-1, U.S. Environmental Protection Agency, Washington, D.C.

Law, A. G., and Schatz, A. L. 1986. **Results of the Separations Area Ground-Water Monitoring Network for 1985.** RHO-RE-SR-86-24-P, Rockwell Hanford Operations, Richland, Washington.

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

National Council on Radiation Protection and Measurements (NCRP). 1975. **Natural Background Radiation in the United States.** NCRP Report No. 45, Washington, D.C.

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

Oakley, D. T. 1972. **Natural Radiation Exposure in the United States.** ORP/SID 72-1, U.S. Environmental Protection Agency, Washington, D.C.

Price, K. R., et al. 1984. **Environmental Surveillance at Hanford for CY-1983.** PNL-5038, Pacific Northwest Laboratory, Richland, Washington.

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

Rickard, W. H., and D. G. Watson. 1985. "Four Decades of Environmental Change and Their Influence Upon Native Wildlife and Fish on the Mid-Columbia River." **Environmental Conservation** 12:241-248.

Sanderson, C. G. 1985. **Semi-Annual Department of Energy Quality Assessment Program Data Evaluation Report.** EML-439, Environmental Measurements Laboratory, U.S. Department of Energy, New York.

Schatz, A. L., and E. J. Jensen. 1986. **Unconfined Water-Table Map.** SD-WM-TI-273. Rockwell Hanford Operations, Richland, Washington.

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

Somers, S. R. 1987. **Hanford Sanitary Water Quality Surveillance, CY-1986.** HEHF-59, Hanford Environmental Health Foundation, Richland, Washington.

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

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

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

Tallman, A. M., et al. 1979. **Geology of the Separation Areas, Hanford Site, South-Central Washington.** RHO-ST-23, Rockwell Hanford Operations, Richland, Washington.

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

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

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

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

U.S. Environmental Protection Agency (USEPA). 1983. **Ground-Water Monitoring Guidance for Owners and Operators of Interim Status Facilities**. PB83-209445, NTIS, Springfield, Virginia.

U.S. Environmental Protection Agency (USEPA). 1986a. **Endangered and Threatened Wildlife and Plants**, 50 CFR (17.11, 17.12), U.S. Government Printing Office, Washington, D.C.

U.S. Environmental Protection Agency (USEPA). 1986b. **Technical Enforcement Guidance: Ground-Water Monitoring Assessment Programs at Interim Status Facilities**. OWSER-9950.1, Washington, D.C.

U.S. Environmental Protection Agency (USEPA) Quarterly Reports. 1981a-1986b. **Environmental Radiation Data**. Quarterly Reports 25-40, Office of Radiation Programs, Eastern Environmental Radiation Facility (EERF), Montgomery, Alabama.

U.S. Environmental Protection Agency (USEPA). 1981a. **Environmental Radiation Data**. Report 25-26, October 1981, EPA 520/5-82-015. USEPA, Office of Radiation Programs, Washington, D.C. 20460.

U.S. Environmental Protection Agency (USEPA). 1981b. **Environmental Radiation Data**. Report 27, December 1981, EPA 520/5-82-016. USEPA, Office of Radiation Programs, Eastern Environmental Radiation Facility (EERF), Montgomery, Alabama.

U.S. Environmental Protection Agency (USEPA). 1982a. **Environmental Radiation Data**. Report 28, March 1982, EPA 520/1-83-002. USEPA, Office of Radiation Programs, Eastern Environmental Radiation Facility (EERF), Montgomery, Alabama.

U.S. Environmental Protection Agency (USEPA). 1982b. **Environmental Radiation Data**. Report 29, June 1982, EPA 520/5-5-83-005. USEPA, Office of Radiation Programs, Eastern Environmental Radiation Facility (EERF), Montgomery, Alabama.

U.S. Environmental Protection Agency (USEPA). 1982c. **Environmental Radiation Data**. Report 30, September 1982, EPA 520/5-6-83-006. USEPA, Office of Radiation Programs, Eastern Environmental Radiation Facility (EERF), Montgomery, Alabama.

U.S. Environmental Protection Agency (USEPA). 1982d. **Environmental Radiation Data**. Report 31, December 1982, EPA 520/5-83-014. USEPA, Office of Radiation Programs, Eastern Environmental Radiation Facility (EERF), Montgomery, Alabama.

U.S. Environmental Protection Agency (USEPA). 1983a. **Environmental Radiation Data**. Report 32, March 1983, EPA 520/5-83-015. USEPA, Office of Radiation Programs, Eastern Environmental Radiation Facility (EERF), Montgomery, Alabama.

U.S. Environmental Protection Agency (USEPA). 1983b. **Environmental Radiation Data**. Report 33, June 1983, EPA 520/5-83-016. USEPA, Office of Radiation Programs, Eastern Environmental Radiation Facility (EERF), Montgomery, Alabama.

U.S. Environmental Protection Agency (USEPA). 1983c. **Environmental Radiation Data**. Report 34, September 1983, EPA 520/5-83-028. USEPA, Office of Radiation Programs, Eastern Environmental Radiation Facility (EERF), Montgomery, Alabama.

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

U.S. Environmental Protection Agency (USEPA). 1984a. **Environmental Radiation Data**. Report 36, March 1984, EPA 520/5-84-013. USEPA, Office

of Radiation Programs, Eastern Environmental Radiation Facility (EERF), Montgomery, Alabama.

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

U.S. Environmental Protection Agency (USEPA). 1984c. **Environmental Radiation Data.** Report 38, September 1984, EPA 520/5-84-029. USEPA, Office of Radiation Programs, Eastern Environmental Radiation Facility (EERF), Montgomery, Alabama.

U.S. Environmental Protection Agency (USEPA). 1984d. **Environmental Radiation Data.** Report 39, December 1984, EPA 520/5-85-009. USEPA, Office of Radiation Programs, Eastern Environmental Radiation Facility (EERF), Montgomery, Alabama.

U.S. Environmental Protection Agency (USEPA). 1985a. **Environmental Radiation Data.** Report 40, March 1985, EPA 520/5-85-022. USEPA, Office of Radiation Programs, Eastern Environmental Radiation Facility (EERF), Montgomery, Alabama.

U.S. Environmental Protection Agency (USEPA). 1985b. **Environmental Radiation Data.** Report 41, June 1985, EPA 520/5-85-030. USEPA, Office of Radiation Programs, Eastern Environmental Radiation Facility (EERF), Montgomery, Alabama.

U.S. Environmental Protection Agency (USEPA). 1985c. **Environmental Radiation Data.** Report

42, September 1985, EPA 520/5-85-031. USEPA, Office of Radiation Programs, Eastern Environmental Radiation Facility (EERF), Montgomery, Alabama.

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

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

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

Washington State Department of Ecology (WDOE). 1982. **Water Quality Standards,** Washington Administrative Code, Chapter 172-201, Olympia, Washington.

Washington State Department of Ecology (WDOE). 1986. **Dangerous Waste Regulations.** Washington Administrative Code, Chapter 173-303, Olympia, Washington.

BIBLIOGRAPHY OF PREVIOUSLY ISSUED PNL ENVIRONMENTAL MONITORING REPORTS

Reports for the Offsite Environment

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

Sula, M. J., et al. 1982. **Environmental Surveillance at Hanford for CY-1981.** PNL-4211, Pacific Northwest Laboratory, Richland, Washington.

Sula, M. J., et al. 1983. **Environmental Surveillance at Hanford for CY-1982.** PNL-4657, Pacific Northwest Laboratory, Richland, Washington.

Price, K. R., et al. 1984. **Environmental Surveillance at Hanford for CY-1983.** PNL-5038, Pacific Northwest Laboratory, Richland, Washington.

Price, K. R., et al. **Environmental Monitoring at Hanford for 1984.** PNL-5407, Pacific Northwest Laboratory, Richland, Washington.

Reports for the Onsite Environment

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

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

Sula, M. J., et al. 1983. **Environmental Status of the Hanford Site for CY-1982.** PNL-4658, Pacific Northwest Laboratory, Richland, Washington.

Price, K. R., et al. 1984. **Environmental Status of the Hanford Site for CY-1983.** PNL-5039, Pacific Northwest Laboratory, Richland, Washington.

Reports for Onsite Ground Water

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

Eddy, P. A., et al. 1982. **Radiological Status of the Ground Water Beneath the Hanford Site, January-December, 1981.** PNL-4237, Pacific Northwest Laboratory, Richland, Washington.

Eddy, P. A., et al. 1983. **Ground-Water Surveillance at the Hanford Site for CY-1982.** PNL-4659, Pacific Northwest Laboratory, Richland, Washington.

Prater, L. S., et al. 1984. **Ground-Water Surveillance at the Hanford Site for CY-1983.** PNL-5041, Pacific Northwest Laboratory, Richland, Washington.

Cline, C. S., et al. 1985. **Ground-Water Monitoring at the Hanford Site, January-December 1984.** PNL-5408, Pacific Northwest Laboratory, Richland, Washington.

Combined Reports

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



APPENDIXES

APPENDIX A

MONITORING RESULTS FOR 1986

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

Composite Group	Sampling Location	Map Location ^(a)
Onsite		
100 Area	100K	1
	100N	2
	100D	3
	Fire Station	4
200 East Area	South of 200E	5
	East of 200E	6
	200E SE	7
North of 200 Areas	Rt. 11A, Mi. 9	8
	N of 200E	9
200 West Area	SW of BC Cribs	10
	Army Loop Camp	11
	GTE Building	12
300 Area	300 Pond	13
	ACRMS	14
	300S Gate	15
400 Area	400E	16
	400W	17
	400S	18
	400N	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 #64	28
Prosser Barricade	Horn Rapids Rd. Substation	29
	Prosser Barricade	30
ALE	ALE	31
West Perimeter	Rattlesnake Springs	32
	Yakima Barricade	33
Northwest Perimeter	Vernita Bridge	34
	Wahluke Slope #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 3.1.

TABLE A.2. Gross Beta Concentrations in Air in the Hanford Environs for 1986

Station No.	Location ^(b)	Gross Beta Concentrations ^(a) pCi/m ³ (10 ⁻¹² µCi/mL)			
		No. Samples	Maximum	Minimum	Mean
ONSITE					
1	100K	25	0.77 ± 0.013	-0.004 ± 0.004	0.070 ± 0.061
2	100N	26	0.69 ± 0.013	0.012 ± 0.004	0.067 ± 0.052
3	100D	26	0.66 ± 0.013	0.014 ± 0.004	0.065 ± 0.050
4	100 Fire Station	25	0.72 ± 0.013	0.011 ± 0.004	0.068 ± 0.057
5	S of 200E	25	0.65 ± 0.012	0.014 ± 0.004	0.078 ± 0.061
6	E of 200E	25	0.47 ± 0.010	0.020 ± 0.004	0.077 ± 0.049
7	200E SE	26	0.52 ± 0.011	0.023 ± 0.005	0.063 ± 0.039
8	Rt. 11A, Mi. 9	26	0.46 ± 0.011	0.013 ± 0.004	0.070 ± 0.045
9	N of 200E	25	0.47 ± 0.010	0.016 ± 0.004	0.071 ± 0.049
10	SW of BC Cribs	25	0.53 ± 0.011	0.014 ± 0.004	0.071 ± 0.053
11	Army Loop Camp	27	0.46 ± 0.010	0.015 ± 0.004	0.067 ± 0.042
12	200 GTE	25	0.48 ± 0.010	0.011 ± 0.004	0.073 ± 0.047
13	300 Pond	27	0.53 ± 0.011	0.019 ± 0.004	0.076 ± 0.052
14	ACRMS	27	0.46 ± 0.011	0.016 ± 0.004	0.064 ± 0.042
15	300S Gate	25	0.47 ± 0.010	0.015 ± 0.004	0.071 ± 0.044
16	400E	26	0.49 ± 0.011	0.015 ± 0.004	0.070 ± 0.045
17	400W	26	0.50 ± 0.011	0.014 ± 0.004	0.071 ± 0.045
18	400S	26	0.47 ± 0.010	0.017 ± 0.004	0.070 ± 0.044
19	400N	26	0.48 ± 0.011	0.016 ± 0.004	0.073 ± 0.049
20	Hanford Townsite	25	0.84 ± 0.014	0.011 ± 0.004	0.074 ± 0.066
21	Wye Barricade	26	0.75 ± 0.013	0.012 ± 0.004	0.070 ± 0.057
OVERALL AVERAGE					
0.071 ± 0.011					
PERIMETER					
22	Berg Ranch	25	0.48 ± 0.011	0.015 ± 0.004	0.067 ± 0.047
23	Sagehill	26	0.42 ± 0.010	0.016 ± 0.004	0.058 ± 0.041
24	Ringold	27	0.54 ± 0.011	0.015 ± 0.005	0.070 ± 0.048
25	Fir Road	26	0.74 ± 0.013	0.010 ± 0.004	0.064 ± 0.055
26	Pettett	25	0.70 ± 0.013	0.016 ± 0.004	0.066 ± 0.054
27	Byers Landing	26	0.65 ± 0.013	0.012 ± 0.004	0.061 ± 0.049
28	RRC #64	25	0.75 ± 0.013	0.013 ± 0.004	0.067 ± 0.058
29	Horn Rapids Substation	26	0.49 ± 0.011	0.012 ± 0.004	0.060 ± 0.045
30	Prosser Barricade	27	0.48 ± 0.011	0.012 ± 0.004	0.067 ± 0.042
31	ALE	27	0.54 ± 0.011	0.015 ± 0.004	0.069 ± 0.049
32	Rattlesnake Springs	25	0.42 ± 0.010	0.015 ± 0.004	0.068 ± 0.042
33	Yakima Barricade	25	0.45 ± 0.010	0.014 ± 0.004	0.069 ± 0.044
34	Vernita Bridge	25	0.72 ± 0.013	0.013 ± 0.004	0.070 ± 0.057
35	Wahluke Slope #2	26	0.61 ± 0.012	0.014 ± 0.004	0.061 ± 0.047
OVERALL AVERAGE					
0.066 ± 0.013					
NEARBY COMMUNITIES					
36	Othello	27	0.46 ± 0.011	0.013 ± 0.004	0.064 ± 0.039
37	Connell	26	0.48 ± 0.011	0.014 ± 0.004	0.068 ± 0.045
38	Pasco	26	0.74 ± 0.013	0.012 ± 0.004	0.065 ± 0.056
39	Richland	26	0.70 ± 0.013	0.014 ± 0.004	0.063 ± 0.053
40	Kennewick	25	0.62 ± 0.012	0.012 ± 0.004	0.061 ± 0.049
41	Benton City	25	0.67 ± 0.013	0.012 ± 0.004	0.063 ± 0.053
42	Prosser	25	0.74 ± 0.013	0.012 ± 0.004	0.068 ± 0.058
43	Eltopia	26	0.47 ± 0.011	0.014 ± 0.004	0.067 ± 0.046
44	Mattawa	22	0.59 ± 0.012	0.009 ± 0.004	0.062 ± 0.052
OVERALL AVERAGE					
0.064 ± 0.016					
DISTANT COMMUNITIES					
45	Moses Lake	26	0.93 ± 0.021	0.016 ± 0.004	0.075 ± 0.070
46	Washtucna	26	0.57 ± 0.012	0.014 ± 0.004	0.059 ± 0.042
47	Walla Walla	25	0.45 ± 0.011	0.006 ± 0.004	0.061 ± 0.046
48	McNary Dam	25	0.49 ± 0.011	0.007 ± 0.004	0.053 ± 0.037
49	Sunnyside	25	0.60 ± 0.012	0.011 ± 0.004	0.061 ± 0.047
50	Yakima	25	0.56 ± 0.012	0.008 ± 0.004	0.052 ± 0.044
OVERALL AVERAGE					
0.059 ± 0.020					

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

(b) Locations are identified in Figure 3.1.

TABLE A.3. Gross Alpha Concentrations in Air in the Hanford Environs for 1986

Station No.	Location ^(b)	Gross Alpha Concentrations ^(a) pCi/m ³ (10 ⁻¹² μCi/mL)			
		No. Samples	Maximum	Minimum	Mean
ONSITE					
3	100D	26	0.0016 ± 0.0006	0.0001 ± 0.0003	0.0010 ± 0.0002
5	S of 200E	25	0.0026 ± 0.0007	0.0005 ± 0.0003	0.0010 ± 0.0002
6	E of 200E	25	0.0026 ± 0.0007	0.0003 ± 0.0003	0.0010 ± 0.0002
7	200E SE	26	0.0030 ± 0.0008	0.0001 ± 0.0003	0.0011 ± 0.0003
8	Rt 11A, Mi. 9	26	0.0027 ± 0.0007	0.0004 ± 0.0003	0.0010 ± 0.0002
9	N of 200E	25	0.0036 ± 0.0008	0.0004 ± 0.0004	0.0010 ± 0.0003
10	SW of BC Cribs	25	0.0030 ± 0.0008	0.0003 ± 0.0003	0.0010 ± 0.0002
11	Army Loop Camp	27	0.0033 ± 0.0008	0.0006 ± 0.0003	0.0011 ± 0.0003
12	200 GTE	26	0.0027 ± 0.0007	0.0002 ± 0.0003	0.0009 ± 0.0002
13	300 Pond	27	0.0038 ± 0.0008	0.0005 ± 0.0004	0.0016 ± 0.0004
15	300S Gate	25	0.0026 ± 0.0006	0.0004 ± 0.0003	0.0011 ± 0.0002
16	400E	26	0.0040 ± 0.0009	0.0004 ± 0.0003	0.0011 ± 0.0003
17	400W	26	0.0035 ± 0.0008	0.0002 ± 0.0002	0.0010 ± 0.0003
18	400S	26	0.0030 ± 0.0007	0.0001 ± 0.0003	0.0010 ± 0.0003
19	400N	25	0.0027 ± 0.0007	0.0003 ± 0.0003	0.0010 ± 0.0002
20	Hanford Townsite	25	0.0024 ± 0.0007	0.0004 ± 0.0003	0.0010 ± 0.0002
21	Wye Barricade	26	0.0030 ± 0.0008	0.0003 ± 0.0004	0.0010 ± 0.0002
OVERALL AVERAGE					0.0011 ± 0.0001
PERIMETER					
22	Berg Ranch	25	0.0022 ± 0.0007	0.0004 ± 0.0003	0.0009 ± 0.0002
23	Sagehill	26	0.0017 ± 0.0006	0.0004 ± 0.0003	0.0010 ± 0.0002
24	Ringold	26	0.0028 ± 0.0008	0.0004 ± 0.0003	0.0011 ± 0.0002
25	Fir Road	26	0.0026 ± 0.0007	0.0002 ± 0.0002	0.0011 ± 0.0002
26	Pettett	25	0.0025 ± 0.0008	0.0005 ± 0.0004	0.0012 ± 0.0002
27	Byers Landing	26	0.0021 ± 0.0007	0.0001 ± 0.0003	0.0010 ± 0.0002
28	RRC #64	25	0.0018 ± 0.0007	0.0004 ± 0.0003	0.0010 ± 0.0002
30	Prosser Barricade	27	0.0031 ± 0.0008	0.0003 ± 0.0003	0.0010 ± 0.0002
33	Yakima Barricade	26	0.0026 ± 0.0007	0.0006 ± 0.0003	0.0011 ± 0.0002
35	Wahluke Slope #2	26	0.0039 ± 0.0009	0.0004 ± 0.0003	0.0011 ± 0.0003
OVERALL AVERAGE					0.0010 ± 0.0007
NEARBY COMMUNITIES					
39	Richland	27	0.0027 ± 0.0008	0.0006 ± 0.0004	0.0010 ± 0.0022
41	Benton City	25	0.0035 ± 0.0008	0.0002 ± 0.0002	0.0011 ± 0.0027
OVERALL AVERAGE					0.0010 ± 0.0017
DISTANT COMMUNITIES					
49	Sunnyside	25	0.0026 ± 0.0007	0.0004 ± 0.0003	0.0010 ± 0.0021
50	Yakima	25	0.0023 ± 0.0009	0.0004 ± 0.0003	0.0008 ± 0.0021
OVERALL AVERAGE					0.0009 ± 0.0015

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

(b) Locations are identified in Figure 3.1.

TABLE A.4. Airborne Radionuclide Concentrations in the Hanford Environs for 1986

Radio-nuclide	Composite Group ^(b)	No. Samples	Concentration, pCi/m ³ ^(a) (10 ⁻¹² μCi/mL)						Derived Concentration Guide pCi/m ³ ^(c)
			Maximum		Minimum		Average		
³ H ^(d)	On Site	69	8.7	± 1.7	-0.5	± 2.1	2.2	± 0.5	200,000
	Perimeter	91	4.5	± 2.8	-1.6	± 1.9	1.1	± 0.3	
	Nearby Communities	11	4.4	± 3.6	-1.0	± 1.7	1.0	± 1.0	
	Distant Communities	24	5.4	± 2.6	-0.7	± 2.1	1.4	± 0.8	
¹⁴ C	On Site	12	1.69	± 0.09	1.31	± 0.12	1.43	± 0.07	500,000
	Distant Communities	12	1.58	± 0.07	1.27	± 0.16	1.38	± 0.06	
⁸⁵ Kr	On Site	28	6100	± 780	18	± 10	1000	± 590	60,000
	Perimeter	38	460	± 61	8	± 10	100	± 31	
	Nearby Communities	29	310	± 43	19	± 7	69	± 2	
	Distant Communities	20	110	± 16	15	± 9	37	± 10	
⁹⁰ Sr	On Site	32	0.0052	± 0.00006	0.00002	± 0.00003	0.00016	± 0.00005	9
	Perimeter	24	0.00030	± 0.00007	0.00002	± 0.00005	0.00012	± 0.00004	
	Nearby Communities	20	0.00033	± 0.00010	0.00004	± 0.00003	0.00015	± 0.00005	
	Distant Communities	16	0.00030	± 0.00013	0.00003	± 0.00007	0.00015	± 0.00005	
¹⁰⁶ Ru	On Site	96	0.054	± 0.028	-0.017	± 0.017	0.004	± 0.003	30
	Perimeter	72	0.054	± 0.015	-0.024	± 0.015	0.002	± 0.003	
	Nearby Communities	59	0.047	± 0.014	-0.012	± 0.011	0.003	± 0.003	
	Distant Communities	48	0.044	± 0.028	-0.013	± 0.013	0.002	± 0.003	
¹²⁹ I	On Site	4	0.00169000	± 0.00020300	0.00017000	± 0.00001390	0.00082500	± 0.00074100	70
	Perimeter	8	0.00002990	± 0.00000251	0.00000333	± 0.00000030	0.00001580	± 0.00000661	
	Distant Communities	5	0.00000244	± 0.00000023	0.00000024	± 0.00000002	0.00000087	± 0.00000085	
¹³¹ I	On Site	177	0.750	± 0.032	-0.008	± 0.006	0.037	± 0.020	400
	Perimeter	129	0.711	± 0.031	-0.006	± 0.005	0.025	± 0.018	
	Nearby Communities	25	0.602	± 0.026	-0.006	± 0.005	0.028	± 0.048	
	Distant Communities	51	1.030	± 0.035	-0.007	± 0.006	0.035	± 0.045	
¹³⁷ Cs	On Site	96	0.1170	± 0.0111	-0.0021	± 0.0026	0.0084	± 0.0055	400
	Perimeter	72	0.1160	± 0.0080	-0.0024	± 0.0020	0.0087	± 0.0067	
	Nearby Communities	59	0.1060	± 0.0076	-0.0028	± 0.0020	0.0086	± 0.0073	
	Distant Communities	48	0.1240	± 0.0101	-0.0017	± 0.0020	0.0089	± 0.0084	
U (total)	On Site	18	0.001500	± 0.000014	0.000028	± 0.000001	0.000156	± 0.000079	0.1
	Perimeter	8	0.000116	± 0.000005	0.000035	± 0.000003	0.000062	± 0.000007	
	Distant Communities	4	0.000115	± 0.000005	0.000024	± 0.000001	0.000056	± 0.000008	
²³⁸ Pu	On Site	32	0.0000011	± 0.0000010	-0.0000000	± 0.0000000	0.0000005	± 0.0000004	0.03
	Perimeter	24	0.0000013	± 0.0000018	-0.0000009	± 0.0000012	0.0000001	± 0.0000002	
	Nearby Communities	20	0.0000015	± 0.0000023	-0.0000004	± 0.0000008	0.0000004	± 0.0000003	
	Distant Communities	16	0.0000011	± 0.0000021	-0.0000008	± 0.0000017	0.0000001	± 0.0000003	
²³⁹ Pu	On Site	32	0.0000093	± 0.0000028	0.0000000	± 0.0000000	0.0000014	± 0.0000007	0.02
	Perimeter	24	0.0000032	± 0.0000023	-0.0000003	± 0.0000006	0.0000005	± 0.0000004	
	Nearby Communities	20	0.0000014	± 0.0000015	-0.0000003	± 0.0000006	0.0000005	± 0.0000003	
	Distant Communities	16	0.0000032	± 0.0000023	0.0000000	± 0.0000000	0.0000008	± 0.0000005	

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

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

Radionuclide	Sampling Location ^(b)	Number of Samples	Concentration, pCi/m ³ (a) (10 ⁻¹² μCi/mL)						
			Maximum		Minimum		Average		Average 1986 Distant ^(b)
3H(c)	N Area (2)	12	3.5	± 1.9	-0.5	± 2.1	1.4	± 0.9	1.4 ± 0.8
	D Area (3)	11	2.0	± 1.7	0.0	± 1.1	1.2	± 0.6	
						1.3	± 0.5		
90Sr	Composite ^(d)	4	0.00052	± 0.00006	0.00002	± 0.00003	0.00019	± 0.00024	0.00015 ± 0.00005
131I	N Area (2)	26	0.750	± 0.032	-0.003	± 0.006	0.036	± 0.058	0.035 ± 0.045
	D Area (3)	26	0.725	± 0.030	-0.007	± 0.005	0.032	± 0.056	
137Cs	Composite	12	0.1000	± 0.0049	-0.0004	± 0.0006	0.0086	± 0.0166	0.0089 ± 0.0084
U(total)	Composite	4	0.000095	± 0.000003	0.000029	± 0.000001	0.000056	± 0.000008	0.000056 ± 0.000008
238Pu	Composite	4	0.0000011	± 0.0000010	0.0000000	± 0.0000000	0.0000004	± 0.0000006	0.0000001 ± 0.0000003
239,240Pu	Composite	4	0.0000013	± 0.0000010	0.0000000	± 0.0000006	0.0000004	± 0.0000007	0.0000008 ± 0.0000005
Gross Beta	K Area (1)	25	0.773	± 0.013	-0.004	± 0.004	0.070	± 0.061	0.059 ± 0.020
	N Area (2)	26	0.690	± 0.013	0.012	± 0.004	0.065	± 0.052	
	D Area (3)	26	0.660	± 0.013	0.014	± 0.004	0.063	± 0.050	
	Fire Station (4)	25	0.724	± 0.013	0.009	± 0.004	0.066	± 0.0571	
						0.066	± 0.027		
Gross Alpha	D Area (3)	26	0.0016	± 0.0006	0.0001	± 0.0003	0.0010	± 0.0002	0.0009 ± 0.0002

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

TABLE A.6. Airborne Radionuclide Concentrations Near the 200E Area

Radionuclide	Sampling Location ^(b)	Number of Samples	Concentration, pCi/m ³ (a) (10 ⁻¹² μCi/mL)						
			Maximum		Minimum		Average		Average 1986 Distant ^(b)
3H(c)	200E SE (7)	12	8.7	± 1.7	1.2	± 2.3	4.5	± 1.3	1.4 ± 0.8
14C	200E SE	6	1.69	± 0.09	1.31	± 0.12	1.43	± 0.13	1.38 ± 0.06
85Kr	200E SE	12	6100	± 780	28	± 7	2200	± 1000	37 ± 10
90Sr	Composite ^(d)	4	0.00036	± 0.00006	0.00004	± 0.00003	0.00014	± 0.00016	0.000015 ± 0.00005
106Ru	Composite	12	0.046	± 0.017	-0.002	± 0.009	0.008	± 0.008	0.002 ± 0.003
129I	200E SE (7)	4	0.00169	± 0.00020	0.00017	± 0.00001	0.00083	± 0.00074	0.0000087 ± 0.0000085
131I	S of 200E (5)	24	0.544	± 0.026	-0.006	± 0.008	0.045	± 0.062	0.035 ± 0.045
	E of 200E (6)	24	0.491	± 0.026	-0.004	± 0.011	0.038	± 0.049	
	200E SE (7)	26	0.529	± 0.027	-0.007	± 0.006	0.035	± 0.048	
U(total)	Composite	4	0.000143	± 0.000007	0.000046	± 0.000002	0.000077	± 0.000011	0.000056 ± 0.000008
238Pu	Composite	4	0.0000006	± 0.0000009	0.0000003	± 0.0000005	0.0000005	± 0.0000004	0.0000001 ± 0.0000003
239Pu	Composite	4	0.0000035	± 0.0000021	0.0000015	± 0.0000014	0.0000024	± 0.0000013	0.0000008 ± 0.0000005
Gross Beta	S of 200E (5)	24	0.651	± 0.012	0.014	± 0.004	0.078	± 0.064	0.059 ± 0.02
	E of 200E (6)	24	0.472	± 0.010	0.020	± 0.004	0.077	± 0.050	
	200E SE (7)	25	0.522	± 0.011	0.023	± 0.005	0.061	± 0.040	
						0.072	± 0.0030		
Gross Alpha	S of 200E (5)	24	0.0026	± 0.0007	0.0005	± 0.0003	0.0010	± 0.0002	0.0009 ± 0.0002
	E of 200E (6)	24	0.0026	± 0.0007	0.0003	± 0.0003	0.0010	± 0.0002	
	200E SE (7)	25	0.0030	± 0.0008	0.0001	± 0.0003	0.0010	± 0.0002	
							0.0010	± 0.0001	

- (a) Maximum and minimum concentrations ±2 sigma counting error. Averages ±2 standard error of the calculated mean. Entries have been rounded for clarity.
 (b) Sample map location numbers are shown in parentheses. Sampling locations are identified in Table A.1 and Figure 3-1.
 (c) January through November.
 (d) Composites of biweekly samples from the individual sampling locations (5-7) in Table A.1.

TABLE A.7. Airborne Radionuclide Concentrations Near the 200W Area

Radio-nuclide	Sampling Location ^(b)	Number of Samples	Concentration, pCi/m ³ (a) (10 ⁻¹² μCi/mL)			
			Maximum	Minimum	Average	Average 1986 Distant ^(b)
³ H(C)	GTE Bldg. (12)	11	2.7 ± 1.7	0.9 ± 1.8	2.0 ± 0.8	1.4 ± 0.8
⁹⁰ Sr	Composite ^(d)	4	0.00024 ± 0.00005	0.00004 ± 0.00003	0.00011 ± 0.00011	0.00015 ± 0.00005
¹⁰⁶ Ru	Composite	12	0.021 ± 0.013	-0.004 ± 0.007	0.002 ± 0.005	0.002 ± 0.003
¹³⁷ Cs	Composite	12	0.0831 ± 0.0052	-0.0006 ± 0.0008	0.0075 ± 0.0138	0.0089 ± 0.0084
U(total)	Composite	4	0.000048 ± 0.000017	0.000035 ± 0.000002	0.000041 ± 0.000002	0.000056 ± 0.000008
²³⁸ Pu	Composite	4	0.0000050 ± 0.0000060	0.0000000 ± 0.0000000	0.0000018 ± 0.0000029	0.0000001 ± 0.0000003
^{239,240} Pu	Composite	4	0.0000093 ± 0.0000028	0.0000003 ± 0.0000010	0.0000037 ± 0.0000045	0.0000008 ± 0.0000005
Gross Beta	SW of BC Crib (10)	25	0.526 ± 0.011	0.014 ± 0.004	0.071 ± 0.053	0.069 ± 0.028
	Army Loop Camp (11)	26	0.458 ± 0.010	0.015 ± 0.004	0.066 ± 0.044	
	GTE Bldg. (12)	25	0.478 ± 0.010	0.011 ± 0.004	0.070 ± 0.049	
						0.059 ± 0.02
Gross Alpha	SW of BC Cribs (10)	25	0.0030 ± 0.0077	0.0003 ± 0.0003	0.0009 ± 0.0002	0.0009 ± 0.0002
	Army Loop Camp (11)	26	0.0033 ± 0.0008	0.0006 ± 0.0003	0.0011 ± 0.0003	
	GTE Bldg. (12)	25	0.0027 ± 0.0007	0.0002 ± 0.0003	0.0009 ± 0.0002	

- (a) Maximum and minimum concentrations ±2 sigma counting error. Averages ±2 standard error of the calculated mean. Entries have been rounded for clarity.
 (b) Distant sampling locations are identified in Table A.1 and Figure 3-1.
 (c) January through November.
 (d) Composites of biweekly samples from the individual sampling locations in Table A.1.

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

Radio-nuclide	Sampling Location ^(b)	Number of Samples	Concentration, pCi/m ³ (a) (10 ⁻¹² μCi/mL)			
			Maximum	Minimum	Average	Average 1986 Distant ^(b)
⁹⁰ Sr	Composite ^(c)	4	0.00026 ± 0.00007	0.00009 ± 0.00006	0.00014 ± 0.00010	0.00015 ± 0.00005
¹⁰⁶ Ru	Composite	12	0.038 ± 0.016	-0.009 ± 0.013	0.002 ± 0.008	0.002 ± 0.003
¹³⁷ Cs	Composite	12	0.0971 ± 0.0067	-0.0005 ± 0.0013	0.0089 ± 0.0161	0.0089 ± 0.0084
²³⁸ Pu	Composite	4	0.0000005 ± 0.0000029	0.0000000 ± 0.0000000	0.0000001 ± 0.0000008	0.0000001 ± 0.0000003
^{239,240} Pu	Composite	4	0.0000010 ± 0.0000014	0.0000003 ± 0.0000006	0.0000007 ± 0.0000006	0.0000008 ± 0.0000005
Gross Beta	Rt. 11 A, Mi. 9 (8)	25	0.463 ± 0.011	0.013 ± 0.004	0.070 ± 0.047	0.073 ± 0.034
	N of 200E (9)	24	0.474 ± 0.010	0.016 ± 0.004	0.076 ± 0.051	
						0.059 ± 0.02
Gross Alpha	Rt. 11 A, Mi. 9 (8)	25	0.0027 ± 0.0007	0.0004 ± 0.0003	0.0009 ± 0.0002	0.0009 ± 0.0002
	N of 200E (9)	24	0.0036 ± 0.0008	0.0004 ± 0.0004	0.0009 ± 0.0003	
						0.0009 ± 0.0002

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

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

Radio-nuclide	Sampling Location ^(b)	Number of Samples	Concentration, pCi/m ³ ^(a) (10 ⁻¹² μCi/mL)			Average 1986 Distant ^(b)
			Maximum	Minimum	Average	
¹⁴ C	300 Pond (13)	6	1.53 ± 0.13	1.32 ± 0.09	1.42 ± 0.08	1.38 ± 0.06
⁸⁵ Kr	300 Pond	11	300 ± 40	18 ± 10	140 ± 65	37 ± 22
⁹⁰ Sr	Composite ^(c)	4	0.00031 ± 0.00008	0.00002 ± 0.00002	0.00012 ± 0.00028	0.00015 ± 0.00005
¹³¹ I	300S Gate (15)	26	0.467 ± 0.025	-0.005 ± 0.005	0.035 ± 0.046	0.035 ± 0.045
¹³⁷ Cs	Composite	12	0.0920 ± 0.0057	-0.0006 ± 0.0006	0.0080 ± 0.0153	0.0089 ± 0.0084
U(total)	Composite	4	0.001530 ± 0.000014	0.000063 ± 0.000002	0.000490 ± 0.000162	0.000056 ± 0.000008
²³⁸ Pu	Composite	4	0.0000007 ± 0.0000014	0.0000000 ± 0.0000000	0.0000003 ± 0.0000005	0.0000001 ± 0.0000003
^{239,240} Pu	Composite	4	0.0000024 ± 0.0000015	0.0000005 ± 0.0000009	0.0000016 ± 0.0000012	0.0000008 ± 0.0000005
Gross Beta	300 Pond	26	0.534 ± 0.011	0.019 ± 0.004	0.074 ± 0.054	0.059 ± 0.02
	ACRMS (14)	26	0.495 ± 0.011	0.016 ± 0.004	0.063 ± 0.044	
	300S Gate	24	0.474 ± 0.010	0.015 ± 0.004	0.068 ± 0.046	
Gross Alpha	300 Pond (13)	26	0.0038 ± 0.0008	0.0005 ± 0.0004	0.068 ± 0.027	0.0009 ± 0.0002
	300S Gate (15)	24	0.0024 ± 0.0007	0.0004 ± 0.0003	0.0015 ± 0.0003	
					0.0011 ± 0.0002	
					0.0013 ± 0.0002	

- (a) Maximum and minimum concentrations ±2 sigma counting error. Averages ±2 standard error of the calculated mean. Entries have been rounded for clarity.
 (b) Sample map location numbers are shown in parentheses. Sampling locations are identified in Table A.1 and Figure 3-1.
 (c) Composites of biweekly samples from the individual sampling locations (13-14) in Table A.1.

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

Radio-nuclide	Sampling Location ^(b)	Number of Samples	Concentration, pCi/m ³ ^(a) (10 ⁻¹² μCi/mL)			Average 1986 Distant ^(b)
			Maximum	Minimum	Average	
³ H(c)	400E (16)	11	1.7 ± 3.1	0.3 ± 0.2	1.4 ± 0.6	1.4 ± 0.8
⁹⁰ Sr	Composite ^(d)	4	0.00028 ± 0.00007	0.00005 ± 0.00003	0.00014 ± 0.00011	0.00015 ± 0.00005
¹³¹ I	400E	25	0.511 ± 0.026	-0.008 ± 0.006	0.037 ± 0.049	0.035 ± 0.045
¹³⁷ Cs	Composite	12	0.0906 ± 0.0047	-0.0005 ± 0.0007	0.0081 ± 0.0150	0.0089 ± 0.0084
²³⁸ Pu	Composite	4	0.0000003 ± 0.0000009	0.0000000 ± 0.0000000	0.0000001 ± 0.0000003	0.0000001 ± 0.0000003
^{239,240} Pu	Composite	4	0.0000008 ± 0.0000007	0.0000002 ± 0.0000004	0.0000005 ± 0.0000004	0.0000008 ± 0.0000005
Gross Beta	400E (16)	25	0.492 ± 0.011	0.015 ± 0.004	0.068 ± 0.047	0.069 ± 0.023
	400W (17)	25	0.495 ± 0.011	0.014 ± 0.004	0.070 ± 0.047	
	400S (18)	25	0.472 ± 0.010	0.017 ± 0.004	0.067 ± 0.045	
	400N (19)	25	0.484 ± 0.011	0.016 ± 0.004	0.072 ± 0.050	
Gross Alpha	400E (16)	25	0.0040 ± 0.0009	0.0004 ± 0.0003	0.0010 ± 0.0003	0.0009 ± 0.0002
	400W (17)	25	0.0035 ± 0.0008	0.0002 ± 0.0002	0.0009 ± 0.0003	
	400S (18)	25	0.0030 ± 0.0007	0.0001 ± 0.0003	0.0009 ± 0.0002	
	400N (19)	25	0.0027 ± 0.0007	0.0003 ± 0.0003	0.0010 ± 0.0002	
					0.0010 ± 0.0001	

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

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

Radionuclide	Sampling Location ^(b)	Number of Samples	Concentration, pCi/m ³ ^(a) (10 ⁻¹² µCi/mL)			
			Maximum	Minimum	Average	Average 1986 Distant ^(b)
⁹⁰ Sr	Wye Barricade (21)	4	0.00045 ± 0.00015	0.00016 ± 0.00013	0.00031 ± 0.00017	0.00015 ± 0.00005
¹³⁷ Cs	Wye Barricade	12	0.107 ± 0.011	-0.001 ± 0.002	0.009 ± 0.018	0.0089 ± 0.0084
²³⁸ Pu	Wye Barricade	4	0.0000018 ± 0.0000026	0.0000000 ± 0.0000000	0.0000008 ± 0.0000014	0.0000001 ± 0.0000003
²³⁹ Pu	Wye Barricade	4	0.0000027 ± 0.0000031	0.0000000 ± 0.0000000	0.0000012 ± 0.0000019	0.0000008 ± 0.0000005
Gross Beta	Hanford (20)	25	0.841 ± 0.014	0.011 ± 0.004	0.073 ± 0.066	
	Wye Barricade (21)	26	0.752 ± 0.013	0.012 ± 0.004	0.069 ± 0.057	0.059 ± 0.02
Gross Alpha	Hanford (20)	25	0.0024 ± 0.0007	0.0004 ± 0.0003	0.0010 ± 0.0002	
	Wye Barricade (21)	26	0.0030 ± 0.0008	0.0003 ± 0.0003	0.0010 ± 0.0002	0.0009 ± 0.0002

(a) Maximum and minimum concentrations ±2 sigma counting error. Averages ±2 standard error of the calculated mean. Entries have been rounded for clarity.

(b) Sample map location numbers are shown in parentheses. Sampling locations are identified in Table A.1 and Figure 3.1.

TABLE A.12. Tritium Concentrations in the Ground Water

Well Name (b)	No. of Samples	³ H Concentration (pCi/L) (a)		
		Maximum	Minimum	Average
1-B3-1	4	2,600 ± 330	1,000 ± 440	1,700 ± 800
1-B3-2P (c)	1			330 ± 250
1-B4-1	3	54,000 --- (d)	8,500 ± 390	29,000 ± 31,000
1-B4-2	4	3,600 ± 340	1,500 ± 440	2,400 ± 1,000
1-B4-3	4	20,000 ± 530	5,900 ± 470	14,000 ± 6,900
1-B4-4	3	1,800 ± 320	540 ± 430	1,300 ± 880
1-B5-1	4	1,300 ± 310	480 ± 430	820 ± 430
1-B9-1	4	1,500 ± 320	540 ± 430	1,000 ± 480
1-D2-5	4	3,600 ± 340	1,300 ± 440	2,400 ± 1,100
1-D5-12	4	5,700 ± 360	2,100 ± 440	4,200 ± 1,700
1-D8-3	4	4,000 ± 340	3,300 ± 480	3,700 ± 390
1-F5-1	4	380 ± 300	-380 ± 420	42 ± 410
1-F5-3	4	1,600 ± 320	250 ± 430	920 ± 690
1-F5-4	4	27,000 ± 540	24,000 ---	26,000 ± 1,600
1-F5-6	4	1,200 ± 440	65 ± 420	830 ± 580
1-F7-1	4	1,000 ± 310	170 ± 430	660 ± 440
1-F8-1	12	42,000 ---	27,000 ± 530	34,000 ± 3,600
1-F8-2	4	3,400 ± 330	2,300 ± 450	2,900 ± 570
1-H3-1	4	5,600 ± 360	4,600 ± 350	5,100 ± 540
1-H4-5	4	520 ± 300	130 ± 410	340 ± 260
1-H4-6	4	3,100 ± 340	1,600 ± 430	2,300 ± 770
1-K-11	4	3,400 ± 340	1,100 ± 310	2,000 ± 1,100
1-K-19	12	17,000 ± 570	7,400 ± 370	10,000 ± 1,800
1-K-20	4	1,400 ± 310	890 ± 430	1,200 ± 310
1-K-22	4	1,000 ± 410	310 ± 430	700 ± 380
1-K-27	4	2,100 ± 320	710 ± 310	1,300 ± 690
1-K-28	4	4,500 ± 330	1,800 ± 440	3,200 ± 1,300
1-K-29	4	50,000 ---	5,300 ± 350	27,000 ± 22,000
1-K-30	4	910,000 ---	350,000 ---	640,000 ± 270,000
1-K-31	4	4,700 ± 340	4,400 ± 340	4,500 ± 230
1-N-2	4	57,000 ---	40,000 ---	49,000 ± 8,500
1-N-3	4	55,000 ---	26,000 ± 640	38,000 ± 14,000
1-N-4	3	83,000 ---	33,000 ---	51,000 ± 34,000
1-N-5	4	63,000 ---	29,000 ± 670	45,000 ± 16,000
1-N-6	4	120,000 ---	40,000 ---	76,000 ± 39,000
1-N-7	4	89,000 ---	32,000 ---	59,000 ± 28,000
1-N-14	4	81,000 ---	41,000 ---	59,000 ± 19,000
1-N-15	3	81,000 ---	31,000 ---	49,000 ± 34,000
1-N-16	2	540 ± 410	310 ± 430	430 ± 410
1-N-17	4	38,000 ---	27,000 ± 680	31,000 ± 5,200
1-N-18	4	38,000 ---	24,000 ± 520	30,000 ± 7,000
1-N-19	4	47,000 ---	13,000 ± 570	31,000 ± 16,000
1-N-20	4	42,000 ---	8,100 ± 520	25,000 ± 16,000
1-N-21	4	10,000 ± 520	1,600 ± 320	5,200 ± 4,100
1-N-22	4	6,200 ± 480	1,300 ± 440	3,100 ± 2,400
1-N-23	4	7,800 ± 490	3,000 ± 340	5,500 ± 2,400
1-N-24	2	3,400 ± 340	1,700 ± 320	2,600 ± 2,200
1-N-25	3	490 ± 410	10 ± 300	240 ± 380
1-N-26	2	250 ± 410	94 ± 430	170 ± 360

TABLE A.12. (contd)

Well Name ^(b)	No. of Samples	³ H Concentration (pCi/L) ^(a)		
		Maximum	Minimum	Average
1-N-27	4	240,000 ---	41,000 ---	110,000 ± 95,000
1-N-28	4	120,000 ---	48,000 ---	72,000 ± 33,000
1-N-29	4	120,000 ---	29,000 ---	85,000 ± 43,000
1-N-30	4	89,000 ---	36,000 ---	60,000 ± 26,000
1-N-31	4	100,000 ---	37,000 ---	82,000 ± 31,000
1-N-32	4	120,000 ---	40,000 ---	84,000 ± 39,000
1-N-33	4	93,000 ---	31,000 ---	63,000 ± 30,000
1-N-34	4	110,000 ---	41,000 ---	72,000 ± 32,000
1-N-36	4	120,000 ---	45,000 ---	85,000 ± 36,000
1-N-37	4	110,000 ---	49,000 ---	88,000 ± 31,000
1-N-39	4	110,000 ---	30,000 ---	71,000 ± 37,000
1-N-45	3	210,000 ---	26,000 ± 640	100,000 ± 120,000
2-E19-1	2	220 ± 290	66 ± 290	140 ± 280
2-E23-1	2	12,000 ± 410	5,400 ± 350	8,700 ± 8,300
2-E24-7	2	11,000 ± 400	8,100 ± 380	9,600 ± 3,600
2-E25-2	2	11,000 ± 410	9,600 ± 390	10,000 ± 1,800
2-E26-1	2	6,300 ± 360	2,800 ± 330	4,600 ± 4,400
2-E26-3	2	5,400 ± 350	4,600 ± 340	5,000 ± 1,000
2-E26-8 ^(c)	1			-38 ± 230
2-E27-1	2	2,700 ± 330	2,400 ± 310	2,600 ± 440
2-E28-1	2	4,400 ± 340	3,200 ± 330	3,800 ± 1,500
2-E28-5	2	7,000 ± 360	6,700 ± 370	6,900 ± 460
2-E33-12 ^(c)	1			390 ± 250
2-E33-14	2	580 ± 290	500 ± 300	540 ± 230
2-W6-1	2	46,000 ---	44,000 ---	45,000 ± 2,400
2-W10-5	2	8,100 ± 510	7,700 ± 380	7,900 ± 640
2-W11-9	2	43,000 ---	400 ± 430	22,000 ± 53,000
2-W12-1	2	3,200 ± 340	2,300 ± 450	2,800 ± 1,200
2-W15-2	1			81 ± 420
2-W18-3	2	160 ± 430	-89 ± 300	36 ± 410
2-W21-1	2	150,000 ---	120,000 ---	140,000 ± 36,000
2-W22-7	2	370,000 ---	340,000 ---	360,000 ± 36,000
2-W22-9	2	8,200,000 ---	7,900,000 ---	8,100,000 ± 430,000
3-1-1	4	510 ± 430	-110 ± 410	220 ± 350
3-1-2	4	800 ± 310	-230 ± 420	230 ± 530
3-1-3	4	370 ± 290	-300 ± 410	75 ± 370
3-1-4	4	360 ± 300	-370 ± 420	-47 ± 400
3-1-5	4	290 ± 300	17 ± 410	130 ± 230
3-1-6	4	310 ± 300	-190 ± 420	45 ± 300
3-2-1	4	240 ± 300	-210 ± 410	38 ± 280
3-2-2	4	450 ± 300	-320 ± 420	150 ± 420
3-2-3	4	550 ± 300	150 ± 430	270 ± 270
3-3-1	4	700 ± 310	-130 ± 410	140 ± 440
3-3-2	4	430 ± 290	-410 ± 410	100 ± 440
3-3-3	4	1,600 ± 310	10 ± 410	600 ± 790
3-3-6	4	860 ± 300	-62 ± 410	380 ± 480
3-3-7	4	2,200 ± 320	620 ± 450	1,300 ± 790
3-3-9	4	670 ± 310	-300 ± 420	180 ± 510
3-3-10	4	470 ± 300	-310 ± 410	25 ± 420
3-3-11	4	1,900 ± 320	450 ± 420	1,000 ± 720
3-3-12	4	2,600 ± 330	470 ± 300	1,500 ± 1,100

TABLE A.12. (contd)

Well Name (b)	No. of Samples	³ H Concentration (pCi/L) (a)		
		Maximum	Minimum	Average
3-4-1	4	990 ± 300	100 ± 410	550 ± 470
3-4-7	4	1,400 ± 300	350 ± 430	760 ± 560
3-4-9	4	1,400 ± 310	-83 ± 430	380 ± 740
3-4-10	4	1,300 ± 310	110 ± 430	710 ± 620
3-5-1	4	230 ± 300	-140 ± 290	68 ± 240
3-6-1	4	290 ± 410	83 ± 290	200 ± 190
3-8-1	4	230 ± 410	-360 ± 420	33 ± 340
3-8-2	4	0 ± 290	-390 ± 420	-190 ± 260
3-8-3	4	620 ± 410	120 ± 430	330 ± 300
3-8-4	4	230 ± 410	-120 ± 290	73 ± 250
4-S0-7	3	35,000 ± 580	20,000 ± 610	30,000 ± 9,900
4-S0-8	2	21,000 ± 620	390 ± 300	11,000 ± 26,000
4-S1-7B	4	62,000 ---	57,000 ---	60,000 ± 2,400
4-S1-7C	4	85,000 ---	80,000 ---	83,000 ± 2,400
4-S1-8A	4	92,000 ---	88,000 ---	91,000 ± 2,000
4-S1-8B	3	89,000 ---	88,000 ---	88,000 ± 680
6-1-18	4	55,000 ---	52,000 ---	54,000 ± 1,500
6-2-3	13	110,000 ---	210 ± 410	100,000 ± 17,000
6-2-7	4	16,000 ± 560	12,000 ± 410	14,000 ± 11,000
6-2-33A	3	190 ± 290	6 ± 290	110 ± 230
6-3-45	2	35 ± 400	-40 ± 290	-3 ± 260
6-4-E6	4	360 ± 280	-280 ± 300	45 ± 350
6-8-17	4	160,000 ---	140,000 ---	150,000 ± 7,800
6-8-25	4	42,000 ---	40,000 ---	41,000 ± 1,100
6-8-32	4	320 ± 410	-230 ± 290	11 ± 310
6-9-E2	4	340 ± 290	-310 ± 420	28 ± 360
6-10-54A	4	130 ± 290	-250 ± 290	-33 ± 240
6-10-E12	3	14,000 ± 420	12,000 ± 530	13,000 ± 1,300
6-13-1C	1			-330 ± 420
6-13-64	4	330 ± 290	-300 ± 290	12 ± 350
6-14-38	4	770 ± 410	-320 ± 300	230 ± 550
6-14-47	3	290 ± 290	-280 ± 300	-3 ± 430
6-14-E6T	2	41,000 ---	40,000 ---	41,000 ± 1,600
6-15-15B	4	260 ± 290	8 ± 410	150 ± 200
6-15-26	4	78,000 ---	67,000 ---	71,000 ± 5,500
6-17-5	4	64 ± 420	-360 ± 290	-160 ± 260
6-17-70	4	190 ± 290	-290 ± 400	-19 ± 280
6-19-43	4	310 ± 280	-330 ± 300	-34 ± 350
6-19-58	4	-53 ± 400	-260 ± 290	-170 ± 190
6-19-88	4	120 ± 420	-150 ± 290	33 ± 210
6-20-20	4	230,000 ---	220,000 ---	230,000 ± 4,400
6-20-39(c)	4	210 ± 410	-330 ± 300	55 ± 310
6-20-82	4	190 ± 290	-160 ± 300	-6 ± 240
6-20-E12	4	12,000 ± 420	60 ± 290	3,300 ± 5,800
6-20-E12P(c)	2	260 ± 410	-250 ± 290	5 ± 690
6-20-E5A	4	55,000 ---	49,000 ---	53,000 ± 3,000
6-20-E5AP(c)	3	120 ± 410	-210 ± 290	-74 ± 290
6-20-E5AQ(c)	3	41 ± 290	-170 ± 400	-58 ± 230
6-20-E5AR(c)	2	-90 ± 400	-190 ± 290	-140 ± 280
6-21-6	12	57,000 ---	50,000 ---	54,000 ± 1,200
6-22-70	4	290 ± 290	-260 ± 300	49 ± 310
6-22-70P(c)	1			-17 ± 250

TABLE A.12. (contd)

Well Name ^(b)	No. of Samples	³ H Concentration (pCi/L) ^(a)		
		Maximum	Minimum	Average
6-24-1P ^(c)	3	28 ± 230	-260 ± 400	-120 ± 270
6-24-1Q ^(c)	2	-45 ± 290	-55 ± 400	-50 ± 250
6-24-1R ^(c)	2	160 ± 410	-140 ± 290	10 ± 450
6-24-1S ^(c)	2	-43 ± 400	-230 ± 290	-140 ± 340
6-24-1T	2	9,900 ± 400	9,200 ± 500	9,600 ± 960
6-24-33	4	64,000 ---	41,000 ---	50,000 ± 11,000
6-24-46	4	360 ± 290	-340 ± 300	74 ± 380
6-25-55	4	100 ± 290	-320 ± 420	-120 ± 260
6-25-70	4	1,700 ± 300	880 ± 300	1,200 ± 430
6-26-15A	4	410,000 ---	340,000 ---	370,000 ± 35,000
6-27-8	4	390,000 ---	340,000 ---	360,000 ± 23,000
6-28-40	4	13,000 ± 420	11,000 ± 400	12,000 ± 670
6-28-40P ^(c)	2	-34 ± 290	-230 ± 490	-130 ± 380
6-28-52A	4	290 ± 290	61 ± 280	190 ± 200
6-29-4	12	130,000 ---	120,000 ---	130,000 ± 2,700
6-29-78	3	660 ± 410	-270 ± 300	240 ± 660
6-31-31	4	120,000 ---	63,000 ---	87,000 ± 28,000
6-31-31P ^(c)	2	500 ± 300	120 ± 410	310 ± 540
6-31-53B	1			-450 ± 420
6-32-22	4	370,000 ---	310,000 ---	340,000 ± 31,000
6-32-43	4	180,000 ---	120,000 ---	150,000 ± 31,000
6-32-62	4	1,700 ± 330	1,100 ± 430	1,300 ± 340
6-32-70B	3	280,000 ---	270,000 ---	270,000 ± 8,200
6-32-72	4	140,000 ---	130,000 ---	140,000 ± 5,800
6-32-77	4	360 ± 430	-210 ± 300	140 ± 320
6-33-42	4	240,000 ---	200,000 ---	220,000 ± 20,000
6-33-56	3	3,700 ± 330	48 ± 280	1,400 ± 2,500
6-34-39A	4	17,000 ± 450	11,000 ± 410	14,000 ± 2,700
6-34-41B	4	72,000 ---	62,000 ---	67,000 ± 5,100
6-34-42	4	120,000 ---	79,000 ---	100,000 ± 20,000
6-34-51	4	200 ± 290	-300 ± 300	36 ± 290
6-34-88	3	240 ± 290	-260 ± 300	-8 ± 390
6-35-66	4	1,200,000 ---	1,200,000 ---	1,200,000 ± 24,000
6-35-70	4	1,600,000 ---	1,500,000 ---	1,600,000 ± 53,000
6-35-9	4	170,000 ---	160,000 ---	170,000 ± 6,300
6-36-46P ^(c)	2	150 ± 410	-100 ± 280	25 ± 400
6-36-46Q ^(c)	2	-72 ± 280	-300 ± 400	-190 ± 380
6-36-61B	3	100 ± 410	-290 ± 300	-97 ± 330
6-36-93	2	360 ± 290	-440 ± 420	-40 ± 1,000
6-37-43	4	47,000 ---	22,000 ± 620	29,000 ± 12,000
6-37-82A	4	120 ± 290	-320 ± 300	-66 ± 270
6-37-E4	12	38,000 ---	28,000 ---	32,000 ± 2,000
6-38-15	4	550,000 ---	510,000 ---	530,000 ± 18,000
6-38-65	4	340,000 ---	290,000 ---	320,000 ± 23,000
6-38-70	4	1,800 ± 440	860 ± 320	1,400 ± 490
6-39-0	14	240,000 ---	220,000 ---	230,000 ± 3,000
6-39-39	2	850 ± 300	160 ± 430	510 ± 900
6-39-79	3	320 ± 410	-230 ± 300	97 ± 420
6-40-1	4	240,000 ---	220,000 ---	230,000 ± 9,700
6-40-33A	4	530 ± 290	-310 ± 300	80 ± 440
6-40-62	4	62,000 ---	52,000 ---	58,000 ± 4,700
6-41-1	14	240,000 ---	220,000 ---	230,000 ± 2,700
6-41-23	4	220,000 ---	180,000 ---	200,000 ± 17,000
6-42-2	14	220,000 ---	200,000 ---	210,000 ± 2,700

TABLE A.12. (contd)

Well Name ^(b)	No. of Samples	³ H Concentration (pCi/L) ^(a)		
		Maximum	Minimum	Average
6-42-12A	4	310,000 ---	300,000 ---	300,000 ± 5,300
6-42-40C ^(c)	1			310 ± 240
6-43-3	14	230,000 ± 2000	200,000 ---	220,000 ± 5,100
6-43-88	3	-47 ± 410	-230 ± 300	-140 ± 230
6-44-4	12	140,000 ---	100,000 ---	120,000 ± 6,400
6-44-64	4	650 ± 290	-170 ± 410	200 ± 430
6-45-2	6	210,000 ---	170,000 ---	190,000 ± 13,000
6-45-42	4	52,000 ---	51,000 ---	51,000 ± 490
6-45-69A	4	600 ± 300	150 ± 290	370 ± 270
6-46-4	13	190,000 ---	140,000 ---	160,000 ± 10,000
6-46-21B	4	42,000 ---	41,000 ---	42,000 ± 630
6-46-32 ^(c)	1			13 ± 230
6-47-5	14	180,000 ± 2000	87,000 ---	150,000 ± 18,000
6-47-35A	4	210 ± 280	-350 ± 290	19 ± 320
6-47-46A	4	140 ± 290	-310 ± 300	-70 ± 270
6-47-50 ^(c)	1			370 ± 240
6-47-60	4	360 ± 280	-290 ± 290	-97 ± 360
6-48-7	4	380 ± 290	-150 ± 410	180 ± 300
6-48-18	4	280 ± 280	-230 ± 290	6 ± 300
6-48-71	4	290 ± 430	11 ± 280	120 ± 210
6-49-13E	4	4,000 ± 340	110 ± 300	1,100 ± 1,900
6-49-28	4	1,000 ± 290	430 ± 410	730 ± 330
6-49-32B ^(c)	1			61 ± 230
6-49-55A	4	15,000 ± 430	9,000 ± 500	12,000 ± 2,800
6-49-55B ^(c)	1			-240 ± 230
6-49-57	4	4,000 ± 450	2,800 ± 330	3,300 ± 610
6-49-79	4	510 ± 300	-8 ± 290	160 ± 300
6-50-28B	4	710 ± 290	-130 ± 400	350 ± 440
6-50-30	4	290 ± 290	-150 ± 290	79 ± 270
6-50-42 ^(c)	4	3,700 ± 320	2,000 ± 430	2,700 ± 840
6-50-45 ^(c)	1			-55 ± 230
6-50-48B ^(c)	1			-91 ± 230
6-50-53	4	2,100 ± 310	700 ± 410	1,300 ± 680
6-50-85	4	230 ± 300	-170 ± 400	69 ± 250
6-51-46 ^(c)	1			-67 ± 250
6-51-63	4	390 ± 290	-270 ± 490	150 ± 370
6-51-75	4	230 ± 290	-70 ± 280	70 ± 220
6-52-46A ^(c)	1			-60 ± 250
6-52-48 ^(c)	1			41 ± 250
6-53-35	4	180 ± 420	65 ± 300	120 ± 170
6-53-50 ^(c)	1			-130 ± 250
6-53-103 ^(c)	2	78 ± 290	-330 ± 420	-130 ± 570
6-54-34	4	690 ± 410	-150 ± 300	240 ± 440
6-54-37A	4	390 ± 420	-42 ± 300	210 ± 270
6-54-42	4	250 ± 290	-160 ± 300	120 ± 260
6-54-45A	2	3,500 ± 330	220 ± 290	1,900 ± 4,200
6-54-57 ^(c)	1			160 ± 240
6-55-40	4	320 ± 290	-96 ± 300	110 ± 260
6-55-44	4	330 ± 290	-48 ± 280	170 ± 250
6-55-50A	4	430 ± 290	65 ± 300	230 ± 240
6-55-50C	4	1,300 ± 420	-19 ± 300	550 ± 660
6-55-50D	4	300 ± 290	-59 ± 300	110 ± 240
6-55-70	3	160 ± 290	16 ± 410	110 ± 220
6-56-43	4	360 ± 290	-130 ± 300	55 ± 290

TABLE A.12. (contd)

Well Name (b)	No. of Samples	³ H Concentration (pCi/L) (a)		
		Maximum	Minimum	Average
6-56-53 ^(c)	1			10 ± 250
6-57-25A	4	650 ± 410	150 ± 290	380 ± 290
6-57-29A	4	1,200 ± 300	570 ± 420	870 ± 360
6-58-24	4	270 ± 290	54 ± 280	190 ± 190
6-59-32	4	830 ± 300	170 ± 430	650 ± 360
6-59-58	4	1,100 ± 430	470 ± 310	750 ± 350
6-60-32	4	1,000 ± 300	350 ± 430	810 ± 370
6-60-57	4	1,200 ± 440	380 ± 310	710 ± 430
6-60-60	4	7,800 ± 370	7,500 ± 380	7,600 ± 250
6-61-37	4	970 ± 300	500 ± 430	840 ± 280
6-61-41	4	360 ± 300	-300 ± 420	170 ± 360
6-61-62	4	8,800 ± 390	8,200 ± 510	8,600 ± 350
6-61-66	4	6,200 ± 490	-190 ± 290	1,600 ± 3,100
6-62-43F	4	950 ± 300	400 ± 430	800 ± 310
6-63-25A	4	160 ± 290	-320 ± 290	-69 ± 280
6-63-51	4	810 ± 300	-170 ± 420	410 ± 500
6-63-55	4	660 ± 300	-230 ± 420	260 ± 460
6-63-58	4	870 ± 290	31 ± 420	540 ± 440
6-63-90	3	93 ± 290	35 ± 500	65 ± 220
6-64-27	5	170 ± 290	-170 ± 420	37 ± 190
6-64-62	4	18,000 ± 600	8,800 ± 390	11,000 ± 4,500
6-65-50	4	1,000 ± 300	150 ± 430	660 ± 450
6-65-59	3	780 ± 290	130 ± 420	500 ± 490
6-65-72	4	4,000 ± 340	3,700 ± 450	3,800 ± 230
6-65-83	4	1,300 ± 300	790 ± 300	1,100 ± 290
6-66-58	4	730 ± 290	52 ± 420	440 ± 370
6-66-64	4	7,800 ± 370	5,100 ± 480	6,400 ± 1,300
6-66-103	4	360 ± 290	-150 ± 420	200 ± 300
6-67-51	4	1,200 ± 290	210 ± 430	830 ± 490
6-67-86	4	1,300 ± 300	1,000 ± 420	1,100 ± 220
6-67-98	4	480 ± 290	-390 ± 400	110 ± 450
6-68-105	4	390 ± 300	-370 ± 420	150 ± 400
6-69-38	4	350 ± 290	-190 ± 420	140 ± 310
6-70-68	4	1,900 ± 310	1,100 ± 440	1,700 ± 430
6-71-30	4	280 ± 290	-140 ± 400	29 ± 260
6-71-52	5	1,400 ± 300	700 ± 430	1,100 ± 300
6-71-77	4	2,700 ± 320	1,400 ± 420	2,300 ± 640
6-72-73	2	2,800 ± 320	920 ± 430	1,900 ± 2,300
6-72-88	4	3,200 ± 320	2,900 ± 320	3,000 ± 240
6-72-92	2	3,200 ± 320	1,300 ± 440	2,200 ± 2,400
6-72-98	1			610 ± 300
6-73-61	4	280 ± 290	-69 ± 420	130 ± 240
6-74-44	4	130 ± 290	-420 ± 420	-100 ± 310
6-77-36	5	310 ± 290	120 ± 290	200 ± 160
6-81-58	4	210 ± 410	-86 ± 290	55 ± 220
6-83-47	3	1,000 ± 300	240 ± 430	760 ± 580
6-84-35A0	2	350 ± 290	130 ± 290	240 ± 340
6-87-55	4	57,000 ---	49,000 ---	53,000 ± 4,000
6-89-35	5	750 ± 290	320 ± 290	560 ± 220
6-90-45	5	4,400 ± 340	3,800 ± 330	4,100 ± 270
6-96-49	4	17,000 ± 460	15,000 ± 560	16,000 ± 1,000
6-97-43	4	10,000 ± 390	9,300 ± 500	9,700 ± 490
6-97-51A	4	15,000 ± 550	13,000 ± 430	14,000 ± 1,000
6-101-48B	4	290 ± 300	-120 ± 400	52 ± 260

TABLE A.12. (contd)

Well Name ^(b)	No. of Samples	³ H Concentration (pCi/L) ^(a)		
		Maximum	Minimum	Average
6-S3-25	1			330 ± 290
6-S3-E12	5	4,700 ± 330	4,000 ± 450	4,400 ± 300
6-S6-E4B	5	24,000 ± 520	23,000 ---	23,000 ± 560
6-S6-E4D	5	35,000 ---	32,000 ---	34,000 ± 1,200
6-S6-E14A ^(c)	3	57 ± 290	-350 ± 420	-130 ± 340
6-S7-34	4	160 ± 290	-160 ± 400	-11 ± 220
6-S8-19	4	330 ± 410	-46 ± 290	190 ± 250
6-S11-E12A	2	2,200 ± 320	1,500 ± 310	1,900 ± 900
6-S11-E12AP ^(c)	3	250 ± 280	-350 ± 290	-3 ± 440
6-S12-3	4	270 ± 410	-330 ± 300	-3 ± 330
6-S14-20A	4	320 ± 290	-180 ± 290	82 ± 290
6-S16-24 ^(c)	1			3 ± 250
6-S19-11	2	290 ± 290	26 ± 290	160 ± 390
6-S19-E13	5	5,400 ± 360	3,900 ± 470	4,700 ± 610
6-S24-19	1			-93 ± 290
6-S27-E14	12	820 ± 320	-410 ± 420	90 ± 220
6-S29-E12	4	340 ± 280	-60 ± 290	180 ± 250
6-S30-E15A	4	200 ± 300	-160 ± 300	18 ± 250
6-S31-1P ^(c)	4	420 ± 300	-280 ± 300	98 ± 380

- a) Maximum and minimum concentrations ±2 sigma counting error. Average concentrations for 1986 ±2 standard error of the calculated mean (or ± the counting error for one sample).
- b) See Figure 3.10 for well locations.
- c) Wells that sample a confined aquifer or a composite of a confined and the unconfined aquifer.
- d) Counting errors were not reported.

TABLE A.13. Gross Alpha Concentrations in the Ground Water

Well Name ^(b)	No. of Samples	Gross Alpha Concentration (pCi/L) ^(a)		
		Maximum	Minimum	Average
2-W22-10	2	1.5 ± 1.5	1.1 ± 5.0	1.3 ± 2.7
6-2-3	1			-1.0 ± 1.4
6-20-20	1			2.4 ± 1.9
6-26-15A	1			2.7 ± 1.8
6-29-4	1			1.4 ± 1.8
6-32-62	4	6.0 ± 3.0	0.7 ± 0.9	3.3 ± 2.8
6-33-56	3	5.5 ± 4.9	-1.0 ± 1.4	2.2 ± 4.8
6-40-1	1			4.3 ± 3.6
6-42-2	1			1.1 ± 1.6
6-47-5	1			5.7 ± 3.7

(a) Maximum and minimum concentrations for 1986 ±2 sigma counting error. Average concentrations ±2 standard error of the calculated mean (or ± counting error for one sample).

(b) See Figure 3.10 for well locations.

TABLE A.14. Gross Beta Concentrations in the Ground Water

Well Name ^(b)	No. of Samples	Gross Beta Concentration (pCi/L) ^(a)		
		Maximum	Minimum	Average
1-H3-1	4	14 ± 15	-1.9 ± 14	4.5 ± 11
1-H4-3	4	720 ± 32	160 ± 19	500 ± 270
1-H4-4	4	440 ± 27	53 ± 16	210 ± 190
1-H4-5	4	12 ± 14	6.5 ± 14	9.1 ± 7.5
1-H4-6	4	11 ± 14	-2.2 ± 14	3.0 ± 9.5
1-K-31	2	6.2 ± 14	5.0 ± 14	5.6 ± 10
3-1-1	4	22 ± 15	11 ± 14	17 ± 8.9
3-1-2	4	27 ± 15	8.7 ± 14	20 ± 12
3-1-3	4	38 ± 15	21 ± 15	27 ± 11
3-1-4	4	21 ± 14	3.1 ± 14	13 ± 11
3-1-5	4	23 ± 15	13 ± 14	19 ± 8.7
3-1-6	4	18 ± 14	0.3 ± 14	8.0 ± 11
3-2-1	4	21 ± 15	7.8 ± 14	16 ± 9.7
3-2-2	4	29 ± 15	15 ± 14	24 ± 10
3-2-3	4	16 ± 15	7.1 ± 14	11 ± 8.3
3-3-1	4	21 ± 15	10 ± 14	15 ± 8.9
3-3-2	4	7.4 ± 14	2.2 ± 14	4.5 ± 7.4
3-3-3	4	12 ± 14	2.5 ± 14	7.6 ± 8.4
3-3-6	4	24 ± 15	9.0 ± 14	18 ± 10
3-3-7	4	18 ± 15	2.2 ± 14	10 ± 10
3-3-9	4	20 ± 15	12 ± 14	16 ± 8.1
3-3-10	4	20 ± 15	9.6 ± 14	14 ± 8.8
3-3-11	4	31 ± 15	15 ± 14	25 ± 11
3-3-12	4	25 ± 15	14 ± 14	20 ± 9
3-4-1	4	20 ± 15	-1.2 ± 14	9.3 ± 13
3-4-7	4	44 ± 15	5.9 ± 14	23 ± 20
3-4-9	4	27 ± 15	4.0 ± 14	15 ± 13
3-4-10	4	24 ± 15	13 ± 14	20 ± 9
3-5-1	4	46 ± 15	14 ± 14	27 ± 17
3-6-1	4	11 ± 14	2.5 ± 14	7.0 ± 8.1
3-8-1	4	21 ± 15	5.0 ± 14	11 ± 11
3-8-2	4	24 ± 15	7.4 ± 14	18 ± 11
3-8-3	4	43 ± 15	4.3 ± 14	16 ± 20
3-8-4	4	15 ± 14	-3.7 ± 14	6.0 ± 11
4-S1-7C	4	58 ± 16	18 ± 14	30 ± 21
4-S1-8A	4	31 ± 15	12 ± 14	24 ± 12
4-S1-8B	3	34 ± 15	26 ± 15	29 ± 10
6-20-20	1			50 ± 16
6-26-15A	1			60 ± 16
6-29-4	1			39 ± 15
6-40-1	1			82 ± 17
6-42-2	1			60 ± 16
6-47-5	1			32 ± 15
6-S27-E14	1			-0.9 ± 14

- (a) Maximum and minimum concentrations ±2 sigma counting error. Average concentrations for 1986 ±2 standard error of the calculated mean (or ± counting error for one sample).
- (b) See Figure 3.10 for well locations.

TABLE A.15. Cobalt-60 Concentrations in the Ground Water

Well Name ^(b)	No. of Samples	⁶⁰ Co Concentration (pCi/L) ^(a)		
		Maximum	Minimum	Average
1-B3-2p ^(c)	1			3.0 ± 3.5
1-B4-4	3	20 ± 25	9.2 ± 9.2	15 ± 13
1-D5-12	4	20 ± 25	10 ± 10	15 ± 11
1-H3-1	4	15 ± 20	-20 ± 20	4.3 ± 19
1-H4-3	4	49 ± 34	8.8 ± 8.8	23 ± 23
1-H4-4	4	25 ± 27	-15 ± 17	7.7 ± 21
1-H4-5	4	12 ± 12	-12 ± 12	3.8 ± 13
1-H4-6	4	22 ± 13	-13 ± 5.4	7.5 ± 18
1-K-11	3	15 ± 15	-3.5 ± 18	8.5 ± 16
1-K-27	4	20 ± 25	-7.3 ± 9.6	11 ± 16
1-K-28	4	22 ± 22	-5.1 ± 5.3	12 ± 16
1-K-29	4	21 ± 6.0	4.4 ± 20	15 ± 12
1-K-30	4	26 ± 26	-15 ± 22	7.4 ± 22
1-N-2	4	93 ± 9.8	21 ± 25	60 ± 37
1-N-3	4	55 ± 18	20 ± 2.5	45 ± 18
1-N-4	3	84 ± 52	25 ± 6.7	58 ± 44
1-N-5	4	69 ± 37	8.4 ± 8.4	29 ± 32
1-N-6	4	150 ± 17	83 ± 11	110 ± 34
1-N-7	4	110 ± 9.2	20 ± 25	76 ± 47
1-N-14	4	110 ± 32	50 ± 17	79 ± 32
1-N-15	3	89 ± 20	15 ± 20	59 ± 52
1-N-16	2	15 ± 15	5.4 ± 8.8	10 ± 15
1-N-17	4	21 ± 21	-6.0 ± 12	8.5 ± 16
1-N-18	4	33 ± 33	15 ± 20	21 ± 15
1-N-19	4	37 ± 5.2	15 ± 20	23 ± 15
1-N-20	4	380 ± 50	10 ± 9.0	110 ± 180
1-N-21	4	20 ± 25	6.3 ± 6.3	14 ± 11
1-N-22	4	23 ± 23	-1.0 ± 7.4	12 ± 15
1-N-23	4	30 ± 22	20 ± 25	23 ± 13
1-N-24	2	20 ± 25	5.0 ± 5.0	13 ± 23
1-N-25	3	28 ± 28	3.1 ± 4.0	17 ± 21
1-N-26	2	1.6 ± 10	-1.0 ± 7.3	0.3 ± 7.0
1-N-27	5	290 --- (d)	100 ± 29	180 ± 74
1-N-28	5	200 ± 23	20 ± 20	140 ± 70
1-N-29	5	230 ± 28	13 ± 3.3	140 ± 84
1-N-30	5	140 ± 22	15 ± 20	72 ± 49
1-N-31	4	230 ± 38	120 ± 7.5	160 ± 55
1-N-32	5	240 ± 9.4	140 ± 6.6	190 ± 39
1-N-33	5	130 ± 8.4	22 ± 22	93 ± 42
1-N-34	5	170 ± 28	89 ± 21	140 ± 32
1-N-36	4	220 ± 21	130 ± 10	180 ± 43
1-N-37	4	200 --- (d)	99 ± 10	160 ± 50
1-N-39	4	170 ± 11	59 ± 37	130 ± 55
1-N-45	3	210 ± 10	83 ± 7.4	160 ± 87
2-E19-1	2	18 ± 22	0.2 ± 10	9.1 ± 25
2-E23-1	2	20 ± 25	20 ± 25	20 ± 18
2-E24-7	2	0.5 ± 12	-10 ± 10	-4.7 ± 15
2-E25-2	2	20 ± 25	-1.0 ± 25	9.5 ± 32
2-E26-1	2	15 ± 15	1.7 ± 11	8.4 ± 19

TABLE A.15. (contd)

Well Name (b)	No. of Samples	⁶⁰ Co Concentration (pCi/L) (a)		
		Maximum	Minimum	Average
2-E26-3	2	19 ± 23	15 ± 15	17 ± 15
2-E26-8(c)	1			-3.5 ± 9.1
2-E27-1	2	-2.6 ± 26	-8.8 ± 23	-5.7 ± 19
2-E28-1	2	15 ± 20	1.1 ± 9.7	8.1 ± 21
2-E28-5	2	20 ± 25	-2.8 ± 19	8.6 ± 33
2-E33-12(c)	1			20 ± 11
2-E33-14	2	-2.6 ± 26	-20 ± 19	-11 ± 27
2-W6-1	1			-20 ± 25
2-W10-5	2	11 ± 11	1.6 ± 16	6.3 ± 15
2-W11-9	2	12 ± 12	-17 ± 23	-2.5 ± 39
2-W12-1	2	12 ± 12	-20 ± 25	-4.0 ± 42
2-W15-2	1			8.3 ± 4.7
2-W18-3	2	15 ± 15	0.2 ± 12	7.6 ± 21
2-W21-1	2	13 ± 13	1.5 ± 10	7.3 ± 17
2-W22-10	1			-17 ± 20
2-W22-7	2	18 ± 18	-6.9 ± 9.3	5.6 ± 33
2-W22-9	2	17 ± 17	-10 ± 13	3.5 ± 35
3-1-1	4	23 ± 23	-9.4 ± 14	12 ± 18
3-1-2	4	20 ± 25	-5.0 ± 3.7	8.7 ± 14
3-1-3	4	18 ± 18	-20 ± 25	2.6 ± 21
3-1-4	4	12 ± 12	-20 ± 28	-4.5 ± 18
3-1-5	4	20 ± 25	-20 ± 34	1.2 ± 22
3-1-6	4	15 ± 20	-0.5 ± 10	7.2 ± 9.8
3-2-1	4	20 ± 20	-0.1 ± 4.1	12 ± 13
3-2-2	4	21 ± 21	-20 ± 25	4.6 ± 22
3-2-3	4	64 ± 32	9.0 ± 9.0	24 ± 28
3-3-1	4	23 ± 23	-20 ± 25	-1.4 ± 23
3-3-2	4	15 ± 15	-8.5 ± 4.6	3.4 ± 13
3-3-3	4	12 ± 12	-20 ± 25	1.8 ± 17
3-3-6	4	20 ± 25	-20 ± 25	6.8 ± 22
3-3-7	4	20 ± 25	4.0 ± 26	11 ± 13
3-3-9	4	13 ± 13	-9.6 ± 22	2.0 ± 13
3-3-10	4	22 ± 25	-13 ± 24	9.3 ± 20
3-3-11	4	22 ± 22	-9.3 ± 14	11 ± 18
3-3-12	4	20 ± 25	-5.0 ± 9.1	8.5 ± 15
3-4-1	4	18 ± 18	-17 ± 19	2.1 ± 19
3-4-7	4	13 ± 13	-22 ± 27	-5.9 ± 19
3-4-9	4	16 ± 16	-6.5 ± 6.0	3.5 ± 12
3-4-10	4	20 ± 20	1.1 ± 7.2	13 ± 13
3-5-1	4	15 ± 15	-13 ± 20	3.6 ± 16
3-6-1	4	20 ± 25	-6.1 ± 6.2	4.8 ± 15
3-8-1	4	26 ± 26	-5.5 ± 4.7	13 ± 18
3-8-2	4	15 ± 20	7.0 ± 17	11 ± 8.8
3-8-3	4	25 ± 25	-19 ± 19	5.5 ± 24
3-8-4	4	20 ± 25	2.7 ± 16	10 ± 13
4-S0-7	3	15 ± 20	-15 ± 32	-0.4 ± 25
4-S0-8	2	15 ± 20	5.7 ± 6.8	10 ± 16
4-S1-7B	3	13 ± 13	-8.5 ± 19	-0.3 ± 18
4-S1-7C	4	20 ± 25	-11 ± 6.6	5.3 ± 17
4-S1-8A	4	21 ± 21	-0.3 ± 11	6.5 ± 14
4-S1-8B	3	20 ± 25	10 ± 28	14 ± 15

TABLE A.15. (contd)

Well Name ^(b)	No. of Samples	⁶⁰ Co Concentration (pCi/L) ^(a)		
		Maximum	Minimum	Average
6-2-3	10	15 ± 20	-22 ± 34	-0.8 ± 11
6-8-17	4	20 ± 25	4.5 ± 25	14 ± 13
6-8-25	4	20 ± 25	-5.9 ± 19	13 ± 17
6-12-4B	2	14 ± 14	-8.6 ± 14	2.7 ± 30
6-15-15B	4	20 ± 25	-11 ± 4.7	11 ± 18
6-15-26	4	31 ± 31	-6.0 ± 15	15 ± 21
6-17-5	4	14 ± 14	0.7 ± 7.4	7.6 ± 8.2
6-20-20	4	20 ± 25	-20 ± 25	7.8 ± 22
6-20-39 ^(c)	3	18 ± 27	-15 ± 14	6.0 ± 25
6-20-E5A	4	21 ± 21	-12 ± 21	8.3 ± 19
6-20-E5AP ^(c)	2	10 ± 10	2.3 ± 3.2	6.1 ± 11
6-20-E5AQ ^(c)	2	10 ± 10	3.0 ± 3.5	6.5 ± 10
6-22-70	3	20 ± 25	4.7 ± 8.1	13 ± 15
6-22-70P ^(c)	1			2.3 ± 3.2
6-24-1P ^(c)	2	9.6 ± 9.6	1.1 ± 2.1	5.3 ± 12
6-24-33	4	22 ± 22	-13 ± 9.0	5.0 ± 19
6-26-15A	4	20 ± 20	-9.0 ± 13	11 ± 15
6-27-8	3	14 ± 14	-3.2 ± 5.3	6.9 ± 13
6-28-40	4	16 ± 16	9.8 ± 18	13 ± 9.8
6-28-40P ^(c)	2	15 ± 20	13 ± 13	14 ± 12
6-28-52A	4	24 ± 16	-17 ± 21	4.0 ± 21
6-29-4	1			20 ± 20
6-31-31	4	17 ± 20	-1.0 ± 5.8	7.9 ± 11
6-31-31P ^(c)	2	15 ± 20	9.0 ± 9.0	12 ± 13
6-31-53B	1			20 ± 25
6-32-22	4	20 ± 25	5.8 ± 20	14 ± 12
6-32-43	4	15 ± 20	-20 ± 25	0.8 ± 19
6-32-62	1			15 ± 20
6-32-70B	2	15 ± 20	15 ± 20	15 ± 14
6-32-72	4	18 ± 18	-2.0 ± 20	12 ± 14
6-32-77	4	15 ± 20	-25 ± 16	0.0 ± 21
6-33-42	4	20 ± 25	9.2 ± 11	15 ± 11
6-33-56	3	19 ± 19	-11 ± 7.0	7.0 ± 22
6-34-39A	4	15 ± 15	-11 ± 15	3.0 ± 14
6-34-41B	4	20 ± 20	-20 ± 25	5.2 ± 22
6-34-42	4	14 ± 15	-17 ± 20	2.7 ± 17
6-34-51	4	17 ± 17	-18 ± 20	4.3 ± 20
6-35-9	4	22 ± 22	-2.2 ± 18	14 ± 15
6-35-66	4	20 ± 25	0.5 ± 17	12 ± 13
6-35-70	3	31 ± 31	15 ± 20	22 ± 18
6-36-46P ^(c)	2	12 ± 15	-11 ± 18	0.5 ± 31
6-36-46Q ^(c)	2	20 ± 25	20 ± 19	20 ± 16
6-37-43	4	20 ± 25	-14 ± 6.0	7.3 ± 19
6-37-E4	13	25 ± 25	-31 ± 31	5.3 ± 11
6-38-15	4	25 ± 25	11 ± 12	17 ± 12
6-38-65	3	20 ± 25	-20 ± 25	-3.2 ± 31
6-38-70	3	20 ± 25	1.0 ± 2.8	10 ± 16
6-39-0	14	25 ± 25	-21 ± 35	10 ± 8.5
6-39-39	2	17 ± 17	13 ± 16	15 ± 13
6-39-79	3	15 ± 20	-21 ± 25	2.3 ± 27
6-40-1	4	20 ± 20	-8.4 ± 9.2	6.7 ± 18
6-40-33A	3	20 ± 25	11 ± 11	15 ± 12
6-41-1	2	14 ± 7.8	6.1 ± 4.9	9.8 ± 10
6-41-23	4	27 ± 31	-20 ± 25	11 ± 26

TABLE A.15. (contd)

Well Name ^(b)	No. of Samples	⁶⁰ Co Concentration (pCi/L) ^(a)		
		Maximum	Minimum	Average
6-42-2	3	22 ± 22	-9.1 ± 12	6.8 ± 23
6-42-12A	4	33 ± 33	20 ± 25	26 ± 13
6-42-40C ^(c)	1			-3.3 ± 9.5
6-43-3	2	11 ± 6.7	8.5 ± 6.0	9.8 ± 5.5
6-44-4	12	42 ± 25	-20 ± 25	12 ± 12
6-44-64	3	20 ± 25	-10 ± 5.0	7.0 ± 22
6-45-2	7	25 ± 25	3.3 ± 20	17 ± 11
6-45-42	4	20 ± 25	-10 ± 5.7	7.6 ± 17
6-45-69A	3	20 ± 25	-10 ± 20	8.3 ± 24
6-46-4	2	-0.6 ± 7.3	-0.7 ± 9.1	-0.6 ± 5.8
6-46-32 ^(c)	1			-13 ± 12
6-47-5	3	25 ± 25	9.1 ± 9.9	16 ± 14
6-47-46A	3	15 ± 20	-24 ± 23	-2.7 ± 29
6-47-50 ^(c)	1			4.0 ± 4.0
6-47-60	4	27 ± 27	1.8 ± 3.6	15 ± 16
6-49-32B ^(c)	1			-4.7 ± 9.1
6-49-55A	3	220 --- ^(d)	160 ± 28	180 ± 43
6-49-55B ^(c)	1			-6.2 ± 6.2
6-49-57	4	62 ± 5.0	13 ± 25	36 ± 25
6-50-45 ^(c)	1			-2.7 ± 6.9
6-50-48B ^(c)	1			2.0 ± 2.9
6-50-53	4	370 --- ^(d)	140 ± 28	260 ± 110
6-51-46 ^(c)	1			7.9 ± 6.0
6-52-46A ^(c)	1			3.0 ± 3.5
6-52-48 ^(c)	1			-4.7 ± 9.1
6-53-35	3	16 ± 16	-13 ± 14	5.3 ± 22
6-53-50 ^(c)	1			-25 ± 16
6-54-57 ^(c)	1			1.1 ± 2.3
6-55-50C	3	15 ± 20	-7.8 ± 15	6.1 ± 18
6-56-53 ^(c)	1			9.6 ± 6.4
6-66-103	1			-5.8 ± 9.3
6-68-105	1			20 ± 25
6-S16-24 ^(c)	1			3.2 ± 3.7

- (a) Maximum and minimum concentrations ±2 sigma counting error. Average concentrations for 1986 ±2 standard error of the calculated mean (or ± counting error for one sample).
- (b) See Figure 3.10 for well locations.
- (c) Wells that sample a confined aquifer or a composite of a confined and the unconfined aquifer.
- (d) Counting error was not reported.

TABLE A.16. Cesium-137 Concentrations in the Ground Water

Well Name ^(b)	No. of Samples	¹³⁷ Cs Concentration (pCi/L) ^(a)		
		Maximum	Minimum	Average
1-B3-2P ^(c)	1			0.3 ± 4.3
1-H4-4	1			16 ± 3.1
1-H4-6	1			23 ± 13
1-N-6	1			9.4 ± 6.2
1-N-21	1			18 ± 2.9
1-N-24	1			17 ± 2.3
1-N-28	1			14 ± 5.1
1-N-29	1			26 ± 6.6
1-N-30	1			31 ± 17
1-N-32	1			31 ± 6.9
1-N-33	1			14 ± 7.0
1-N-34	1			26 ± 9.4
1-N-45	1			17 ± 4.8
2-E26-8 ^(c)	1			-3.0 ± 8.3
2-E33-12 ^(c)	1			7.3 ± 7.2
2-W10-5	1			30 ± 4.7
3-1-6	1			15 --- ^(d)
6-20-E5AP ^(c)	1			4.5 ± 5.8
6-20-E5AP ^(c)	1			2.2 ± 4.9
6-22-70P ^(c)	1			-4.1 ± 7.5
6-24-1P ^(c)	1			-3.0 ± 6.3
6-39-0	2	7.7 ± 5.1	1.3 ± 9.1	4.5 ± 9.6
6-41-1	2	5.5 ± 3.9	-0.3 ± 4.1	2.6 ± 7.8
6-42-2	2	5.5 ± 3.9	-1.7 ± 6.6	1.9 ± 9.8
6-42-40C ^(c)	1			-9.5 ± 8.6
6-43-3	2	0.7 ± 5.8	-1.3 ± 5.7	-0.3 ± 4.7
6-46-4	2	9.4 ± 5.7	4.1 ± 3.4	6.8 ± 7.4
6-46-32 ^(c)	1			2.1 ± 5.8
6-47-5	2	-1.0 ± 6.7	-5.7 ± 8.0	-3.3 ± 7.8
6-47-50 ^(c)	1			-0.3 ± 4.1
6-49-32B ^(c)	1			-7.8 ± 9.0
6-49-55B ^(c)	1			-5.2 ± 7.0
6-49-57	1			24 ± 5.2
6-50-45 ^(c)	1			-1.7 ± 8.7
6-50-48B ^(c)	1			3.5 ± 5.2
6-51-46 ^(c)	1			3.4 ± 3.1
6-52-46A ^(c)	1			2.2 ± 4.9
6-52-48 ^(c)	1			-0.4 ± 5.8
6-53-50 ^(c)	1			-11 ± 8.2
6-54-57 ^(c)	1			3.4 ± 3.1
6-56-53 ^(c)	1			3.7 ± 7.6
6-S16-24 ^(c)	1			1.3 ± 9.0

(a) Maximum and minimum concentrations for 1986 ± 2 sigma counting error. Average concentrations ± 2 standard error of the calculated mean (or ± counting error for one sample).

(b) See Figure 3.10 for well locations.

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

(d) Counting errors were not reported.

TABLE A.17. Ruthenium-103 Concentrations in the Ground Water

Well Name ^(a)	No. of Samples	¹⁰³ Ru Concentration (pCi/L)
1-N-27	1	2,800 --- ^(b)
1-N-31	1	240 ---
1-N-36	1	1,000 ---
1-N-37	1	880 ---
1-N-39	1	390 ---

(a) See Figure 3.10 for well locations.
 (b) Counting errors were not reported.

TABLE A.18. Ruthenium-106 Concentrations in the Ground Water

Well Name ^(b)	No. of Samples	¹⁰⁶ Ru Concentration (pCi/L) ^(a)		
		Maximum	Minimum	Average
1-B3-2P ^(c)	1			2.7 ± 62
1-N-6	1			150 ± 59
1-N-27	1			970 ± 220
1-N-28	1			180 ± 49
1-N-29	2	450 ± 140	270 ± 65	360 ± 240
1-N-32	2	250 ± 27	230 ± 51	240 ± 38
1-N-33	4	380 ± 130	120 ± 40	230 ± 130
1-N-34	2	270 ± 130	230 ± 35	250 ± 84
1-N-36	1			220 ± 70
1-N-37	1			310 ± 78
1-N-39	1			170 ± 55
1-N-45	1			200 ± 41
2-E26-8 ^(c)	1			18 ± 77
2-E33-12 ^(c)	1			-140 ± 94
6-20-E5AP ^(c)	1			-34 ± 63
6-20-E5AQ ^(c)	1			24 ± 42
6-22-70P ^(c)	1			26 ± 43
6-24-1P ^(c)	1			-58 ± 65
6-38-65	1			560 ± 210
6-39-0	2	14 ± 64	7.2 ± 62	11 ± 46
6-41-1	2	69 ± 40	35 ± 45	52 ± 53
6-42-2	2	50 ± 58	-52 ± 60	-1.0 ± 130
6-42-40C ^(c)	1			-31 ± 73
6-43-3	2	27 ± 55	-14 ± 55	6.3 ± 64
6-46-4	2	-11 ± 72	-78 ± 65	-44 ± 97
6-46-32 ^(c)	1			-21 ± 55
6-47-5	2	39 ± 56	-31 ± 70	4.2 ± 98
6-47-50 ^(c)	1			-24 ± 57
6-49-32B ^(c)	1			38 ± 55
6-49-55B ^(c)	1			-46 ± 61
6-50-45 ^(c)	1			-22 ± 41
6-50-48B ^(c)	1			24 ± 42
6-51-46 ^(c)	1			5.7 ± 50
6-52-46A ^(c)	1			-47 ± 63
6-52-48 ^(c)	1			55 ± 39
6-53-50 ^(c)	1			-46 ± 64
6-54-57 ^(c)	1			14 ± 39
6-56-53 ^(c)	1			-14 ± 55
6-S16-24 ^(c)	1			-73 ± 72

(a) Maximum and minimum concentrations ±2 sigma counting error. Average concentrations ±2 standard error of the calculated mean (or ± counting error for one sample).
 (b) See Figure 3.10 for well locations.
 (c) Wells that sample a confined aquifer or a composite of a confined and the unconfined aquifer.

TABLE A.19. Antimony-125 Concentrations in the Ground Water

Well Name ^(b)	No. of Samples	¹²⁵ Sb Concentration (pCi/L) ^(a)		
		Maximum	Minimum	Average
1-K-27	1			370 ± 56
1-N-6	3	320 ± 68	120 ± 18	210 ± 140
1-N-14	1			360 ± 180
1-N-27	3	250 ± 38	210 ± 19	230 ± 32
1-N-28	3	370 ± 240	200 ± 18	280 ± 140
1-N-29	3	520 ± 180	280 ± 22	380 ± 170
1-N-30	1			290 ± 130
1-N-31	3	500 ± 120	120 ± 9.0	330 ± 280
1-N-32	3	440 ± 72	190 ± 41	320 ± 170
1-N-33	4	250 ± 38	140 ± 58	180 ± 58
1-N-34	5	470 ± 200	180 ± 26	310 ± 120
1-N-36	3	460 ± 35	230 ± 35	320 ± 160
1-N-37	4	540 ± 270	190 ± 36	310 ± 180
1-N-39	3	190 ± 42	87 ± 21	140 ± 72
1-N-45	2	700 ± 170	120 ± 25	410 ± 730

- (a) Maximum and minimum concentrations ±2 sigma counting error. Average concentrations for 1986 ±2 standard error of the calculated mean (or ± counting error for one sample).
 (b) See Figure 3.10 for well locations.

TABLE A.20. Iodine-131 Concentrations in the Ground Water

Well Name ^(b)	No. of Samples	¹³¹ I Concentration (pCi/L) ^(a)		
		Maximum	Minimum	Average
1-N-4	1			5,400 ± 1,100
1-N-6	4	530,000 --- ^(c)	590 ---	140,000 ± 260,000
1-N-7	2	340 ± 29	230 ± 66	290 ± 140
1-N-15	1			2,000 ± 280
1-N-27	5	470,000 ---	270 ---	160,000 ± 180,000
1-N-28	3	530,000 ---	290 ---	200,000 ± 360,000
1-N-29	3	940,000 ---	1,400 ---	330,000 ± 640,000
1-N-30	3	74,000 ---	1,000 ± 90	26,000 ± 50,000
1-N-31	4	50,000 ---	820 ---	21,000 ± 24,000
1-N-32	5	260,000 ---	390 ---	70,000 ± 100,000
1-N-33	4	120,000 ---	1,300 ---	32,000 ± 58,000
1-N-34	5	380,000 ---	2,200 ---	86,000 ± 150,000
1-N-36	4	99,000 ---	4,800 ---	42,000 ± 46,000
1-N-37	4	44,000 ---	240 ---	17,000 ± 21,000
1-N-39	3	1,500 ---	370 ---	1,100 ± 770
1-N-45	3	79,000 ---	720 ---	47,000 ± 53,000

- (a) Maximum and minimum concentrations ±2 sigma counting error. Average concentrations for 1986 ±2 standard error of the calculated mean (or ± counting error for one sample).
 (b) See Figure 3.10 for well locations.
 (c) Counting errors were not reported.

TABLE A.21. Iodine-129 Concentrations in the Ground Water

Well Name (a)	Date Sampled	¹²⁹ I Concentration pCi/L	% Error (b)
2-E17-1	1/2/86	29.4 ^(c)	5.6
2-E17-9	1/2/86	31.6 ^(c)	5.7
2-E24-2	1/2/86	39.1	5.2
2-E25-12	6/6/86	0.29 ^(c)	3.6
2-E25-20	1/2/86	1.53	5.1
2-E28-21	1/27/86	0.76 ^(c)	4.0
6-25-55	5/29/86	0.000094	4.1
6-27-8	1/27/86	2.42	3.7
6-32-22	6/6/86	4.89	3.7
6-35-9	1/27/86	0.218	3.9
6-35-70	1/27/86	101.8	4.1
6-37-E4	1/7/86	0.024	5.6
6-41-1	1/8/86	0.214	5.6
6-41-23	1/27/86	4.72	3.5
6-46-4	1/8/86	0.140	5.6
6-48-7	1/27/86	0.00031	4.0
6-50-85	1/27/86	0.00018	3.7
6-101-48B	5/29/86	0.000044	4.9

(a) See Figure 3.10 for well locations.

(b) The percent error estimates are standard (1σ) counting errors.

(c) Iodine-129 samples that were collected and analyzed for Rockwell; the wells located in the 200 Areas can be located in Hanford Wells (McGhan, Mitchell and Argo 1985).

TABLE A.22. Uranium Concentrations in the Ground Water

Well Name ^(b)	No. of Samples	Uranium Concentration (pCi/L) ^(a)		
		Maximum	Minimum	Average
1-H3-1	4	9.6 ± 2.7	6.8 ± 2.4	8.0 ± 2.0
1-H4-3	4	820 ± 23	190 ± 11	460 ± 310
1-H4-4	4	90 ± 9.0	10 ± 3.7	40 ± 39
1-H4-5	4	4.3 ± 2.8	2.8 ± 2.3	3.6 ± 1.4
1-H4-6	4	6.5 ± 3.1	2.7 ± 2.6	4.2 ± 2.3
3-1-1	4	21 ± 6.0	15 ± 3.2	17 ± 3.6
3-1-2	4	20 ± 4.1	5.5 ± 5.2	11 ± 7.3
3-1-3	4	40 ± 5.2	4.0 ± 5.0	27 ± 18
3-1-4	4	12 ± 3.7	2.8 ± 2.5	8.7 ± 4.7
3-1-5	4	27 ± 4.3	7.1 ± 3.1	18 ± 9.9
3-1-6	4	12 ± 3.5	5.7 ± 5.1	8.5 ± 3.6
3-2-1	4	12 ± 3.0	7.8 ± 3.1	9.7 ± 2.5
3-2-2	4	29 ± 4.4	18 ± 4.1	23 ± 5.7
3-2-3	4	13 ± 5.6	-2.8 ± 1.8	8.3 ± 7.9
3-3-1	4	11 ± 3.3	5.3 ± 2.8	8.4 ± 3.2
3-3-2	4	14 ± 3.6	4.0 ± 2.8	10 ± 5.1
3-3-3	4	17 ± 4.1	4.8 ± 2.8	11 ± 6.2
3-3-6	4	17 ± 5.8	5.6 ± 2.2	13 ± 5.9
3-3-7	4	16 ± 3.3	1.6 ± 2.5	9.2 ± 7.2
3-3-9	4	31 ± 5.0	7.7 ± 2.5	18 ± 11
3-3-10	4	27 ± 4.3	0.4 ± 2.3	16 ± 13
3-3-11	4	64 ± 6.9	12 ± 5.6	30 ± 25
3-3-12	4	44 ± 5.7	22 ± 4.3	31 ± 11
3-4-1	4	21 ± 4.3	18 ± 3.5	19 ± 2.5
3-4-7	4	47 ± 7.4	22 ± 4.3	34 ± 12
3-4-9	4	33 ± 5.0	8.8 ± 3.2	26 ± 12
3-4-10	4	38 ± 5.3	19 ± 3.6	30 ± 9.5
3-5-1	4	51 ± 5.8	7.0 ± 3.0	18 ± 21
3-6-1	4	13 ± 5.6	4.3 ± 2.8	8.5 ± 4.6
3-8-1	4	6.6 ± 2.3	3.0 ± 1.8	5.1 ± 2.1
3-8-2	4	21 ± 6.0	1.8 ± 2.5	7.7 ± 9.5
3-8-3	4	31 ± 4.9	3.8 ± 2.8	12 ± 13
3-8-4	4	5.2 ± 3.0	2.5 ± 4.7	4.0 ± 2.1
4-S1-7C	4	19 ± 3.7	3.2 ± 2.6	10 ± 7.9
4-S1-8A	4	16 ± 3.4	4.3 ± 2.9	9.6 ± 5.9
4-S1-8B	3	10 ± 3.3	6.4 ± 2.9	7.7 ± 3.0
6-20-20	1			4.7 ± 2.9
6-26-15A	1			6.2 ± 2.9
6-29-4	1			7.3 ± 3.2
6-39-0	2	3.7	2.6	3.2 ± 1.4
6-40-1	1			5.7 ± 5.2
6-41-1	2	3.6	3.4	3.5 ± 0.3
6-42-2	3	8.2 ± 5.3	2.5	4.5 ± 4.9
6-43-3	2	3.2	2.8	3.0 ± 0.5
6-46-4	2	2.1	1.6	1.8 ± 0.6
6-47-5	3	4.9 ± 2.7	1.7	2.9 ± 2.7
6-S6-E4B	5	5.8 ± 2.9	0.5 ± 1.3	3.9 ± 2.3
6-S6-E4D	5	5.2 ± 2.8	-0.9 ± 2.0	3.0 ± 2.6
6-S19-E13	5	10 ± 3.4	2.7 ± 5.2	5.1 ± 3.2
6-S27-E14	11	28 ± 4.7	4.8 ± 2.9	9.3 ± 4.1
6-S29-E12	4	8.3 ± 3.1	2.4 ± 1.6	4.4 ± 3.3
6-S30-E15A	4	23 ± 4.5	1.9 ± 1.5	8.4 ± 10

(a) Maximum and minimum concentrations ±2 sigma counting error. Average concentrations for 1986 ±2 standard error of the calculated mean (or ± counting error for one sample).
 (b) See Figure 3.10 for well locations.
 (c) Counting errors were not reported.

TABLE A.23. Isotopic Uranium, Plutonium, and Strontium-89 Concentrations in the Ground Water in Wells Near the Hanford Townsite

Radionuclide	Well Name ^(b)	No. of Samples	Concentration (pCi/L) ^(a)		
			Maximum	Minimum	Average
²³⁴ U	6-39-0	2	2.2 ± 0.16	2.1 ± 0.13	2.1 ± 0.16
	6-41-1	2	2.4 ± 0.14	2.0 ± 0.13	2.2 ± 0.42
	6-42-2	2	2.1 ± 0.13	1.6 ± 0.11	1.9 ± 0.63
	6-43-3	2	2.2 ± 0.13	2.1 ± 0.13	2.1 ± 0.18
	6-46-4	2	2.0 ± 0.13	1.9 ± 0.13	2.0 ± 0.10
	6-47-5	2	1.8 ± 0.12	1.7 ± 0.11	1.8 ± 0.19
²³⁵ U	6-39-0	2	0.061 ± 0.028	0.036 ± 0.016	0.048 ± 0.036
	6-41-1	2	0.058 ± 0.022	0.056 ± 0.021	0.057 ± 0.015
	6-42-2	2	0.064 ± 0.022	0.049 ± 0.020	0.057 ± 0.024
	6-43-3	2	0.059 ± 0.022	0.047 ± 0.019	0.053 ± 0.021
	6-46-4	2	0.045 ± 0.020	0.025 ± 0.021	0.035 ± 0.028
	6-47-5	2	0.056 ± 0.020	0.033 ± 0.016	0.044 ± 0.032
²³⁸ U	6-39-0	2	1.7 ± 0.11	1.6 ± 0.14	1.6 ± 0.11
	6-41-1	2	1.7 ± 0.11	1.5 ± 0.11	1.6 ± 0.23
	6-42-2	2	1.5 ± 0.11	1.2 ± 0.096	1.3 ± 0.40
	6-43-3	2	1.5 ± 0.11	1.5 ± 0.11	1.5 ± 0.077
	6-46-4	2	1.2 ± 0.10	1.2 ± 0.10	1.2 ± 0.10
	6-47-5	2	1.2 ± 0.096	1.1 ± 0.091	1.2 ± 0.12
^{239,240} Pu	6-39-0	2	0.0 --- ^(c)	0.0 ---	0.0 ± 0.0
	6-41-1	2	0.0052 ± 0.010	0.0 ± 0.0094	0.0026 ± 0.0095
	6-42-2	2	0.0 ± 0.0075	-0.0025 ± 0.0051	-0.0013 ± 0.0055
	6-43-3	2	0.0027 ± 0.0054	0.0019 ± 0.0038	0.0023 ± 0.0034
	6-46-4	2	0.0 ± 0.0066	0.0 ---	0.0 ± 0.0047
	6-47-5	2	0.0050 ± 0.0071	-0.0023 ± 0.0047	0.0013 ± 0.010
²³⁸ Pu	6-39-0	2	0.0 ---	-0.0028 ± 0.0057	-0.0014 ± 0.0053
	6-41-1	2	0.017 ± 0.018	0.010 ± 0.021	0.014 ± 0.016
	6-42-2	2	0.015 ± 0.014	0.011 ± 0.015	0.013 ± 0.012
	6-43-3	2	0.0038 ± 0.0054	0.0 ± 0.0076	0.0019 ± 0.0067
	6-46-4	2	0.0 ---	-0.0027 ± 0.0054	-0.0013 ± 0.0051
	6-47-5	2	0.0025 ± 0.0050	0.0 ---	0.0013 ± 0.0047
⁹⁰ Sr	6-39-0	2	0.24 ± 0.36	0.086 ± 0.36	0.16 ± 0.32
	6-41-1	2	0.13 ± 0.41	-0.27 ± 0.41	-0.07 ± 0.57
	6-42-2	2	-0.16 ± 0.38	-0.57 ± 0.43	-0.36 ± 0.59
	6-43-3	2	0.074 ± 0.36	0.041 ± 0.34	0.057 ± 0.25
	6-46-4	2	0.22 ± 0.34	-0.015 ± 0.34	0.10 ± 0.38
	6-47-5	2	0.020 ± 0.35	-0.15 ± 0.34	-0.067 ± 0.33

- (a) Maximum and minimum concentrations ±2 sigma counting error. Average concentrations ±2 standard error of the calculated mean.
 (b) See Figure 3.10 for well locations.
 (c) Counting errors were not reported.

TABLE A.24. Strontium-90 Concentrations in the Ground Water

Well Name ^(b)	No. of Samples	⁹⁰ Sr Concentration (pCi/L) ^(a)		
		Maximum	Minimum	Average
1-N-2	3	6,200	2,700 ± 35	4,600 ± 2,400
1-N-3	3	1,900	1,700 ± 33	1,800 ± 190
1-N-4	2	27 ± 3.4	14 ± 2.5	21 ± 17
1-N-5	3	210 ± 11	150 ± 11	180 ± 43
1-N-6	3	98 ± 6.5	90 ± 7.5	95 ± 6.6
1-N-7	3	120 ± 8.4	4.5 ± 1.6	43 ± 78
1-N-14	3	930 ± 20	780 ± 21	850 ± 100
1-N-15	2	3.5 ± 1.4	1.9 ± 1.2	2.7 ± 2.2
1-N-16	2	2.1 ± 1.2	1.8 ± 1.4	1.9 ± 1.0
1-N-17	3	51 ± 4.6	27 ± 3.5	36 ± 17
1-N-18	3	170 ± 9.3	60 ± 7.0	110 ± 76
1-N-19	3	89 ± 7.6	43 ± 6.9	70 ± 32
1-N-20	3	77 ± 7.3	24 ± 3.5	55 ± 36
1-N-21	3	16 ± 2.7	4.9 ± 1.6	11 ± 7.9
1-N-22	3	2.0 ± 1.2	1.4 ± 1.1	1.8 ± 0.8
1-N-23	3	200 ± 10	1.4 ± 1.1	69 ± 140
1-N-24	1			18 ± 2.9
1-N-25	2	3.2 ± 1.4	1.3 ± 1.1	2.3 ± 2.5
1-N-26	2	1.9 ± 1.2	0.3 ± 1.0	1.1 ± 2.2
1-N-27	3	380 ± 14	8.4 ± 1.9	130 ± 250
1-N-28	3	5.4 ± 1.6	2.6 ± 1.3	3.9 ± 2.1
1-N-29	3	510 ± 16	26 ± 3.2	190 ± 330
1-N-30	3	6.4 ± 1.8	3.9 ± 1.6	5.5 ± 2.0
1-N-31	3	34 ± 3.6	26 ± 3.4	30 ± 5.4
1-N-32	3	11 ± 2.3	0.7 ± 0.9	4.5 ± 6.8
1-N-33	3	1,200 ± 22	830 ± 20	1,000 ± 260
1-N-34	2	39 ± 4.4	37 ± 4.2	38 ± 4.2
1-N-36	3	37 ± 4.9	19 ± 2.8	26 ± 13
1-N-37	3	52 ± 4.7	33 ± 4.3	40 ± 13
1-N-39	3	820 ± 19	470 ± 15	670 ± 240
1-N-45	2	1,400 ± 24	390 ± 15	910 ± 1,300
2-W22-10	1			36 ± 4.3
3-2-2	1			2.8 ± 1.4
3-3-9	4	5.1 ± 1.6	1.2 ± 1.1	2.8 ± 2.0
3-3-10	4	5.6 ± 1.7	0.9 ± 1.1	3.2 ± 2.4
3-3-11	4	9.0 ± 2.3	6.7 ± 1.9	7.7 ± 1.6
3-3-12	4	2.5 ± 1.5	1.3 ± 1.0	1.9 ± 0.9
3-4-9	4	3.4 ± 1.4	1.0 ± 1.0	2.0 ± 1.4
3-4-10	4	3.3 ± 1.4	0.1 ± 2.0	2.0 ± 1.7
6-20-20	1			2.5 ± 1.4
6-26-15A	1			1.3 ± 1.1
6-29-4	1			1.7 ± 1.2
6-39-0	2	0.3 ± 0.2	0.2 ± 0.2	0.2 ± 0.2
6-40-1	1			4.4 ± 1.6
6-41-1	2	0.4 ± 0.3	0.3 ± 0.3	0.3 ± 0.3
6-42-2	3	1.8 ± 1.2	0.3 ± 0.3	0.9 ± 1.1
6-43-3	2	0.2 ± 0.2	0.2 ± 0.2	0.2 ± 0.1
6-46-4	2	0.2 ± 0.2	0.1 ± 0.2	0.1 ± 0.2
6-47-5	3	1.1 ± 1.1	0.2 ± 0.2	0.5 ± 0.7

(a) Maximum and minimum concentrations ±2 sigma counting error. Average concentrations for 1986 ±2 standard error of the calculated mean (or ± counting error for one sample).

(b) See Figure 3.10 for well locations.

(c) Counting errors were not reported.

TABLE A.25. Nitrate (As Nitrate) Concentrations in the Ground Water

Well Name (b)	No. of Samples	NO ₃ ⁻ Concentration (mg/L) (a)		
		Maximum	Minimum	Average
1-B3-1	2	53	36	45 ± 21
1-B3-2p (c)	1			0.2 (d) --- (e)
1-B4-1	1			14 ---
1-B4-2	2	13	11	12 ± 1.8
1-B4-3	2	16	13	14 ± 4.0
1-B4-4	2	12	11	11 ± 0.9
1-B5-1	2	12	11	12 ± 1.8
1-B9-1	2	25	20	22 ± 5.8
1-D2-5	2	83	82	82 ± 0.6
1-D5-12	2	68	66	67 ± 2.6
1-D8-3	2	21	20	20 ± 1.5
1-F5-1	2	14	13	13 ± 1.0
1-F5-3	2	56	<0.5	28 ± 70
1-F5-4	2	66	58	62 ± 11
1-F5-6	2	1.9	<0.5	1.2 ± 1.7
1-F7-1	2	110	94	100 ± 25
1-F8-1	6	140	110	130 ± 11
1-F8-2	2	110	96	100 ± 13
1-H3-1	2	61	60	60 ± 1.5
1-H4-5	2	33	26	30 ± 8.0
1-H4-6	2	33	29	31 ± 5.3
1-K-11	2	63	52	58 ± 14
1-K-19	6	65	50	57 ± 5.0
1-K-20	2	28	23	26 ± 6.0
1-K-22	2	4.0	3.3	3.7 ± 0.8
1-N-2	2	39	35	37 ± 5.6
1-N-4	1			38 ---
1-N-5	2	50.7	51.5	51.1 ± 1.0
1-N-6	2	47.2	52.4	49.8 ± 6.5
1-N-7	2	40.1	55.8	48.0 ± 19.7
1-N-14	2	28	25	26 ± 4.3
1-N-15	1			43 ---
1-N-17	2	<0.5	<0.5	<0.5 ---
1-N-18	2	<0.5	<0.5	<0.5 ---
1-N-19	2	25	22	23 ± 3.5
1-N-20	2	31	29	30 ± 2.1
1-N-21	2	16	11	14 ± 6.6
1-N-22	2	14	13	13 ± 1.4
1-N-23	2	18	15	16 ± 4.0
1-N-24	2	13	7.9	10 ± 5.9
1-N-25	2	27	13	20 ± 17
1-N-27	2	84	27	55 ± 72
1-N-28	2	28	27	27 ± 1.4
1-N-29	2	50	41	46 ± 11
1-N-30	2	53	42	48 ± 14
1-N-31	2	53	32	42 ± 27
1-N-32	2	48	37	42 ± 13
1-N-33	2	45	30	37 ± 19
1-N-34	2	51	49	50 ± 3.3
1-N-36	2	37	24	30 ± 16
1-N-37	2	34	30	32 ± 5.8
1-N-39	2	29	27	28 ± 2.9
1-N-45	1			29 ---
2-E26-8 (c)	1			0.5 (d) ---
2-E33-12 (c)	1			4.9 (d) ---

TABLE A.25. (contd)

Well Name (b)	No. of Samples	NO ₃ ⁻ Concentration (mg/L) (a)		
		Maximum	Minimum	Average
3-1-1	2	24	18	21 ± 7.4
3-1-2	2	23	17	20 ± 6.8
3-1-3	2	21	7.2	14 ± 18
3-1-4	2	13	5.9	9.4 ± 8.8
3-1-5	2	18	4.4	11 ± 17
3-1-6	2	16	6.0	11 ± 13
3-2-1	2	24	24	24 ± 0.1
3-2-2	2	28	19	24 ± 11
3-2-3	2	26	25	25 ± 1.5
3-3-1	2	20	18	19 ± 1.8
3-3-2	2	7.9	6.8	7.4 ± 1.4
3-3-3	2	12	12	12 ± 0.0
3-3-6	2	17	13	15 ± 4.1
3-3-7	2	18	16	17 ± 1.8
3-3-9	2	20	16	18 ± 5.8
3-3-10	2	19	18	18 ± 0.4
3-3-11	2	22	15	19 ± 8.5
3-3-12	2	25	20	22 ± 5.6
3-4-1	2	14	13	14 ± 0.8
3-4-10	2	20	19	20 ± 1.0
3-4-7	2	18	18	18 ± 0.0
3-4-9	2	22	20	21 ± 2.1
3-5-1	2	57	46	52 ± 13
3-6-1	2	29	25	27 ± 4.9
3-8-1	2	18	15	16 ± 4.6
3-8-2	2	22	20	21 ± 2.3
3-8-3	2	12	12	12 ± 0.0
3-8-4	2	25	22	24 ± 3.6
4-S0-7	1			5 ---
4-S1-7B	2	<0.5	<0.5	<0.5 ---
4-S1-7C	2	29	28	29 ± 1.4
4-S1-8A	2	30	29	30 ± 0.8
4-S1-8B	2	29	28	28 ± 1.5
6-1-18	2	22	22	22 ± 0.9
6-2-3	6	32	28	29 ± 1.2
6-2-7	2	37	33	35 ± 4.8
6-2-33A	1			3.3 ---
6-3-45	2	3.8	1.4	2.6 ± 2.9
6-4-E6	2	13	12	13 ± 1.4
6-8-17	2	35	34	34 ± 0.9
6-8-25	2	21	20	20 ± 2.1
6-8-32	2	4.0	3.6	3.8 ± 0.5
6-9-E2	2	3.2	3.1	3.1 ± 0.1
6-10-54A	2	12	11	11 ± 1.9
6-10-E12	2	24	20	22 ± 4.0
6-13-64	2	0.5	<0.5	0.5 ± 0.0
6-14-38	2	3.1	3.1	3.1 ± 0.0
6-14-47	1			<0.5 ---
6-14-E6T	1			20 ---
6-15-15B	2	23	22	22 ± 1.6
6-15-26	2	26	23	25 ± 3.3
6-17-5	2	64	63	64 ± 0.8
6-17-70	2	47	46	47 ± 0.4
6-19-43	2	7.5	7.1	7.3 ± 0.4
6-19-58	2	<0.5	<0.5	<0.5 ---
6-19-88	2	1.8	1.5	1.7 ± 0.4
6-20-20	2	42	40	41 ± 3.5
6-20-39 ^(c)	2	4.1	3.7	3.9 ± 0.5
6-20-82	2	18	17	18 ± 1.0
6-20-E12	2	41	36	38 ± 5.5
6-20-E12P ^(c)	1			<0.5 ---

TABLE A.25. (contd)

Well Name ^(b)	No. of Samples	NO ₂ Concentration (mg/L) ^(a)		
		Maximum	Minimum	Average
6-20-E5A	2	25	20	22 ± 5.1
6-20-E5AP ^(c)	1			<0.5 ---
6-20-E5AQ ^(c)	1			<0.5 ---
6-20-E5AR ^(c)	1			<0.5 ---
6-21-6	5	39	31	34 ± 3.1
6-22-70	2	11	11	11 ± 0.1
6-24-1P ^(c)	1			<0.5 ---
6-24-1Q ^(c)	1			<0.5 ---
6-24-1R ^(c)	1			<0.5 ---
6-24-1S ^(c)	1			<0.5 ---
6-24-1T	1			<0.5 ---
6-24-33	2	23	20	21 ± 2.6
6-24-46	2	7.1	7.0	7.1 ± 0.2
6-25-55	2	15	14	15 ± 0.5
6-25-70	2	13	13	13 ± 0.0
6-26-15A	2	41	39	40 ± 2.0
6-26-89	1			3.0 ---
6-27-8	2	47	38	42 ± 12
6-28-40	2	14	12	13 ± 1.5
6-28-40P ^(c)	1			<0.5 ---
6-28-52A	2	<0.5	<0.5	<0.5 ---
6-29-4	5	32	29	30 ± 1.5
6-29-78	1			7.1 ---
6-31-31	2	11	10	11 ± 0.8
6-31-31P ^(c)	1			<0.5 ---
6-32-22	2	40	38	39 ± 2.9
6-32-43	2	29	27	28 ± 1.8
6-32-62	2	30	28	29 ± 2.0
6-32-70B	1			18 ---
6-32-72	2	4.4	0.7	2.6 ± 4.6
6-32-77	2	5.0	5.0	5.0 ± 0.0
6-33-42	2	30	29	29 ± 1.3
6-33-56	2	9.2	9.1	9.2 ± 0.1
6-34-39A	2	3.9	3.4	3.7 ± 0.7
6-34-41B	2	15	13	14 ± 1.8
6-34-42	2	18	17	17 ± 1.4
6-34-51	2	9.8	9.7	9.7 ± 0.1
6-34-88	1			20 ---
6-35-9	2	39	36	38 ± 3.8
6-35-66	2	26	26	26 ± 0.4
6-35-70	2	33	30	31 ± 3.5
6-36-46P ^(c)	1			<0.5 ---
6-36-46Q ^(c)	1			<0.5 ---
6-36-61A	1			22 ---
6-36-61B	1			<0.5 ---
6-36-93	1			39 ---
6-37-43	2	8.8	4.2	6.5 ± 5.8
6-37-82A	2	39	33	36 ± 7.9
6-37-E4	6	27	25	26 ± 0.7
6-38-15	2	64	63	64 ± 1.8
6-38-65	2	160	150	150 ± 14
6-38-70	2	240	240	240 ± 8.8
6-39-0	7	42	38	40 ± 1.0
6-39-39	1			<0.5 ---
6-39-79	1			1.2 ---
6-40-1	2	42	39	41 ± 3.9
6-40-33A	2	<0.5	<0.5	<0.5 ---
6-40-62	2	46	41	43 ± 5.8
6-41-1	7	55	39	43 ± 4.4
6-41-23	2	28	24	26 ± 4.9
6-42-12A	2	45	42	44 ± 4.0
6-42-2	7	41	37	39 ± 1.3
6-42-40C ^(c)	1			0.3 ^(d) ---

TABLE A.25. (contd)

Well Name ^(b)	No. of Samples	NO ₃ Concentration (mg/L) ^(a)		
		Maximum	Minimum	Average
6-43-3	7	49	37	40 ± 3.5
6-43-88	1			14 ---
6-44-4	6	4.6	<0.5	1.8 ± 1.3
6-44-64	2	49	42	45 ± 9.1
6-45-2	2	38	35	36 ± 3.6
6-45-42	2	6.9	6.3	6.6 ± 0.8
6-45-69A	2	29	26	27 ± 3.9
6-46-21B	2	17	16	16 ± 1.1
6-46-4	7	30	26	28 ± 1.2
6-46-32 ^(c)	1			0.7 ^(d) ---
6-47-5	7	30	24	28 ± 1.8
6-47-35A	2	19	18	18 ± 1.6
6-47-46A	2	15	11	13 ± 4.5
6-47-50 ^(c)	1			0.6 ^(d) ---
6-47-60	2	24	23	23 ± 0.9
6-48-7	2	5.3	4.2	4.7 ± 1.4
6-48-18	2	6.7	6.2	6.4 ± 0.5
6-48-71	2	23	22	23 ± 0.8
6-49-13E	2	6.2	6.0	6.1 ± 0.2
6-49-28	2	<0.5	<0.5	<0.5 ^(d) ---
6-49-32B ^(c)	1			0.7 ^(d) ---
6-49-55A	2	170	150	160 ± 21
6-49-55B ^(c)	1			0.8 ^(d) ---
6-49-57	2	76	75	75 ± 1.8
6-49-79	2	45	40	42 ± 5.1
6-50-28B	2	3.8	3.6	3.7 ± 0.2
6-50-30	2	3.6	<0.5	2.0 ± 3.8
6-50-42 ^(c)	2	2.4	2.2	2.3 ± 0.3
6-50-45 ^(c)	1			0.5 ^(d) ---
6-50-48 ^(c)	1			0.5 ^(d) ---
6-50-53	2	340	320	330 ± 26
6-50-85	2	26	25	25 ± 0.9
6-51-46	1			0.7 ^(d) ---
6-51-63	2	17	16	17 ± 1.1
6-51-75	2	2.8	2.6	2.7 ± 0.2
6-52-19	2	27	4.4	16 ± 28
6-52-46A ^(c)	1			1.5 ^(d) ---
6-52-48 ^(c)	1			0.2 ^(d) ---
6-53-50 ^(c)	1			0.2 ^(d) ---
6-53-103 ^(c)	1			<0.5 ---
6-53-35	2	<0.5	>0.5	<0.5 ---
6-54-34	2	8.6	6.3	7.5 ± 2.9
6-54-37A	2	<0.5	<0.5	<0.5 ---
6-54-42	2	<0.5	<0.5	<0.5 ---
6-54-45A	2	<0.5	<0.5	<0.5 ---
6-55-40	2	<0.5	<0.5	<0.5 ---
6-55-44	2	<0.5	<0.5	<0.5 ---
6-55-50A	2	<0.5	<0.5	<0.5 ---
6-55-50C	2	1.8	1.4	1.6 ± 0.5
6-55-50D	2	11	3.8	7.2 ± 8.6
6-55-70	1			<0.5 ---
6-55-76	2	4.9	0.6	2.7 ± 5.4
6-55-89	2	3.5	3.4	3.5 ± 0.2
6-56-43 ^(c)	2	<0.5	<0.5	<0.5 ^(d) ---
6-56-53 ^(c)	1			0.7 ^(d) ---
6-57-25A	2	3.5	3.3	3.4 ± 0.2
6-57-29A	2	2.7	2.7	2.7 ± 0.1
6-57-83A	1			<0.5 ---
6-58-24	2	2.6	2.5	2.6 ± 0.2
6-59-32	2	4.2	4.2	4.2 ± 0.1
6-59-58	2	0.8	0.7	0.7 ± 0.1
6-59-80B	2	20	<0.5	10 ± 24
6-60-32	2	5.3	5.1	5.2 ± 0.3
6-60-57	2	<0.5	<0.5	<0.5 ---

TABLE A.25. (contd)

Well Name ^(b)	No. of Samples	NO ₃ ⁻ Concentration (mg/L) ^(a)		
		Maximum	Minimum	Average
6-60-60	2	<0.5	<0.5	<0.5 ---
6-61-37	2	4.3	4.2	4.2 ± 0.2
6-61-41	2	2.8	2.5	2.7 ± 0.4
6-61-62	2	37	33	35 ± 4.4
6-61-66	2	4.5	4.4	4.5 ± 0.1
6-62-31	2	45	38	41 ± 8.5
6-62-43F	2	3.7	3.5	3.6 ± 0.2
6-63-25A	2	20	19	20 ± 1.0
6-63-51	2	7.8	1.7	4.8 ± 7.6
6-63-55	2	1.5	1.1	1.3 ± 0.5
6-63-58	2	18	7.9	13 ± 13
6-63-90	1			5.3 ---
6-64-27	3	43	41	42 ± 1.7
6-64-62	2	25	25	25 ± 0.8
6-65-50	2	2.2	1.9	2.0 ± 0.3
6-65-59	2	1.2	1.0	1.1 ± 0.2
6-65-72	2	22	21	22 ± 1.9
6-65-83	2	4.2	4.1	4.2 ± 0.1
6-66-23	3	45	41	43 ± 3.0
6-66-38	2	<0.5	<0.5	<0.5 ---
6-66-39	2	<0.5	<0.5	<0.5 ---
6-66-58	2	2.6	1.5	2.0 ± 1.4
6-66-64	2	16	10	13 ± 6.9
6-66-103	2	<0.5	<0.5	<0.5 ---
6-67-51	2	1.3	1.2	1.2 ± 0.1
6-67-86	2	2.8	2.7	2.7 ± 0.1
6-67-98	2	5.2	4.7	5.0 ± 0.6
6-68-105	2	2.0	1.8	1.9 ± 0.2
6-69-38	2	<0.5	<0.5	<0.5 ---
6-70-68	2	3.1	3.1	3.1 ± 0.0
6-71-30	2	27	26	27 ± 0.8
6-71-52	3	6.6	6.4	6.5 ± 0.1
6-71-77	2	7.0	5.9	6.4 ± 1.4
6-72-73	1			7.9 ---
6-72-88	2	12	4.6	8.5 ± 9.6
6-72-92	1			9.5 ---
6-73-61	2	8.2	7.5	7.8 ± 0.9
6-74-44	2	1.8	1.4	1.6 ± 0.5
6-77-36	3	78	61	71 ± 11
6-77-54	2	7.8	7.8	7.8 ± 0.1
6-78-62	1			7.7 ---
6-80-43P ^(c)	1			<0.5 ---
6-80-43Q	1			<0.5 ---
6-80-43R	1			<0.5 ---
6-80-43S	1			8.1 ---
6-81-58	2	1.9	1.6	1.7 ± 0.4
6-84-35AO	1			<0.5 ---
6-87-55	2	19	19	19 ± 1.0
6-89-35	3	9.4	9.3	9.3 ± 0.1
6-90-45	2	5.0	4.8	4.9 ± 0.3
6-96-49	2	18	15	16 ± 4.6
6-97-43	2	25	25	25 ± 0.6
6-97-51A	2	21	19	20 ± 1.9
6-101-48B	2	1.1	1.0	1.1 ± 0.1
6-S3-25	1			<0.5 ---
6-S3-E12	3	26	25	25 ± 1.1
6-S6-E4B	3	18	16	17 ± 0.8
6-S6-E4D	3	28	25	26 ± 1.6
6-S6E14A ^(c)	2	7.3	6.6	6.9 ± 0.9
6-S7-34	2	<0.5	<0.5	<0.5 ---
6-S8-19	2	6.5	6.2	6.3 ± 0.4
6-S11-E12A	1			23 ---
6-S11-E12AP ^(c)	2	<0.5	<0.5	<0.5 ---
6-S12-3	2	11	9.8	10 ± 1.2

TABLE A.25. (contd)

Well Name ^(b)	No. of Samples	NO ₃ ⁻ Concentration (mg/L) ^(a)		
		Maximum	Minimum	Average
6-S12-29	2	19	18	18 ± 1.3
6-S14-20A	2	2.3	2.0	2.1 ± 0.4
6-S16-24 ^(c)	1			0.2 ^(d) ---
6-S18-51 ^(c)	2	1.0	<0.5	0.7 ± 0.6
6-S19-11	1			9.9 ---
6-S19-E13	2	22	21	22 ± 0.5
6-S24-19	1			<0.5 ---
6-S27-E14	5	28	22	24 ± 2.3
6-S29-E12	2	21	21	21 ± 0.4
6-S31-1P ^(c)	2	3.5	3.2	3.3 ± 0.3

- (a) Average concentrations for 1986 ±2 standard error of the calculated mean.
 (b) See Figure 3.10 for well locations.
 (c) Wells that sample a confined aquifer or a composite of a confined and the unconfined aquifer.
 (d) Analyzed by the phenoldisulphonic method (all others by the Ion Chromatography method).
 (e) No standard error can be calculated.

TABLE A.26. Chromium Concentrations in the Ground Water

Well Name ^(b)	No. of Samples	Cr Concentration (mg/L) ^(a)		
		Maximum	Minimum	Average
1-H3-1	4	0.058	0.034	0.048 ± 0.012
1-H4-3	4	0.61	0.0032	0.39 ± 0.29
1-H4-4	4	0.55	0.10	0.30 ± 0.22
1-H4-5	4	0.46	0.25	0.37 ± 0.10
1-H4-6	4	0.039	0.0027	0.023 ± 0.018
3-1-1	4	0.0033	0.0022	0.0025 ± 0.0005
3-1-2	4	0.0038	0.0017	0.0029 ± 0.0010
3-1-3	4	0.0036	0.0017	0.0024 ± 0.0009
3-1-4	4	0.0033	0.0012	0.0023 ± 0.0010
3-1-5	4	0.0035	0.0006	0.0019 ± 0.0014
3-1-6	4	0.0027	0.0021	0.0023 ± 0.0003
3-2-1	4	0.0025	0.0011	0.0015 ± 0.0007
3-2-2	4	0.0017	0.0009	0.0013 ± 0.0004
3-2-3	4	0.0024	0.0003	0.0010 ± 0.0010
3-3-1	4	0.0016	0.0002	0.0007 ± 0.0007
3-3-1	4	0.0018	0.0001	0.0010 ± 0.0008
3-3-2	4	0.0027	0.0016	0.0021 ± 0.0005
3-3-3	4	0.0031	0.0015	0.0024 ± 0.0008
3-3-6	4	0.0060	0.0021	0.0032 ± 0.0019
3-3-7	4	0.0029	0.0013	0.0020 ± 0.0008
3-3-9	4	0.0027	0.0016	0.0020 ± 0.0005
3-3-11	4	0.0029	0.0005	0.0015 ± 0.0012
3-3-12	4	0.0038	0.0015	0.0030 ± 0.0011
3-4-1	4	0.0029	0.0016	0.0024 ± 0.0006
3-4-7	4	0.0022	0.0005	0.0015 ± 0.0008
3-4-9	4	0.0033	0.0006	0.0015 ± 0.0013
3-4-10	4	0.0022	0.0004	0.0012 ± 0.0009
3-5-1	4	0.0029	0.0013	0.0025 ± 0.0008
3-6-1	4	0.0030	0.0002	0.0017 ± 0.0014
3-8-1	4	0.0027	0.0007	0.0020 ± 0.0010
3-8-2	4	0.0032	0.0006	0.0018 ± 0.0012
3-8-3	4	0.0020	0.0006	0.0014 ± 0.0007
3-8-4	4	0.0023	0.0003	0.0014 ± 0.0010
4-S1-7C	4	0.0038	0.0009	0.0024 ± 0.0014
4-S1-8A	4	0.0049	0.0019	0.0034 ± 0.0015
4-S1-8B	3	0.0025	0.0003	0.0016 ± 0.0015
6-S27-E14 ^(c)	12	0.0024	0.0004	0.0015 ± 0.0003
6-S30-E15A ^(c)	4	0.0018	0.0006	0.0010 ± 0.0006

(a) Average concentrations ±2 standard error of the calculated mean.

(b) See Figure 3.10 for well locations.

(c) Well is just south of the 300 Area (see Figure 3.10).

TABLE A.27. Fluoride Concentrations in the Ground Water

Well Name ^(b)	No. of Samples	F Concentration (mg/L) ^(a)		
		Maximum	Minimum	Average
1-H3-1	4	0.26	0.22	0.24 ± 0.02
1-H4-3	4	0.49	0.16	0.31 ± 0.16
1-H4-4	4	0.39	0.10	0.24 ± 0.14
1-H4-5	4	0.13	0.07	0.10 ± 0.03
1-H4-6	4	0.28	0.17	0.22 ± 0.05
3-1-1	4	0.51	0.36	0.43 ± 0.07
3-1-2	4	0.54	0.35	0.42 ± 0.09
3-1-3	4	0.54	0.38	0.46 ± 0.08
3-1-4	4	0.63	0.40	0.51 ± 0.11
3-1-5	4	0.57	0.50	0.55 ± 0.03
3-1-6	4	0.63	0.34	0.46 ± 0.14
3-2-1	4	0.44	0.31	0.38 ± 0.06
3-2-2	4	0.87	0.36	0.59 ± 0.25
3-2-3	4	0.53	0.29	0.39 ± 0.12
3-3-1	4	0.34	0.25	0.31 ± 0.04
3-3-2	4	0.35	0.25	0.31 ± 0.05
3-3-3	4	0.32	0.23	0.28 ± 0.04
3-3-6	4	0.35	0.15	0.25 ± 0.10
3-3-7	4	0.51	0.19	0.35 ± 0.16
3-3-9	4	0.38	0.32	0.35 ± 0.03
3-3-10	4	0.43	0.35	0.40 ± 0.04
3-3-11	4	0.44	0.34	0.39 ± 0.05
3-3-12	4	0.44	0.29	0.36 ± 0.07
3-4-1	4	0.32	0.28	0.31 ± 0.02
3-4-7	4	0.42	0.32	0.39 ± 0.05
3-4-9	4	0.41	0.33	0.38 ± 0.04
3-4-10	4	0.43	0.30	0.38 ± 0.06
3-5-1	4	0.30	0.22	0.26 ± 0.04
3-6-1	4	0.30	0.21	0.26 ± 0.04
3-8-1	4	0.30	0.24	0.27 ± 0.03
3-8-2	4	0.33	0.25	0.29 ± 0.04
3-8-3	4	0.40	0.28	0.35 ± 0.06
3-8-4	4	0.43	0.26	0.33 ± 0.08
4-S1-7C	4	0.23	0.16	0.20 ± 0.03
4-S1-8A	4	0.34	0.27	0.32 ± 0.03
4-S1-8B	3	0.22	0.17	0.20 ± 0.03
6-S18-51 ^(c)	5	9.8	7.1	8.0 ± 1.0
6-S19-E13 ^(d)	5	0.37	0.28	0.31 ± 0.04
6-S27-E14 ^(d)	12	0.30	0.16	0.23 ± 0.02
6-S29-E12 ^(d)	3	0.31	0.26	0.28 ± 0.03
6-S30-E15A ^(d)	4	0.17	0.13	0.16 ± 0.02

(a) Average concentrations ±2 standard error of the calculated mean.

(b) See Figure 3.10 for well locations.

(c) Well that samples a confined aquifer or a composite of a confined and the unconfined aquifer.

(d) Well is close to the 300 Area (see Figure 3.10).

TABLE A.28. Number of Ground-Water Chemical Monitoring Results Below Detection Limit

Constituent	Detection Limit	Units	Number of Samples	Number of Samples Below Detection
Contamination Indicators				
Specific conductance		µmho/cm	138	0
pH			134	0
Total organic halogen	100	µg/L	191	191
Total organic carbon	1,000	µg/L	187	92
Primary Drinking Water Constituents				
Coliform bacteria	2.2	mpn	137	117
Gross beta	8	pCi/L	131	5
Radium	1	pCi/L	131	105
Gross alpha	4	pCi/L	131	35
Barium	6	µg/L	137	1
Cadmium	2	µg/L	137	111
Chromium	10	µg/L	137	100
Silver	10	µg/L	137	136
Arsenic	5	µg/L	137	121
Mercury	0.1	µg/L	137	134
Selenium	5	µg/L	137	136
Endrin	1	µg/L	139	139
Methoxychlor	1	µg/L	139	139
Toxaphene	1	µg/L	139	139
Alpha-BHC	1	µg/L	139	139
Beta-BHC	1	µg/L	139	139
Gamma-BHC	1	µg/L	139	139
Delta-BHC	1	µg/L	139	139
Lead (graphite furnace)	5	µg/L	49	31
Nitrate	500	µg/L	137	2
Fluoride	500	µg/L	137	99
2,4-D	1	µg/L	139	139
2,4,5-TP silvex	1	µg/L	139	139
Quality Characteristics				
Sodium	100	µg/L	137	0
Manganese	5	µg/L	137	57
Iron	50	µg/L	137	16
Phenol	10	µg/L	64	64
Sulfate	500	µg/L	137	1
Chloride	500	µg/L	137	1
Site-Specific Constituents				
Beryllium	5	µg/L	54	52
Osmium	300	µg/L	54	54
Strontium	300	µg/L	54	46
Zinc	5	µg/L	54	12
Calcium	50	µg/L	54	0
Lead	30	µg/L	89	84
Nickel	10	µg/L	137	111
Copper	10	µg/L	137	110
Vanadium	5	µg/L	137	9
Antimony	100	µg/L	137	137
Aluminum	150	µg/L	137	113
Potassium	100	µg/L	137	0
Arochlor 1016	1	µg/L	71	71
Arochlor 1221	1	µg/L	71	71
Arochlor 1232	1	µg/L	71	71
Arochlor 1242	1	µg/L	71	71
Arochlor 1248	1	µg/L	71	71
Arochlor 1254	1	µg/L	71	71
Arochlor 1260	1	µg/L	71	71

TABLE A.28. (contd)

Constituent	Detection Limit	Units	Number of Samples	Number of Samples Below Detection
Tetrachloromethane	10	µg/L	81	79
Benzene	10	µg/L	81	81
Dioxane	500	µg/L	81	81
Methyl ethyl ketone	10	µg/L	81	81
Pyridine	500	µg/L	81	81
Toluene	10	µg/L	81	81
1,1,1-trichloroethane	10	µg/L	81	77
1,1,2-trichloroethane	10	µg/L	81	81
Trichloroethylene	10	µg/L	81	81
Perchloroethylene	10	µg/L	81	81
Xylene-o,p	10	µg/L	81	81
Xylene-m	10	µg/L	81	81
1,2-dichlorobenzene	10	µg/L	64	64
1,3-dichlorobenzene	10	µg/L	64	64
1,4-dichlorobenzene	10	µg/L	64	63
Hexachlorobenzene	10	µg/L	64	64
Pentachlorobenzene	10	µg/L	64	64
1,2,4,5-tetrachlorobenzene	10	µg/L	64	64
1,2,4-trichlorobenzene	10	µg/L	64	64
Hexachloropropene	10	µg/L	37	37
Hexachlorophene	10	µg/L	64	64
Naphthalene	10	µg/L	64	64
1,2,3-trichlorobenzene	10	µg/L	64	64
1,3,5-trichlorobenzene	10	µg/L	64	64
1,2,3,4-tetrachlorobenzene	10	µg/L	64	64
1,2,3,5-tetrachlorobenzene	10	µg/L	64	64
Chlorobenzilate	100	µg/L	73	73
Formalin	500	µg/L	81	81
Phosphate	1,000	µg/L	137	136
Kerosene	10,000	µg/L	64	64
Ammonium ion	50	µg/L	83	18
Strychnine	50	µg/L	36	36
Maleic hydrazide	500	µg/L	36	36
Nicotinic acid	100	µg/L	36	36

TABLE A.29. Water Quality Parameters Analyzed by HEHF in 1986

Well Name (a)	Date	pH	Cond. Activity $\mu\text{mho/cm}$	mg/L											
				Alk. as CaCO_3 (b)	HCO_3^- Alk. as CaCO_3 (c)	CO_3^{2-} Alk. as CaCO_3 (d)	TDS (e)	Cl	SO_4	$\text{NO}_3\text{-N}$ (f)	Ca	Mg	Na	K	B
1-H3-1	12-16	7.9	1001	201	185	2.0	432	10.9	76	14.0	76	21.3	24	7.1	0.32
1-H4-3	12-16	8.1	1636	143	135	2.5	1150	8.4	98	147	24	4.3	308	7.4	0.14
1-H4-4	12-16	8.1	1026	127	105	2.2	725	5.2	67	94	44	6.5	167	6.8	0.21
1-H4-5	12-16	8.3	444	131	120	1.6	247	5.2	50	6.7	56	10.1	10	4.8	0.15
1-H4-6	12-16	7.8	611	132	125	0.9	353	15.7	94	7.7	63	14.7	25	6.7	0.17
6-2-3	12-1	8.0	429	123	110	1.3	329	9.9	54	7.20	43	11.7	17	7.3	0.08
6-2-7	12-1	7.7	1013	157	150	1.9	775	36	293	8.30	112	36	51	11.0	0.26
6-2-E5A	12-1	8.1	350	114	100	1.6	306	7.8	31	5.10	40	10.4	11	7.0	0.12
6-10-54A	18-8	7.9	332	121	115	1.1	238	5.1	20	2.55	33	11.2	11	3.8	0.06
6-14-47	12-8	7.4	275	103	100	<0.5	175	4.1	19	0.09	27	8.5	13	5.1	0.17
6-15-26	12-1	8.0	461	150	145	1.8	343	9.3	55	5.40	48	13.1	24	7.7	0.18
6-19-43	12-8	7.8	390	113	110	0.6	245	6.5	50	1.76	39	10.3	16	6.2	0.07
6-25-70	12-8	7.8	345	127	115	0.9	216	4.7	21	3.00	29	11.8	15	4.5	0.07
6-26-15A	12-1	8.1	429	119	117	1.2	334	14.2	52	10.1	44	11.7	20	7.1	0.14
6-26-89	12-29	8.0	364	168	160	1.5	229	11.7	45	1.49	35	14.6	17	4.7	0.13
6-34-42	12-8	8.0	325	101	95	1.2	127	4.2	3.9	3.95	22	7.8	22	5.9	0.14
6-35-70	12-8	7.8	444	133	125	1.1	316	24	30	7.10	43	14.2	22	6.3	0.16
6-36-93	12-29	7.7	434	93	95	1.0	226	16.6	50	8.13	38	15.9	13	4.6	0.10
6-40-1	12-16	7.9	413	127	117	1.1	292	12.2	39	8.3	42	12.4	17	5.7	0.15
6-40-33A	12-15	8.1	348	173	160	2.1	345	3.4	<1	<0.05	12.0	4.0	58	7.6	0.14
6-45-42	12-15	8.0	301	102	100	1.6	375	10.2	67	3.40	22.5	10.5	18	4.9	0.14
6-45-69A	12-8	7.9	403	120	115	1.1	280	11.9	5.7	5.73	39	16.4	12	4.0	0.16
6-49-13E	12-15	7.8	340	137	130	1.0	311	5.6	25	1.52	33	8.3	26	5.7	0.17
6-49-79	12-8	8.0	389	100	100	1.1	118	10.2	9.3	9.30	41	14.2	8.2	4.2	0.09
6-50-28B	12-15	7.8	342	128	115	0.9	315	8.9	28	0.85	26	11.4	22	4.4	0.14
6-50-53	12-15	7.7	1446	72	70	0.5	1236	39	312	69	162	511	52	12.8	0.16
6-55-50C	12-15	8.1	297	114	110	1.6	334	5.8	16	4.0	31	10.1	4.6	4.5	0.13
6-59-58	12-15	8.1	267	117	110	1.6	334	4.7	14	0.23	19.3	6.9	27	5.6	0.14
6-63-90	12-29	8.0	323	121	85	1.3	218	8.4	29	1.35	33	12.4	11	4.5	0.09
6-64-27	12-16	7.7	817	151	140	1.0	542	41	186	9.3	85	21.0	53	7.8	0.19
6-66-64	12-29	8.1	318	116	105	1.5	214	6.1	26	3.25	28	9.1	18	5.6	0.09
6-71-77	12-29	8.0	305	122	110	1.4	209	4.0	23	1.33	26	9.6	15	5.0	0.11
6-72-88	12-29	7.9	333	110	105	1.0	204	5.3	39	1.94	34	7.8	9.2	4.5	0.11
6-74-44	12-16	8.5	259	74	69	3.1	162	9.3	39	0.5	16	6.7	29	3.0	0.12
6-78-62	12-29	8.1	358	110	105	1.6	211	6.6	57	1.80	36	11.2	16	5.1	0.10
6-81-58	12-29	8.1	220	95	90	1.3	113	1.0	15	0.50	29	7.7	3.3	2.6	0.10
6-87-55	12-29	8.2	301	89	90	1.7	171	3.7	29	4.20	28	9.6	14	3.7	0.12
6-89-35	12-16	7.8	428	156	145	1.1	238	4.8	37	2.1	33	12.5	34	5.2	0.15
6-S3-E12	12-1	8.3	327	111	104	2.6	269	8.0	23	5.80	33	10.1	13	5.4	0.13
6-S8-25	12-8	7.8	582	154	140	0.9	372	21.8	79	<0.05	56	15.7	24	8.7	0.16
6-S19-E13	12-1	8.1	436	130	125	1.8	318	19	49	4.90	43	12.7	23	7.3	0.11
6-S28-E0	12-1	8.1	326	119	112	1.7	254	10.6	22	2.60	34	9.1	12	5.4	0.06
6-S31-1P	12-8	8.0	259	93	90	1.1	111	4.9	16	0.78	26	6.5	8.0	4.8	0.10

(a) Well locations are identified in Figure 3.10
 (b) Alkalinity as calcium carbonate.
 (c) Bicarbonate alkalinity as calcium carbonate.
 (d) Carbonate alkalinity as calcium carbonate.
 (e) Total dissolved solids.
 (f) Nitrate analyzed as nitrogen. To convert to nitrate ion, multiply by 4.4.

TABLE A.30. Radionuclide Concentrations Measured in Columbia River Water at Priest Rapids Dam in 1986

Radionuclide ^(b)	No. of Samples	Concentration (pCi/L) ^(a)			Average	Drinking Water Standard ^(c)
		Maximum	Minimum	Average		
Gross Alpha	12	0.91 ± 0.45	0.21 ± 0.26	0.51 ± 0.16	15	
Gross Beta	12	2.8 ± 1.5	0.8 ± 1.3	1.9 ± 0.6	50	
³ H	12	130 ± 10	60 ± 7	100 ± 10	20,000	
⁸⁹ Sr	12	0.17 ± 0.07	-0.05 ± 0.09	0.05 ± 0.04	20	
⁹⁰ Sr	12	0.19 ± 0.06	0.10 ± 0.04	0.15 ± 0.02	8	
²³⁴ U	12	0.40 ± 0.07	0.027 ± 0.005	0.25 ± 0.06	--- ^(d)	
²³⁵ U	12	0.022 ± 0.014	-0.007 ± 0.014	0.007 ± 0.005	---	
²³⁸ U	12	0.28 ± 0.05	0.024 ± 0.004	0.20 ± 0.05	---	
⁶⁰ Co P	25	0.0041 ± 0.0059	-0.0044 ± 0.0046	-0.0005 ± 0.0015	100	
⁶⁰ Co D	25	0.008 ± 0.015	-0.0074 ± 0.015	-0.0008 ± 0.0030	---	
⁹⁵ Nb P	25	0.0076 ± 0.0058	-0.0021 ± 0.0037	0.0021 ± 0.0014	300	
⁹⁵ Nb D	25	0.0132 ± 0.0086	-0.010 ± 0.011	0.0037 ± 0.0029	---	
⁹⁵ Zr P	25	0.008 ± 0.009	-0.010 ± 0.010	-0.0005 ± 0.0021	200	
⁹⁵ Zr D	25	0.009 ± 0.017	-0.011 ± 0.018	-0.001 ± 0.004	---	
¹⁰⁶ Ru P	25	0.0046 ± 0.0036	-0.057 ± 0.051	-0.022 ± 0.009	30	
¹⁰⁶ Ru D	25	0.021 ± 0.079	-0.110 ± 0.088	-0.037 ± 0.020	---	
¹²⁹ I D	4	1.0x10 ⁻⁵ ± 1.3x10 ⁻⁶	7.6x10 ⁻⁶ ± 9.4x10 ⁻⁷	8.6x10 ⁻⁶ ± 1.5x10 ⁻⁶	1	
¹³¹ I P	25	0.016 ± 0.006	0.001 ± 0.007	0.006 ± 0.002	3	
¹³¹ I D	25	0.110 ± 0.014	0.003 ± 0.017	0.021 ± 0.010	---	
¹³⁴ Cs P	25	0.004 ± 0.003	-0.0045 ± 0.0066	0.00009 ± 0.0014	20,000	
¹³⁴ Cs D	25	0.017 ± 0.011	-0.010 ± 0.009	-0.0002 ± 0.0032	---	
¹³⁷ Cs P	25	0.0071 ± 0.0039	-0.010 ± 0.005	0.0004 ± 0.0018	200	
¹³⁷ Cs D	25	0.0134 ± 0.0089	-0.009 ± 0.012	0.0003 ± 0.0031	---	
¹⁴⁴ Ce P	25	0.006 ± 0.015	-0.015 ± 0.012	-0.008 ± 0.003	---	
¹⁴⁴ Ce D	25	0.009 ± 0.033	-0.044 ± 0.026	-0.016 ± 0.007	---	
²³⁸ Pu P	4	1.4x10 ⁻⁶ ± 5.5x10 ⁻⁶	-2.1x10 ⁻⁶ ± 8.7x10 ⁻⁶	-2.2x10 ⁻⁷ ± 3.3x10 ⁻⁶	---	
²³⁸ Pu D	4	3.1x10 ⁻⁵ ± 3.9x10 ⁻⁵	-1.1x10 ⁻⁴ ± 3.3x10 ⁻⁴	-4.9x10 ⁻⁵ ± 1.3x10 ⁻⁴	---	
^{239,240} Pu P	4	2.4x10 ⁻⁵ ± 8.8x10 ⁻⁶	6.8x10 ⁻⁶ ± 4.6x10 ⁻⁷	1.7x10 ⁻⁵ ± 9.3x10 ⁻⁶	---	
^{239,240} Pu D	4	1.1x10 ⁻⁴ ± 1.2x10 ⁻⁴	1.6x10 ⁻⁵ ± 1.5x10 ⁻⁴	4.8x10 ⁻⁵ ± 7.5x10 ⁻⁵	---	

(a) Maximum and minimum values ±2 sigma counting error. Average ±2 standard error of the calculated mean.
 (b) Radionuclides measured using the large volume sampler 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 Appendix C, Table C.2).
 (d) Dashes indicate no guide value.

TABLE A.31. Radionuclide Concentrations Measured in Columbia River Water at the Richland Pumphouse or 300 Area in 1986

Radionuclide ^(b)	No. of Samples	Concentration (pCi/L) ^(a)			Drinking Water Standard ^(c)
		Maximum	Minimum	Average	
RICHLAND PUMPHOUSE					
Gross Alpha	12	1.01 ± 0.45	0.28 ± 0.34	0.60 ± 0.15	15
Gross Beta	12	2.8 ± 1.5	0.5 ± 1.0	1.6 ± 0.6	50
³ H	12	210 ± 10	110 ± 10	150 ± 20	20,000
⁸⁹ Sr	12	0.27 ± 0.07	-0.03 ± 0.14	0.05 ± 0.06	20
⁹⁰ Sr	12	0.24 ± 0.08	0.10 ± 0.03	0.16 ± 0.03	8
²³⁴ U	12	0.38 ± 0.06	0.025 ± 0.004	0.27 ± 0.05	---(d)
²³⁵ U	12	0.019 ± 0.012	0.000 ± 0.005	0.007 ± 0.004	---
²³⁸ U	12	0.34 ± 0.05	0.025 ± 0.004	0.22 ± 0.05	---
300 AREA					
⁶⁰ Co P	22	0.0081 ± 0.0058	-0.0015 ± 0.0058	0.0017 ± 0.0015	100
D	22	0.009 ± 0.011	-0.007 ± 0.012	0.002 ± 0.003	
⁹⁵ Nb P	22	0.0051 ± 0.0044	-0.0023 ± 0.0037	0.0016 ± 0.0012	300
D	22	0.012 ± 0.010	-0.0057 ± 0.0092	0.0033 ± 0.0025	
⁹⁵ Zr P	22	0.0039 ± 0.0076	-0.010 ± 0.011	-0.0014 ± 0.0020	200
D	22	0.006 ± 0.014	-0.014 ± 0.016	-0.0010 ± 0.0039	
¹⁰⁶ Ru P	22	0.001 ± 0.034	-0.042 ± 0.034	-0.020 ± 0.009	30
D	22	-0.009 ± 0.062	-0.080 ± 0.075	-0.038 ± 0.017	
¹²⁹ I D	4	1.6x10 ⁻⁴ ± 1.5x10 ⁻⁵	7.9x10 ⁻⁵ ± 7.2x10 ⁻⁶	1.0x10 ⁻⁴ ± 4.0x10 ⁻⁵	1
¹³¹ I P	22	0.013 ± 0.012	-0.0004 ± 0.0047	0.0039 ± 0.0018	3
D	22	0.038 ± 0.021	-0.003 ± 0.012	0.010 ± 0.005	
¹³⁴ Cs P	22	0.0052 ± 0.0049	-0.0066 ± 0.0048	0.0004 ± 0.0014	20,000
D	22	0.0068 ± 0.0085	-0.0011 ± 0.014	-0.0006 ± 0.0028	
¹³⁷ Cs P	22	0.0101 ± 0.0042	-0.0083 ± 0.0046	0.0005 ± 0.0017	200
D	22	0.0098 ± 0.0084	-0.016 ± 0.009	-0.0014 ± 0.0029	
¹⁴⁴ Ce P	22	0.0014 ± 0.0087	-0.025 ± 0.016	-0.0077 ± 0.0033	---
D	22	0.002 ± 0.018	-0.037 ± 0.034	-0.016 ± 0.006	
²³⁸ Pu P	4	1.4x10 ⁻⁶ ± 4.3x10 ⁻⁶	-5.2x10 ⁻⁷ ± 2.3x10 ⁻⁶	5.5x10 ⁻⁷ ± 2.0x10 ⁻⁶	---
D	4	-4.9x10 ⁻⁵ ± 2.9x10 ⁻⁴	-2.8x10 ⁻⁴ ± 9.6x10 ⁻⁴	-1.2x10 ⁻⁴ ± 2.9x10 ⁻⁴	
^{239,240} Pu P	4	3.2x10 ⁻⁵ ± 8.0x10 ⁻⁶	1.3x10 ⁻⁵ ± 7.4x10 ⁻⁶	2.2x10 ⁻⁵ ± 1.0x10 ⁻⁵	---
D	4	2.8x10 ⁻⁴ ± 9.6x10 ⁻⁴	3.4x10 ⁻⁵ ± 1.5x10 ⁻⁴	1.2x10 ⁻⁴ ± 2.7x10 ⁻⁴	

- (a) Maximum and minimum values ±2 sigma counting error. Average ±2 standard error of the calculated mean.
 (b) Radionuclides measured using the large volume sampler 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 Appendix C, Table C.2).
 (d) Dashes indicate no guide value.

TABLE A.32. Columbia River Water Quality Data

Analysis	Units	Vernita Bridge (Upstream)			Richland Pumphouse (Downstream)			State Standard ^(b)		
		No. of Samples	Maximum	Minimum	Annual Average ^(a)	No. of Samples	Maximum		Minimum	Annual Average ^(a)
PML Environmental Monitoring										
pH	pH units	9	8.3	6.0	NA	9	8.1	6.1	NA	6.5 - 8.5
Fecal coliform	#/100 mL	12	240	<2	2 ^(c)	12	240	<2	8 ^(c)	100
Total coliform	#/100 mL	12	>2400	2	49 ^(c)	12	1600	17	130 ^(c)	
Biological oxygen demand	mg/L	12	8.2	<0.5	3.1 ± 1.1	12	5.9	0.5	2.8 ± 0.8	
Nitrate	mg/L	12	0.53	<0.05	0.17 ± 0.08	12	2.1	<0.05	0.3 ± 0.3	
USGS Sampling Program^(d)										
Temperature ^(e)	°C	365	20.1	1.5	11.1 ± 3.6	365	21.1	1.1	11 ± 3.9	20 (maximum)
Dissolved oxygen	mg/L	6	13.8	8.4	11.5 ± 1.9	4	13.0	9.2	11.2 ± 1.8	8 (minimum)
Turbidity	NTU ^(f)	4	4.0	1.2	2.0 ± 1.3	4	3.2	1.4	2.6 ± 0.8	5 + background
pH	pH units	6	8.4	7.3	NA	4	8.4	7.2	NA	6.5 - 8.5
Fecal coliform	#/100 mL	4	4	0	1.5 ^(c)	3	16	1	1 ^(c)	100
Suspended solids, 105°C	mg/L	4	7	1	3.5 ± 2.6	4	8	3	4.8 ± 2.2	
Dissolved solids, 180°C	mg/L	4	93	73	82 ± 8	4	80	68	75 ± 5	
Specific conductance		6	150	130	140 ± 8	4	150	130	140 ± 11	
Hardness, as CaCO ₃	mg/L	4	78	59	65 ± 9	4	68	59	65 ± 4	
Phosphorus, total	mg/L	6	0.06	0.02	0.03 ± 0.02	4	0.04	0.02	0.03 ± 0.01	
Chloride, dissolved	mg/L	4	1.2	0.9	1.1 ± 0.1	4	1.3	0.8	1.1 ± 0.2	
Chromium, dissolved	µg/L	2	<1	<1	<1	4	30	<10	<15	
Nitrogen, Kjeldahl	mg/L	6	0.3	<0.2	0.22 ± 0.03	4	0.4	<0.2	0.25 ± 0.10	
Total organic carbon	mg/L	3	6.8	2.2	5.0 ± 3.1	4	6.8	1.7	4.2 ± 2.2	
Iron, dissolved	µg/L	2	14	11	12.1 ± 4.1	4	18	6	10.0 ± 5.4	
Ammonia, dissolved (as N)	mg/L	6	0.05	<0.01	0.02 ± 0.02	4	0.04	<0.01	0.03 ± 0.01	

(a) Average values ±2 standard error of the calculated mean.

(b) See Appendix C.

(c) Annual median.

(d) Provisional data subject to revision.

(e) Maximum and minimum represent daily averages.

(f) Nephelometric Turbidity Units.

NA = Not Applicable.

TABLE A.33. Radionuclide Concentrations in Onsite Ponds in 1986

Location	Radionuclide	No. of Samples	Concentration, pCi/L (a)		
			Maximum	Minimum	Average
West Lake	Gross Alpha	4	214 ± 14	64 ± 8	160 ± 73
	Gross Beta	4	237 ± 32	115 ± 22	184 ± 61
	³ H	4	720 ± 180	530 ± 210	640 ± 140
	⁹⁰ Sr	4	2.4 ± 0.2	2.0 ± 0.2	2.2 ± 0.2
	¹³⁷ Cs	4	3.1 ± 1.6	-0.5 ± 2.2	1.4 ± 2.1
Gable Pond	Gross Alpha	4	1.4 ± 0.6	0.49 ± 0.34	0.95 ± 0.51
	Gross Beta	4	27.9 ± 3.6	9.7 ± 2.2	15.9 ± 9.0
	³ H	4	200 ± 210	10 ± 170	110 ± 130
	⁹⁰ Sr	4	4.4 ± 0.2	1.9 ± 0.1	2.7 ± 1.2
	¹³⁷ Cs	4	12.0 ± 2.3	2.5 ± 1.0	6.7 ± 4.7
B Pond	Gross Alpha	4	1.6 ± 0.6	0.6 ± 0.4	1.1 ± 0.5
	Gross Beta	4	8.5 ± 2.2	3.7 ± 1.5	6.0 ± 2.6
	³ H	4	6070 ± 320	10 ± 200	1600 ± 3000
	⁹⁰ Sr	4	1.5 ± 1.0	-0.57 ± 0.29	0.5 ± 1.0
	¹³⁷ Cs	4	1.9 ± 2.2	0.3 ± 1.3	1.1 ± 1.1
FFTF Pond	Gross Alpha	4	1.5 ± 1.4	0.1 ± 1.2	0.72 ± 0.92
	Gross Beta	4	45 ± 12	19.7 ± 7.6	29 ± 13
	³ H	4	2530 ± 210	230 ± 210	1300 ± 1100
	¹³⁷ Cs	4	2.5 ± 1.9	-1.4 ± 1.9	0.5 ± 2.3
	²² Na	4	0.1 ± 2.0	-1.8 ± 3.1	-0.7 ± 1.7

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

TABLE A.34. Radionuclides in Milk Samples

Location ^(b)	¹³¹ I			¹³⁷ Cs		
	Concentration, pCi/L ^(a)			Concentration, pCi/L ^(a)		
	No. of Samples	Maximum	Average	No. of Samples	Maximum	Average
Wahluke East Area Composite	14	39.9 ± 1.2	5.3 ± 2.6	13	7.5 ± 3.7	2.4 ± 2.3
Sage Moor Area Composite	29	97.4 ± 9.1	7.7 ± 45	27	40.5 ± 7.6	5.7 ± 3.8
Riverview Area ^(c)	21	560 ± 16	120 ± 360	19	39.7 ± 6.9	10.7 ± 5.2
Benton City Area	14	15.7 ± 4.9	2.2 ± 11	13	20.4 ± 5.9	2.0 ± 3.8
Sunnyside Area	28	49.6 ± 8.2	3.5 ± 23	26	12.7 ± 5.1	2.7 ± 2.1
Moses Lake Area	13	8.9 ± 2.5	0.11 ± 0.22	13	9.3 ± 4.8	3.4 ± 2.4

Location ^(b)	⁸⁹ Sr			⁹⁰ Sr		
	Concentration, pCi/L ^(a)			Concentration, pCi/L ^(a)		
	No. of Samples	Maximum	Average	No. of Samples	Maximum	Average
Wahluke East Area Composite	5	1.0 ± 1.1	0.12 ± 0.56	5	1.5 ± 0.6	1.1 ± 0.3
Sage Moor Area Composite	NS	---	---	5	1.6 ± 0.4	1.4 ± 0.3
Riverview Area ^(c)	5	1.0 ± 0.6	0.23 ± 0.58	5	2.3 ± 0.6	1.5 ± 0.8
Benton City Area	NS	---	---	4	2.6 ± 0.5	1.8 ± 0.6
Sunnyside Area	5	1.0 ± 0.6	-0.004 ± 0.7	5	1.2 ± 0.4	1.0 ± 0.3
Moses Lake Area	NS	---	---	5	2.7 ± 0.8	1.9 ± 0.5

Location ^(b)	³ H			¹²⁹ I		
	Concentration, pCi/L ^(a)			Concentration, pCi/L ^(a)		
	No. of Samples	Maximum	Average	No. of Samples	Maximum	Average
Wahluke East Area Composite	13	430 ± 210	97 ± 120	2	0.018 ± 0.001	0.016 ± 0.006
Sage Moor Area Composite	15	580 ± 220	190 ± 98	2	0.034 ± 0.002	0.030 ± 0.001
Riverview Area ^(c)	9	410 ± 180	140 ± 120	2	0.013 ± 0.001	0.012 ± 0.003
Benton City Area	13	560 ± 230	140 ± 110	2	0.019 ± 0.001	0.019 ± 0.002
Sunnyside Area	14	290 ± 220	80 ± 80	2	0.020 ± 0.001	0.0013 ± 0.0018
Moses Lake Area	13	320 ± 210	200 ± 72	2	0.0011 ± 0.0001	0.0009 ± 0.0006

(a) Maximum values ±2 sigma counting error. Averages ±2 standard error of the calculated mean.
 (b) Refer to Figure 3.35.
 (c) Drinking and irrigation water obtained from the Columbia River downstream of Hanford.
 NS = No sample.

TABLE A.35. Radionuclides in Leafy Vegetables

Location ^(b)	⁹⁰ Sr			¹³⁷ Cs		
	Concentration, pCi/g, wet weight ^(a)			Concentration, pCi/g, wet weight ^(a)		
	No. of Samples	Maximum	Average	No. of Samples	Maximum	Average
Sage Moor Area	3	0.038 ± 0.004	0.034 ± 0.005	3	0.011 ± 0.008	0.002 ± 0.011
Riverview Area ^(c)	3	0.085 ± 0.005	0.066 ± 0.025	3	0.017 ± 0.009	0.013 ± 0.008
Benton City Area	3	0.050 ± 0.005	0.028 ± 0.024	3	0.013 ± 0.010	0.008 ± 0.009
Sunnyside Area	3	0.023 ± 0.004	0.020 ± 0.004	3	0.015 ± 0.008	0.010 ± 0.009
Moses Lake Area	3	0.027 ± 0.004	0.024 ± 0.005	3	0.021 ± 0.008	0.016 ± 0.008

(a) Maximum concentrations ±2 sigma counting error. Averages ±2 standard error of the calculated mean.
 (b) Refer to Figure 3.35.
 (c) Irrigated with Columbia River water.

TABLE A.36. Radionuclides in Vegetables

Type/Location ^(b)	Concentration, pCi/g, wet weight ^(a)			Concentration, pCi/g, wet weight ^(a)		
	No. of Samples	⁹⁰ Sr		No. of Samples	¹³⁷ Cs	
		Maximum	Average		Maximum	Average
Tomatoes						
Riverview Area ^(c)	3	0.003 ± 0.002	0.002 ± 0.002	3	0.005 ± 0.010	0.0005 ± 0.0076
Carrots						
Riverview Area ^(c)	3	0.008 ± 0.003	0.006 ± 0.002	3	0.008 ± 0.008	0.006 ± 0.006
Potatoes						
Riverview Area ^(c)	3	0.006 ± 0.002	0.006 ± 0.001	3	0.008 ± 0.007	0.003 ± 0.008
Sagemoor Area	3	0.006 ± 0.002	0.005 ± 0.002	3	0.008 ± 0.006	0.004 ± 0.006
Wahluke East Area	3	0.016 ± 0.004	0.007 ± 0.010	3	0.004 ± 0.008	0.002 ± 0.006

- (a) Maximum values ±2 sigma counting error. Averages ±2 standard error of the calculated mean.
 (b) Refer to Figure 3.35.
 (c) Water supplied from the Columbia River.

TABLE A.37. Radionuclides in Fruit

Fruit/ Location ^(c)	Concentration, pCi/g, wet weight ^(a,b)			Concentration, pCi/g, wet weight ^(a,b)			Concentration, pCi/g, wet weight ^(a,b)		
	No. of Samples	¹³⁷ Cs		No. of Samples	⁹⁰ Sr		No. of Samples	³ H	
		Maximum	Average		Maximum	Average		Maximum	Average
Apples									
Riverview Area	3	0.0088 ± 0.0086	0.0041 ± 0.0093	3	0.0031 ± 0.0022	0.0028 ± 0.0007	3	427 ± 203	360 ± 109
Sagemoor Area	3	0.0097 ± 0.0047	0.0006 ± 0.011	3	0.0025 ± 0.0021	0.0021 ± 0.0005	3	84 ± 153	57 ± 45
Cold Creek Area	3	0.0056 ± 0.0074	0.0031 ± 0.0027	3	0.0037 ± 0.0019	0.0033 ± 0.0004	3	116 ± 156	26 ± 110
Sunnyside Area	3	0.0077 ± 0.0077	0.0037 ± 0.0054	3	0.0045 ± 0.0025	0.0037 ± 0.0009	3	110 ± 151	26 ± 138
Wahluke Area	3	0.0003 ± 0.0059	-0.0040 ± 0.0066	3	0.0052 ± 0.0025	0.0042 ± 0.0017	3	51 ± 190	20 ± 120
Cherries									
Sagemoor Area	3	0.012 ± 0.0060	0.0071 ± 0.0082	3	0.0063 ± 0.0028	0.0054 ± 0.0010	3	230 ± 189	146 ± 109
Sunnyside Area	3	0.0087 ± 0.0060	0.0055 ± 0.0038	3	0.0034 ± 0.0025	0.0030 ± 0.0066	3	463 ± 194	308 ± 165
Grapes									
Riverview Area	3	0.011 ± 0.0054	0.0012 ± 0.014	3	0.0055 ± 0.0030	0.0046 ± 0.0016	3	166 ± 155	99 ± 100
Sagemoor Area	3	0.0064 ± 0.0080	0.0033 ± 0.0042	3	0.0055 ± 0.0025	0.0040 ± 0.0016	3	177 ± 162	96 ± 100
Cold Creek Area	3	0.0005 ± 0.0061	0.0022 ± 0.0021	3	0.0091 ± 0.0027	0.0082 ± 0.0012	3	76 ± 190	4.4 ± 77
Sunnyside Area	3	0.0016 ± 0.0059	0.0012 ± 0.0009	3	0.0042 ± 0.0031	0.0027 ± 0.0018	3	103 ± 159	81 ± 33
Melons									
Riverview Area	3	0.0048 ± 0.011	0.0029 ± 0.0020	3	0.0035 ± 0.0030	0.0028 ± 0.0008	3	45 ± 190	63 ± 100

- (a) Except for ³H, which is given in pCi/L of water.
 (b) Maximum values ±2 sigma counting error. Averages ±2 standard error of the calculated mean.
 (c) Refer to Figure 3.35.

TABLE A.38. Radionuclides in Wheat and Alfalfa

Type/Location ^(b)	⁹⁰ Sr			¹³⁷ Cs		
	No. of Samples	Concentration, pCi/g, dry weight ^(a)		No. of Samples	Concentration, pCi/g, dry weight ^(a)	
		Maximum	Average		Maximum	Average
Wheat						
Wahluke East Area	3	0.014 ± 0.003	0.016 ± 0.003	3	0.009 ± 0.006	0.010 ± 0.003
Sage Moor Area	3	0.014 ± 0.003	0.012 ± 0.003	3	0.009 ± 0.006	0.007 ± 0.003
Riverview Area ^(c)	3	0.021 ± 0.003	0.019 ± 0.003	3	0.009 ± 0.005	0.007 ± 0.002
Benton City Area	3	0.009 ± 0.003	0.007 ± 0.002	3	0.016 ± 0.007	0.007 ± 0.010
Sunnyside Area	3	0.029 ± 0.003	0.013 ± 0.007	3	0.009 ± 0.006	0.008 ± 0.002
Moses Lake Area	3	0.084 ± 0.003	0.009 ± 0.002	3	0.006 ± 0.006	0.002 ± 0.004
Alfalfa						
Wahluke East Area	3	0.038 ± 0.014	0.014 ± 0.034	3	0.28 ± 0.05	0.22 ± 0.09
Sage Moor Area	3	0.029 ± 0.021	0.020 ± 0.013	3	0.26 ± 0.01	0.19 ± 0.08
Riverview Area ^(c)	3	0.19 ± 0.02	0.08 ± 0.12	3	0.22 ± 0.01	0.15 ± 0.08
Benton City Area	3	0.016 ± 0.013	0.011 ± 0.010	3	0.24 ± 0.03	0.21 ± 0.04
Sunnyside Area	3	0.15 ± 0.01	0.13 ± 0.02	3	0.005 ± 0.017	0.001 ± 0.005
Moses Lake Area	3	0.013 ± 0.017	-0.008 ± 0.037	3	0.02 ± 0.01	0.009 ± 0.008

- (a) Maximum values ±2 sigma counting error. Averages ±2 standard error of the calculated mean.
 (b) Refer to Figure 3.35.
 (c) Irrigated with Columbia River water.

TABLE A.39. Radionuclides in Beef, Chickens, and Eggs

Type/Location ^(b)	⁹⁰ Sr			¹³⁷ Cs		
	No. of Samples	Concentration, pCi/g, wet weight ^(a)		No. of Samples	Concentration, pCi/g, wet weight ^(a)	
		Maximum	Average		Maximum	Average
Beef						
Sunnyside Area	1	---	0.002 ± 0.003	1	---	0.012 ± 0.007
Chickens						
Sage Moor Area	2	0.003 ± 0.003	0.003 ± 0.007	2	0.006 ± 0.006	-0.002 ± 0.021
Sunnyside Area	2	0.005 ± 0.003	0.002 ± 0.006	2	-0.009 ± 0.024	-0.010 ± 0.003
Eggs						
Sage Moor Area	2	0.004 ± 0.002	0.004 ± 0.001	2	0.003 ± 0.005	0.001 ± 0.005
Sunnyside Area	2	0.009 ± 0.004	0.005 ± 0.008	2	0.007 ± 0.007	0.002 ± 0.013

- (a) Maximum values ±2 sigma counting error. Averages ±2 standard error of the calculated mean.
 (b) Refer to Figure 3.35.

TABLE A.40. Cesium-137 in Deer Muscle and Plutonium-239,240 in Deer Liver

Location	Type	¹³⁷ Cs			^{239,240} Pu		
		Concentration, pCi/g, wet weight ^(a)			Concentration, pCi/g, wet weight ^(a)		
		No. of Samples	Maximum	Average	No. of Samples	Maximum	Average
Random (road kills)	Muscle	3	0.025 ± 0.008	0.014 ± 0.018	NS	---	---
	Liver	NS	---	---	3	0.00022 ± 0.00021	0.00008 ± 0.00017

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

TABLE A.41. Radionuclides in Columbia River Fish

Type/Location ^(b)	⁶⁰ Co			⁹⁰ Sr			¹³⁷ Cs		
	Concentration, pCi/g, wet weight ^(a)			Concentration, pCi/g, wet weight ^(a)			Concentration, 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	0.025 ± 0.044	0.011 ± 0.025	5	0.011 ± 0.021	0.005 ± 0.004	5	0.048 ± 0.037	0.028 ± 0.024
1000-Area Vicinity	10	0.044 ± 0.026	0.017 ± 0.015	10	0.0037 ± 0.0016	0.0028 ± 0.008	10	0.051 ± 0.031	0.022 ± 0.014
Whitefish Carcass									
Upstream of Site Boundary	NS	---	---	5	0.023 ± 0.004	0.019 ± 0.004	NS	---	---
1000-Area Vicinity	NS	---	---	10	0.11 ± 0.02	0.039 ± 0.016	NS	---	---
Bass Muscle									
100F Sloughs	5	0.011 ± 0.007	0.002 ± 0.010	5	0.022 ± 0.003	0.007 ± 0.008	5	0.045 ± 0.011	0.029 ± 0.013
Bass Carcass									
100F Sloughs	NS	---	---	5	0.52 ± 0.03	0.12 ± 0.20	NS	---	---

(a) Maximum values ±2 sigma counting error. Averages ±2 standard error of the calculated mean.
(b) Refer to Figure 3.40.
NS = No sample.

TABLE A.42. Cobalt-60 and ¹³⁷Cs in Muscle Tissue of Upland Gamebirds

Location ^(b)	⁶⁰ Co			¹³⁷ Cs		
	Concentration, pCi/g, wet weight ^(a)			Concentration, pCi/g, wet weight ^(a)		
	No. of Samples	Maximum	Average	No. of Samples	Maximum	Average
100-Areas Pheasant	7	0.025 ± 0.021	0.002 ± 0.017	7	0.054 ± 0.024	0.021 ± 0.021
200-Areas Pheasant	1	---	-0.020 ± 0.037	1	---	0.11 ± 0.05
300-Area Pheasant	1	---	-0.003 ± 0.025	1	---	0.003 ± 0.025

(a) Maximum values ±2 sigma counting error. Averages ±2 standard error of the calculated mean.
(b) Refer to Figure 3.40.

TABLE A.43. Cesium-137 in Muscle Tissue of Mallard Ducks

Location ^(b)	No. of Samples	Concentration, pCi/g, wet weight ^(a)		
		Maximum	Minimum	Average
200-Area Gable Pond	4	3.7 ± 0.1	0.14 ± 0.04	1.8 ± 1.7
200-Area B Pond	8	9.0 ± 0.2	0.89 ± 0.01	3.6 ± 2.0
300-Area Pond	4	0.88 ± 0.07	0.042 ± 0.020	0.51 ± 0.41

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

(b) Refer to Figure 3.40.

TABLE A.44. Strontium-90 and ¹³⁷Cs in Bone and Muscle Tissue of Rabbits

Location ^(b)	⁹⁰ Sr (Bone)			¹³⁷ Cs (Muscle)		
	No. of Samples	Concentration, pCi/g, wet weight ^(a)		No. of Samples	Concentration, pCi/g, wet weight ^(a)	
		Maximum	Average		Maximum	Average
100-Area Cottontail	1	---	37 ± 2	1	---	-0.03 ± 0.02
200-Area Jack Rabbit	4	93 ± 3	32 ± 44	4	0.24 ± 0.05	0.07 ± 0.12

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

(b) Refer to Figure 3.40.

TABLE A.45. ⁹⁰Sr Concentrations in Soil

		Concentration pCi/g (dry weight) ^(a)					
Location	Map Location ^(b)	1981	1982	1983	1984	1985	1986
ON SITE							
1 Mile NE of 100N Area	1		0.20 ± 0.03	0.70 ± 0.023	0.29 ± 0.017	0.28 ± 0.058	0.24 ± 0.01
1 Mile E of 100N Area	2		0.15 ± 0.06	0.85 ± 0.026	0.22 ± 0.010	0.44 ± 0.091	0.22 ± 0.01
100; Area Fire Station	3		0.28 ± 0.04	1.7 ± 0.033	0.45 ± 0.020	0.57 ± 0.11	0.34 ± 0.01
200E NC	4	0.45 ± 0.02	0.93 ± 0.13	2.7 ± 0.047	0.20 ± 0.19	1.2 ± 0.23	0.61 ± 0.01
E of 200E	5		0.33 ± 0.09	0.78 ± 0.033	0.73 ± 0.48	0.90 ± 0.18	0.39 ± 0.01
200E SE	6	0.18 ± 0.007	0.29 ± 0.05	1.3 ± 0.028	0.44 ± 0.060	0.20 ± 0.042	0.27 ± 0.01
SW of BC Cribs	7		0.13 ± 0.10	0.79 ± 0.033	0.12 ± 0.050	0.39 ± 0.079	0.11 ± 0.01
S of 200E	8		0.18 ± 0.05	0.38 ± 0.020	0.50 ± 0.11	0.14 ± 0.030	0.54 ± 0.01
E of 200M	9	0.48 ± 0.03	0.48 ± 0.11	2.6 ± 0.048	0.33 ± 0.020	0.61 ± 0.12	0.56 ± 0.01
2 Miles S of 200W	10		0.06 ± 0.005	0.28 ± 0.015	0.14 ± 0.020	0.37 ± 0.078	0.23 ± 0.02
NE of FFTF	11	0.04 ± 0.007	0.042 ± 0.035	0.52 ± 0.020	0.18 ± 0.021	0.17 ± 0.039	---
SE of FFTF	12	0.05 ± 0.002	0.047 ± 0.045	0.54 ± 0.019	0.032 ± 0.054	0.20 ± 0.042	0.44 ± 0.01
N of 300 Area	13		0.22 ± 0.030	0.73 ± 0.023	0.58 ± 0.029	0.32 ± 0.068	0.18 ± 0.02
Hanford Townsite	14	0.40 ± 0.004	0.24 ± 0.080	1.9 ± 0.048	0.31 ± 0.029	0.25 ± 0.052	---
Wye Barricade	15	0.20 ± 0.020	0.21 ± 0.030	0.81 ± 0.026	0.31 ± 0.040	0.31 ± 0.062	---
ONSITE AVERAGE		0.30 ± 0.15	0.25 ± 0.12	1.1 ± 0.40	0.32 ± 0.10	0.42 ± 0.15	0.31 ± 0.11
OFF SITE							
Riverview	16	0.21 ± 0.009	0.12 ± 0.040	0.90 ± 0.044	0.039 ± 0.012	0.074 ± 0.019	0.06 ± 0.01
Byers Landing	17	0.06 ± 0.003	0.02 ± 0.01	0.30 ± 0.020	0.064 ± 0.008	0.18 ± 0.016	0.17 ± 0.01
Sagemoor	18	0.02 ± 0.002	0.006 ± 0.003	0.28 ± 0.017	0.25 ± 0.046	0.081 ± 0.019	0.11 ± 0.02
Taylor Flats #2	19	0.25 ± 0.009	0.23 ± 0.060	0.23 ± 0.039	0.042 ± 0.008	0.046 ± 0.013	0.36 ± 0.02
W End Fir Road	20	0.05 ± 0.003	0.07 ± 0.007	1.20 ± 0.031	0.14 ± 0.015	0.091 ± 0.022	0.12 ± 0.02
Ringold	21	0.20 ± 0.002	0.08 ± 0.040	1.80 ± 0.032	0.24 ± 0.014	0.20 ± 0.042	0.26 ± 0.02
Berg Ranch	22	0.11 ± 0.006	0.20 ± 0.090	0.92 ± 0.023	0.20 ± 0.019	0.15 ± 0.033	0.20 ± 0.01
Wahluke Slope #2 ^(d)	23	0.09 ± 0.002	0.10 ± 0.030	0.65 ± 0.023	0.16 ± 0.017	0.21 ± 0.046	0.10 ± 0.01
Vernita Bridge #2 ^(d)	24		0.11 ± 0.070	0.52 ± 0.017	0.17 ± 0.015	0.31 ± 0.064	0.09 ± 0.01
Yakima Barricade ^(d)	25	0.22 ± 0.020	0.09 ± 0.003	0.59 ± 0.023	0.13 ± 0.017	0.54 ± 0.109	---
Rattlesnake Springs ^(d)	26		0.17 ± 0.040	0.89 ± 0.033	0.075 ± 0.009	0.33 ± 0.069	0.18 ± 0.01
ALE ^(d)	27	0.27 ± 0.030	0.30 ± 0.060	1.60 ± 0.032	0.36 ± 0.039	0.61 ± 0.12	---
Prosser Barricade ^(d)	28	0.13 ± 0.007	0.29 ± 0.020	1.10 ± 0.027	0.36 ± 0.020	0.45 ± 0.092	0.17 ± 0.01
S of 300 Area ^(d)	29		0.24 ± 0.150	1.4 ± 0.039	0.35 ± 0.015	0.51 ± 0.10	0.31 ± 0.01
Benton City	30	0.30 ± 0.003	0.21 ± 0.030	0.42 ± 0.018	0.36 ± 0.031	0.12 ± 0.027	0.25 ± 0.01
Sunnyside	31	0.16 ± 0.020	0.12 ± 0.030	1.60 ± 0.040	0.31 ± 0.029	0.26 ± 0.055	0.05 ± 0.01
Walla Walla	32					-0.31 ± 0.015	0.14 ± 0.08
McNary Dam	33					0.29 ± 0.019	0.18 ± 0.08
Moses Lake	34						0.08 ± 0.01
Washtucna	35						0.40 ± 0.02
Connell	36						0.32 ± 0.02
Othello	37						0.27 ± 0.02
Yakima	38						0.04 ± 0.01
OFFSITE AVERAGE		0.14 ± 0.039	0.15 ± 0.045	1.0 ± 0.29	0.20 ± 0.059	0.26 ± 0.080	0.18 ± 0.05

(a) Individual results ±2 sigma counting error. Means ±2 standard error of the calculated mean.
 (b) Locations are identified in Figure 3.47.
 (c) Locations sampled every other year indicated by dashed line.
 (d) Perimeter location on Site near Site boundary.

TABLE A.46. ¹³⁷Cs Concentrations in Soil

Location	Map Location (b)	Concentration pCi/g (dry weight) (a)					
		1981	1982	1983	1984	1985	1986
ON SITE							
1 Mile NE of 100N Area	1		0.67 ± 0.08	0.48 ± 0.04	0.70 ± 0.05	0.76 ± 0.065	0.81 ± 0.05
1 Mile E of 100N Area	2		0.54 ± 0.04	0.77 ± 0.05	0.67 ± 0.04	0.62 ± 0.057	0.55 ± 0.04
100-Area Fire Station	3		0.99 ± 0.06	1.40 ± 0.07	0.98 ± 0.06	1.2 ± 0.082	1.6 ± 0.1
200E WC	4	18 ± 0.16	22 ± 0.37	28 ± 0.33	21 ± 0.23	23 ± 1.4	9.6 ± 0.2
E of 200E	5		1.5 ± 0.10	1.30 ± 0.07	1.4 ± 0.06	3.0 ± 0.20	1.4 ± 0.1
200E SE	6	1.2 ± 0.05	1.8 ± 0.08	0.16 ± 0.03	0.54 ± 0.04	0.55 ± 0.048	0.37 ± 0.03
SW of BC Cribs	7		0.31 ± 0.06	0.31 ± 0.03	0.06 ± 0.02	0.14 ± 0.022	0.12 ± 0.02
S of 200E	8		0.54 ± 0.07	0.15 ± 0.03	0.14 ± 0.02	0.56 ± 0.053	0.71 ± 0.04
E of 200W	9	2.5 ± 0.08	3.2 ± 0.10	5.70 ± 0.15	0.59 ± 0.04	2.0 ± 0.069	3.1 ± 0.1
2 Miles S of 200W	10		0.21 ± 0.06	0.07 ± 0.02	0.17 ± 0.03	0.30 ± 0.030	0.50 ± 0.04
NE of FFTF	11	0.11 ± 0.02	0.13 ± 0.02	0.18 ± 0.03	0.12 ± 0.02	0.080 ± 0.028	---
SE of FFTF	12	0.08 ± 0.02	0.19 ± 0.03	0.20 ± 0.04	0.08 ± 0.02	0.083 ± 0.022	0.04 ± 0.02
N of 300 Area	13		0.85 ± 0.05	0.53 ± 0.04	0.43 ± 0.04	0.46 ± 0.052	0.54 ± 0.05
Hanford Townsite	14	1.6 ± 0.06	0.96 ± 0.08	1.00 ± 0.07	0.91 ± 0.05	1.1 ± 0.086	---
Wye Barricade	15	0.69 ± 0.04	1.1 ± 0.06	0.84 ± 0.05	0.68 ± 0.04	1.3 ± 0.098	---
ONSITE AVERAGE		4.6 ± 4.5	2.4 ± 2.9	2.8 ± 3.7	1.9 ± 2.8	2.3 ± 3.0	1.5 ± 1.4
OFF SITE							
Riverview	16	0.46 ± 0.03	0.49 ± 0.07	1.2 ± 0.07	0.077 ± 0.021	0.21 ± 0.026	0.17 ± 0.04
Byers Landing	17	0.23 ± 0.02	0.28 ± 0.07	0.59 ± 0.05	0.20 ± 0.03	0.19 ± 0.035	0.50 ± 0.04
Sagemoor	18	0.06 ± 0.02	0.06 ± 0.04	0.14 ± 0.03	1.0 ± 0.06	0.10 ± 0.023	0.32 ± 0.04
Taylor Flats #2	19	1.1 ± 0.05	0.61 ± 0.05	2.2 ± 0.07	0.084 ± 0.031	0.085 ± 0.028	1.2 ± 0.1
W End Fir Road	20	0.15 ± 0.02	0.35 ± 0.05	0.25 ± 0.03	0.12 ± 0.03	0.14 ± 0.025	0.25 ± 0.03
Ringold	21	0.94 ± 0.05	0.83 ± 0.06	1.6 ± 0.08	0.44 ± 0.044	1.1 ± 0.046	0.40 ± 0.04
Bergs Ranch	22	0.40 ± 0.02	0.83 ± 0.05	0.61 ± 0.05	0.49 ± 0.046	0.58 ± 0.052	0.60 ± 0.05
Wahlake Slope #2 (d)	23	0.10 ± 0.02	0.34 ± 0.07	0.25 ± 0.03	0.29 ± 0.03	0.47 ± 0.047	0.30 ± 0.03
Vernita Bridge (d)	24		0.58 ± 0.07	0.55 ± 0.05	0.27 ± 0.03	0.46 ± 0.037	0.20 ± 0.03
Yakima Barricade (d)	25	0.31 ± 0.03	0.42 ± 0.04	0.70 ± 0.033	0.10 ± 0.028	1.1 ± 0.066	---
Rattlesnake Springs (d)	26		0.70 ± 0.05	0.52 ± 0.05	0.14 ± 0.03	0.46 ± 0.037	0.37 ± 0.04
ALE (d)	27	0.37 ± 0.03	1.1 ± 0.10	1.5 ± 0.07	0.55 ± 0.04	1.6 ± 0.069	---
Prosser Barricade (d)	28	0.21 ± 0.02	1.2 ± 0.06	0.77 ± 0.05	0.15 ± 0.03	0.73 ± 0.045	0.32 ± 0.03
S of 300 Area (d)	29		1.1 ± 0.06	1.1 ± 0.06	1.1 ± 0.06	0.88 ± 0.072	0.68 ± 0.04
Benton City	30	0.89 ± 0.04	0.75 ± 0.05	0.54 ± 0.05	0.53 ± 0.04	0.87 ± 0.064	0.79 ± 0.05
Sunnyside	31	0.63 ± 0.04	0.41 ± 0.06	1.1 ± 0.06	1.5 ± 0.071	0.29 ± 0.036	0.09 ± 0.03
Walla Walla	32					0.29 ± 0.024	0.25 ± 0.03
McNary Dam	33					0.52 ± 0.040	0.28 ± 0.03
Moses Lake	34						0.24 ± 0.03
Washtucna	35						1.2 ± 0.1
Connell	36						1.7 ± 0.1
Othello	37						0.26 ± 0.02
Yakima	38						0.11 ± 0.01
OFFSITE AVERAGE		0.46 ± 0.13	0.63 ± 0.15	0.85 ± 0.28	0.44 ± 0.21	0.56 ± 0.19	0.80 ± 0.68

(a) Individual results ±2 sigma counting error. Means ±2 standard error of the calculated mean.

(b) Locations are identified in Figure 3.47.

(c) Locations sampled every other year indicated by dashed line.

(d) Perimeter location on Site near Site boundary.

TABLE A.47. ^{239,240}Pu Concentrations in Soil

Location	Map Location (b)	Concentration pCi/g (dry weight) (a)					
		1981	1982	1983	1984	1985	1986
ON SITE							
1 Mile NE of 100N Area	1		0.015 ± 0.003	0.012 ± 0.0030	0.015 ± 0.0020	0.016 ± 0.0016	0.015 ± 0.001
1 Mile E of 100N Area	2		0.026 ± 0.003	0.0069 ± 0.0014	0.016 ± 0.0027	0.013 ± 0.0011	0.012 ± 0.001
100-Area Fire Station	3		0.016 ± 0.003	0.0022 ± 0.0015	0.021 ± 0.0017	0.024 ± 0.0016	0.030 ± 0.002
200E NC	4	0.040 ± 0.0020	0.059 ± 0.009	0.051 ± 0.0065	0.033 ± 0.0040	0.030 ± 0.0019	0.015 ± 0.002
E of 200E	5		0.015 ± 0.002	0.011 ± 0.002	0.012 ± 0.0015	0.026 ± 0.0017	0.011 ± 0.001
200E SE	6	0.030 ± 0.0040	0.024 ± 0.004	0.028 ± 0.0050	0.0091 ± 0.0017	0.022 ± 0.0016	0.008 ± 0.001
SW of BC Cribs	7		0.012 ± 0.001	0.0076 ± 0.0012	0.0034 ± 0.0019	0.024 ± 0.0022	0.004 ± 0.001
S of 200E	8		0.012 ± 0.001	0.0088 ± 0.0017	0.0056 ± 0.0031	0.0041 ± 0.0014	0.007 ± 0.001
E of 200W	9	0.42 ± 0.008	0.78 ± 0.016	0.83 ± 0.027	0.074 ± 0.0040	0.33 ± 0.0069	0.34 ± 0.01
2 Miles S of 200W	10		0.004 ± 0.002	0.0006 ± 0.00095	0.0036 ± 0.0019	0.0094 ± 0.0011	0.013 ± 0.001
NE of FTF	11	0.003 ± 0.0008	0.002 ± 0.001	0.0029 ± 0.0007	0.0021 ± 0.0007	0.0025 ± 0.0005	---
SE of FTF	12	0.003 ± 0.0008	0.005 ± 0.002	0.0042 ± 0.0018	0.0087 ± 0.0011	0.0021 ± 0.0005	0.001 ± 0.001
N of 300 Area	13		0.016 ± 0.003	0.013 ± 0.002	0.0064 ± 0.0029	0.010 ± 0.0011	0.008 ± 0.001
Hanford Townsite	14	0.02 ± 0.002	0.015 ± 0.003	0.021 ± 0.004	0.016 ± 0.0030	0.0059 ± 0.0009	---
Wye Barricade	15	0.012 ± 0.001	0.018 ± 0.003	0.017 ± 0.0022	0.014 ± 0.0020	0.017 ± 0.0015	---
ONSITE AVERAGE		0.069 ± 0.10	0.062 ± 0.10	0.068 ± 0.11	0.016 ± 0.0090	0.035 ± 0.042	0.038 ± 0.055
OFF SITE							
Riverview	16	0.01 ± 0.001	0.006 ± 0.002	0.021 ± 0.005	0.0018 ± 0.0018	0.0052 ± 0.0098	0.003 ± 0.001
Byers Landing	17	0.005 ± 0.001	0.002 ± 0.0009	0.012 ± 0.002	0.0066 ± 0.0040	0.0027 ± 0.0006	0.008 ± 0.001
Sagemoor	18	0.003 ± 0.0007	0.003 ± 0.0009	0.0079 ± 0.0015	0.019 ± 0.0021	0.0018 ± 0.0005	0.006 ± 0.001
Taylor Flats #2	19	0.04 ± 0.002	0.016 ± 0.003	0.031 ± 0.005	0.0014 ± 0.0005	0.0008 ± 0.0003	0.021 ± 0.003
W End Fir Road	20	0.004 ± 0.001	0.005 ± 0.001	0.0059 ± 0.0017	0.0022 ± 0.0015	0.0017 ± 0.0005	0.004 ± 0.001
Ringold	21	0.02 ± 0.002	0.013 ± 0.002	0.028 ± 0.005	0.0075 ± 0.0012	0.017 ± 0.0016	0.006 ± 0.001
Berg Ranch	22	0.01 ± 0.001	0.012 ± 0.002	0.014 ± 0.003	0.0097 ± 0.0015	0.011 ± 0.0011	0.012 ± 0.002
Wahluke Slope #2(d)	23	0.004 ± 0.0008	0.006 ± 0.002	0.010 ± 0.002	0.0061 ± 0.0029	0.0087 ± 0.0015	0.006 ± 0.001
Vernita Bridge(d)	24		0.009 ± 0.002	0.015 ± 0.0026	0.0060 ± 0.0024	0.0095 ± 0.0010	0.003 ± 0.001
Yakima Barricade(d)	25	0.02 ± 0.002	0.011 ± 0.001	0.014 ± 0.002	0.0016 ± 0.0011	0.022 ± 0.0015	---
Rattlesnake Springs(d)	26		0.019 ± 0.002	0.026 ± 0.0049	0.0032 ± 0.0016	0.0085 ± 0.0009	0.006 ± 0.001
ALE(d)	27	0.01 ± 0.001	0.03 ± 0.002	0.031 ± 0.005	0.0091 ± 0.0014	0.034 ± 0.0021	---
Prosser Barricade(d)	28	0.006 ± 0.001	0.033 ± 0.004	0.020 ± 0.004	0.0039 ± 0.0016	0.019 ± 0.0019	0.008 ± 0.001
S of 300 Area(d)	29		0.019 ± 0.003	0.022 ± 0.0013	0.022 ± 0.0023	0.018 ± 0.0015	0.015 ± 0.001
Benton City	30	0.02 ± 0.002	0.024 ± 0.003	0.015 ± 0.0017	0.0099 ± 0.0015	0.019 ± 0.0020	0.016 ± 0.001
Sunnyside	31	0.01 ± 0.001	0.009 ± 0.002	0.026 ± 0.005	0.025 ± 0.0026	0.015 ± 0.0016	0.002 ± 0.001
Walla Walla	32					0.013 ± 0.0012	0.005 ± 0.001
McNary Dam	33					0.015 ± 0.0023	0.007 ± 0.001
Moses Lake	34						0.016 ± 0.001
Washtucna	35						0.024 ± 0.002
Connell	36						0.027 ± 0.002
Othello	37						0.004 ± 0.001
Yakima	38						0.002 ± 0.001
OFFSITE AVERAGE		0.011 ± 0.005	0.013 ± 0.005	0.019 ± 0.004	0.0084 ± 0.0037	0.012 ± 0.0046	0.009 ± 0.003

(a) Individual results ±2 sigma counting error. Means ±2 standard error of the calculated mean.
 (b) Locations are identified in Figure 3.47.
 (c) Locations sampled every other year indicated by dashed line.
 (d) Perimeter location on Site near Site boundary.

TABLE A.48. U Concentrations in Soil

Location	Map Location (b)	Concentration pCi/g (dry weight) (a)					
		1981	1982	1983	1984	1985	1986
ON SITE							
1 Mile NE of 100N	1		0.23 ± 0.08	0.39 ± 0.109	0.42 ± 0.11	0.49 ± 0.16	0.19 ± 0.06
1 Mile E of 100N	2		0.22 ± 0.08	0.28 ± 0.077	0.32 ± 0.088	0.40 ± 0.13	0.45 ± 0.13
100-AREA Fire Station	3		0.32 ± 0.11	0.22 ± 0.061	0.45 ± 0.12	0.44 ± 0.15	0.53 ± 0.15
200E NC	4	0.66 ± 0.23	0.45 ± 0.16	0.25 ± 0.071	0.36 ± 0.098	0.39 ± 0.13	0.28 ± 0.08
E of 200E	5		0.32 ± 0.11	0.26 ± 0.07	0.32 ± 0.08	0.46 ± 0.15	0.47 ± 0.13
200E SE	6	0.42 ± 0.15	0.37 ± 0.13	0.20 ± 0.057	0.37 ± 0.070	0.39 ± 0.13	0.03 ± 0.08
SW of BC Cribs	7		0.27 ± 0.09	0.28 ± 0.078	1.0 ± 0.15	0.33 ± 0.11	0.32 ± 0.09
S of 200E	8		0.30 ± 0.11	0.18 ± 0.05	0.46 ± 0.22	0.34 ± 0.11	0.32 ± 0.09
E of 200W	9	0.72 ± 0.25	0.73 ± 0.26	0.53 ± 0.15	0.53 ± 0.29	0.43 ± 0.14	0.48 ± 0.13
2 Miles S of 200W	10		0.39 ± 0.14	0.26 ± 0.074	0.34 ± 0.092	0.47 ± 0.16	0.49 ± 0.14
NE of FFTF	11	0.49 ± 0.17	0.30 ± 0.10	0.25 ± 0.068	0.30 ± 0.082	0.39 ± 0.13	---
SE of FFTF	12	0.47 ± 0.16	0.28 ± 0.10	0.16 ± 0.046	0.27 ± 0.073	0.40 ± 0.13	0.37 ± 0.11
N of 300 Area	13		0.99 ± 0.35	0.50 ± 0.14	0.76 ± 0.20	3.9 ± 1.1	0.66 ± 0.19
Hanford Townsite	14		0.40 ± 0.14	0.32 ± 0.11	0.24 ± 0.067	0.34 ± 0.093	0.35 ± 0.12
Wye Barricade	15		0.37 ± 0.13	0.38 ± 0.13	0.19 ± 0.053	0.65 ± 0.10	0.29 ± 0.097
ONSITE AVERAGE		0.49 ± 0.11	0.39 ± 0.11	0.28 ± 0.061	0.46 ± 0.11	0.82 ± 0.66	0.40 ± 0.08
OFF SITE							
Riverview	16	0.64 ± 0.23	0.14 ± 0.05	0.37 ± 0.10	0.32 ± 0.085	0.44 ± 0.14	0.26 ± 0.07
Byers Landing	17	0.47 ± 0.17	0.55 ± 0.19	0.32 ± 0.09	0.43 ± 0.11	0.39 ± 0.13	0.26 ± 0.07
Sagemoor	18	0.63 ± 0.22	0.31 ± 0.11	0.38 ± 0.11	0.50 ± 0.13	0.58 ± 0.18	0.31 ± 0.08
Taylor Flats #2	19	0.73 ± 0.26	0.59 ± 0.21	0.47 ± 0.13	1.0 ± 0.26	1.3 ± 0.36	0.44 ± 0.12
W End Fir Road	20	0.88 ± 0.31	0.28 ± 0.10	0.47 ± 0.13	0.54 ± 0.14	0.73 ± 0.22	0.32 ± 0.09
Ringold	21	0.82 ± 0.29	0.43 ± 0.15	0.37 ± 0.10	0.78 ± 0.21	0.84 ± 0.26	1.1 ± 0.3
Berg Ranch	22	0.27 ± 0.10	0.26 ± 0.09	0.24 ± 0.07	0.41 ± 0.11	0.43 ± 0.14	0.28 ± 0.08
Wahluke Slope #2(d)	23	0.46 ± 0.16	0.36 ± 0.13	0.35 ± 0.10	0.43 ± 0.12	0.35 ± 0.12	0.21 ± 0.06
Vernita Bridge (d)	24		0.38 ± 0.13	0.37 ± 0.10	0.92 ± 0.26	0.73 ± 0.22	0.34 ± 0.09
Yakima Barricade (d)	25	0.50 ± 0.17	0.23 ± 0.08	0.26 ± 0.071	0.21 ± 0.056	0.35 ± 0.12	---
Rattlesnake Springs (d)	26		0.30 ± 0.11	0.25 ± 0.07	0.26 ± 0.069	0.44 ± 0.14	0.26 ± 0.07
ALE (d)	27	0.31 ± 0.11	0.35 ± 0.12	0.28 ± 0.08	0.25 ± 0.067	0.46 ± 0.15	---
Prosser Barricade (d)	28	0.35 ± 0.12	0.20 ± 0.07	0.25 ± 0.07	0.36 ± 0.06	0.80 ± 0.24	0.25 ± 0.07
S of 300 Area (d)	29		0.506 ± 0.177	0.31 ± 0.08	1.0 ± 0.29	0.66 ± 0.21	0.56 ± 0.16
Benton City	30	0.63 ± 0.22	0.56 ± 0.19	0.44 ± 0.12	0.91 ± 0.24	0.64 ± 0.20	0.45 ± 0.12
Sunnyside	31	0.34 ± 0.12	0.17 ± 0.06	0.20 ± 0.05	0.26 ± 0.071	0.26 ± 0.090	0.31 ± 0.09
Walla Walla	32					0.20 ± 0.071	0.35 ± 0.10
McNary Dam	33					0.15 ± 0.055	0.41 ± 0.12
Moses Lake	34						0.11 ± 0.03
Washtucna	35						0.20 ± 0.06
Connell	36						0.25 ± 0.07
Othello	37						0.21 ± 0.06
Yakima	38						0.48 ± 0.14
OFFSITE AVERAGE		0.53 ± 0.11	0.35 ± 0.078	0.32 ± 0.048	0.54 ± 0.15	0.54 ± 0.14	0.35 ± 0.09

(a) Individual results ±2 sigma analytical error. Means ±2 standard error of the calculated mean.

(b) Locations are identified in Figure 3.47.

(c) Locations sampled every other year indicated by dashed line.

(d) Perimeter location on Site near Site boundary.

TABLE A.49. Radionuclides in Special Soil Samples Collected Downwind of the Hanford Site

Location	Map Location (b)	Concentration, pCi/g (a)			
		¹³⁷ Cs	⁹⁰ Sr	^{239,240} Pu	Uranium
Pasco Airport	1	0.07 ± 0.05	0.20 ± 0.01	0.013 ± 0.001	0.37 ± 0.10
Taylor Flats Rd.	2	0.67 ± 0.05	0.30 ± 0.02	0.014 ± 0.001	0.36 ± 0.10
Merrills Corner	3	0.54 ± 0.05	0.15 ± 0.02	0.007 ± 0.001	0.33 ± 0.09
Eltopia	4	0.61 ± 0.04	0.26 ± 0.01	0.010 ± 0.001	0.29 ± 0.08
Mesa	5	0.21 ± 0.03	0.11 ± 0.01	0.003 ± 0.001	0.46 ± 0.12
Basin City	6	0.93 ± 0.06	0.31 ± 0.02	0.018 ± 0.001	0.43 ± 0.12
Hollingsworth Rd.	7	0.40 ± 0.04	0.17 ± 0.01	0.008 ± 0.001	0.42 ± 0.12
Ringold Canal	8	0.26 ± 0.02	0.12 ± 0.01	0.005 ± 0.001	0.57 ± 0.16

(a) Individual results ±2 sigma counting error.
 (b) Locations are identified in Figure 3.48.

TABLE A.50. ⁹⁰Sr Concentrations in Vegetation

Location	Map Location (b)	Concentration pCi/g (dry weight) (a)					
		1981	1982	1983	1984	1985	1986
ON SITE							
1 Mile NE of 100N Area	1		0.03 ± 0.002	0.11 ± 0.017	0.069 ± 0.007	0.078 ± 0.072	NS
1 Mile E of 100N Area	2		0.05 ± 0.005	0.29 ± 0.018	0.12 ± 0.012	0.012 ± 0.0012	0.14 ± 0.01
100-Area Fire Station	3		0.05 ± 0.007	0.37 ± 0.020	0.11 ± 0.011	0.17 ± 0.017	0.14 ± 0.01
200E NC	4	0.14 ± 0.003	0.10 ± 0.020	0.63 ± 0.024	0.39 ± 0.020	0.41 ± 0.018	0.38 ± 0.01
E of 200E	5		0.14 ± 0.009	0.91 ± 0.030	0.20 ± 0.030	0.25 ± 0.019	0.18 ± 0.01
200E SE	6	0.07 ± 0.005	0.03 ± 0.003	0.91 ± 0.031	0.20 ± 0.013	0.53 ± 0.018	8.2 ± 0.1
SW of BC Cribs	7		0.05 ± 0.003	0.34 ± 0.016	0.11 ± 0.030	0.41 ± 0.016	NS
S of 200E	8		0.17 ± 0.005	0.53 ± 0.017	1.1 ± 0.066	0.44 ± 0.022	0.14 ± 0.01
E of 200W	9	0.09 ± 0.005	0.07 ± 0.005	0.47 ± 0.022	0.13 ± 0.020	1.1 ± 0.026	0.13 ± 0.01
2 Miles S of 200W	10		0.05 ± 0.003	0.34 ± 0.016	0.19 ± 0.007	0.89 ± 0.035	0.14 ± 0.01
NE of FFTF	11	0.04 ± 0.004	0.009 ± 0.002	1.2 ± 0.037	0.022 ± 0.006	0.28 ± 0.015	NS
SE of FFTF	12	0.04 ± 0.005	0.02 ± 0.002	1.7 ± 0.040	0.088 ± 0.009	0.28 ± 0.019	NS
N of 300 Area	13		0.008 ± 0.001	0.93 ± 0.029	0.023 ± 0.004	0.13 ± 0.016	0.26 ± 0.01
Hanford Townsite	14	0.06 ± 0.003	0.06 ± 0.003	0.29 ± 0.015	0.044 ± 0.006	0.18 ± 0.013	---
Wye Barricade	15	0.05 ± 0.006	0.04 ± 0.008	0.16 ± 0.012	0.016 ± 0.007	0.15 ± 0.012	---
ONSITE AVERAGE		0.069 ± 0.028	0.058 ± 0.024	0.61 ± 0.22	0.19 ± 0.14	0.36 ± 0.16	1.1 ± 1.8
OFF SITE							
Riverview	16	0.05 ± 0.003	0.01 ± 0.002	1.1 ± 0.033	0.015 ± 0.010	0.069 ± 0.085	0.039 ± 0.004
Byers Landing	17	0.03 ± 0.004	0.008 ± 0.002	0.12 ± 0.006	0.018 ± 0.008	0.057 ± 0.089	0.074 ± 0.006
Sagemoor	18	0.03 ± 0.004	0.01 ± 0.004	-0.006 ± 0.017	0.067 ± 0.012	0.097 ± 0.011	NS
Taylor Flats #2	19	0.04 ± 0.02	0.06 ± 0.003	0.037 ± 0.024	0.063 ± 0.010	0.10 ± 0.010	0.054 ± 0.006
W End Fir Road	20	0.06 ± 0.007	0.009 ± 0.014	0.086 ± 0.020	0.047 ± 0.016	0.076 ± 0.088	0.062 ± 0.005
Ringold	21	0.10 ± 0.015	0.018 ± 0.019	0.65 ± 0.026	0.051 ± 0.010	0.066 ± 0.0081	0.059 ± 0.005
Berg Ranch	22	0.03 ± 0.003	0.04 ± 0.002	0.023 ± 0.027	0.092 ± 0.026	0.050 ± 0.079	NS
Wahluke Slope #2 (d)	23	0.05 ± 0.005	0.01 ± 0.004	0.018 ± 0.016	0.046 ± 0.013	0.15 ± 0.012	NS
Vernita Bridge (d)	24		0.03 ± 0.003	0.10 ± 0.011	0.073 ± 0.011	0.21 ± 0.011	NS
Yakima Barricade (d)	25	0.06 ± 0.005	0.05 ± 0.01	0.04 ± 0.008	0.022 ± 0.003	0.21 ± 0.011	---
Rattlesnake Springs (d)	26		0.024 ± 0.004	0.69 ± 0.026	0.087 ± 0.011	1.7 ± 0.033	0.14 ± 0.01
ALE (d)	27	0.05 ± 0.005	0.05 ± 0.005	0.017 ± 0.023	0.082 ± 0.007	0.095 ± 0.090	---
Prosser Barricade (d)	28	0.06 ± 0.005	0.05 ± 0.02	0.021 ± 0.022	0.12 ± 0.009	NS	0.084 ± 0.007
S of 300 Area (d)	29		0.03 ± 0.004	0.05 ± 0.011	0.047 ± 0.005	0.091 ± 0.014	0.10 ± 0.01
Benton City	30	0.04 ± 0.005	0.05 ± 0.008	0.12 ± 0.013	0.055 ± 0.016	0.30 ± 0.013	0.14 ± 0.01
Sunnyside	31	0.19 ± 0.02	0.005 ± 0.003	0.18 ± 0.016	0.037 ± 0.008	0.061 ± 0.075	0.044 ± 0.005
OFFSITE AVERAGE		0.058 ± 0.023	0.031 ± 0.0095	0.20 ± 0.16	0.057 ± 0.015	0.22 ± 0.21	0.080 ± 0.023

(a) Individual results ±2 sigma counting error. Means ±2 standard error of the calculated mean.
 (b) Locations are identified in Figure 3.47.
 (c) Locations sampled every other year indicated by dashed line.
 (d) Perimeter location on Site near Site boundary.
 NS = No sample.

TABLE A.51. ¹³⁷Cs Concentrations in Vegetation

Location	Map Location (b)	Concentration pCi/g (dry weight) (a)					
		1981	1982	1983	1984	1985	1986
ON SITE							
1 Mile NE of 100N Area	1		0.04 ± 0.06	0.003 ± 0.012	0.0097 ± 0.014	0.015 ± 0.011	0.027 ± 0.017
1 Mile E of 100N Area	2		0.09 ± 0.07	0.026 ± 0.008	0.0032 ± 0.013	0.003 ± 0.025	0.007 ± 0.022
100-Area Fire Station	3		0.04 ± 0.07	0.015 ± 0.008	0.015 ± 0.012	0.016 ± 0.014	0.034 ± 0.017
200E NC	4	0.11 ± 0.03	0.23 ± 0.05	0.18 ± 0.014	0.24 ± 0.020	0.36 ± 0.042	0.20 ± 0.03
E of 200E	5		0.37 ± 0.13	0.069 ± 0.010	0.069 ± 0.013	0.12 ± 0.030	0.11 ± 0.03
200E SE	6	0.05 ± 0.02	0.08 ± 0.05	0.053 ± 0.009	0.079 ± 0.017	0.078 ± 0.020	0.10 ± 0.02
SW of BC Cribs	7		0.05 ± 0.02	0.0085 ± 0.0055	0.018 ± 0.013	0.038 ± 0.016	0.011 ± 0.017
S of 200E	8		0.05 ± 0.04	0.019 ± 0.007	0.022 ± 0.011	0.068 ± 0.015	0.029 ± 0.017
E of 200W	9	0.05 ± 0.02	-0.03 ± 0.04	0.03 ± 0.009	0.055 ± 0.016	0.052 ± 0.017	0.032 ± 0.020
2 Miles S of 200W	10		0.0004 ± 0.06	0.025 ± 0.009	0.011 ± 0.012	0.019 ± 0.023	0.029 ± 0.020
NE of FTF	11	0.04 ± 0.01	-0.03 ± 0.04	0.02 ± 0.008	0.0064 ± 0.11	0.048 ± 0.020	---
SE of FTF	12	0.05 ± 0.02	0.01 ± 0.02	0.03 ± 0.009	-0.0095 ± 0.015	0.032 ± 0.018	0.017 ± 0.012
N of 300 Area	13		0.02 ± 0.05	0.010 ± 0.006	0.011 ± 0.009	0.024 ± 0.016	0.017 ± 0.011
Hanford Townsite	14	0.03 ± 0.02	0.07 ± 0.02	0.011 ± 0.011	0.010 ± 0.020	0.038 ± 0.022	---
Wye Barricade	15	0.05 ± 0.02	0.035 ± 0.045	-0.01 ± 0.016	0.0037 ± 0.011	0.035 ± 0.015	---
ONSITE AVERAGE		0.054 ± 0.024	0.072 ± 0.055	0.035 ± 0.023	0.034 ± 0.033	0.062 ± 0.045	0.071 ± 0.051
OFF SITE							
Riverview	16	0.02 ± 0.02	-0.006 ± 0.03	0.021 ± 0.007	-0.0001 ± 0.014	-0.0054 ± 0.011	1.1 ± 0.1
Byers Landing	17	-0.006 ± 0.02	0.08 ± 0.06	0.013 ± 0.011	0.024 ± 0.012	0.017 ± 0.011	1.9 ± 0.1
Sage Moor	18	0.02 ± 0.02	0.05 ± 0.03	0.012 ± 0.012	0.003 ± 0.012	0.013 ± 0.014	1.2 ± 0.1
Taylor Flats #2	19	0.05 ± 0.02	0.02 ± 0.04	0.025 ± 0.012	0.016 ± 0.013	0.011 ± 0.022	1.7 ± 0.1
W End Fir Road	20	0.03 ± 0.02	-0.07 ± 0.04	0.021 ± 0.010	0.095 ± 0.021	0.022 ± 0.021	1.2 ± 0.1
Ringold	21	-0.01 ± 0.02	0.0005 ± 0.08	0.020 ± 0.008	-0.0008 ± 0.013	0.0083 ± 0.013	1.5 ± 0.1
Berg Ranch	22	-0.04 ± 0.02	0.05 ± 0.04	0.014 ± 0.009	0.027 ± 0.011	0.0073 ± 0.014	0.009 ± 0.013
Wahluke Slope #2 (d)	23	-0.005 ± 0.02	-0.04 ± 0.07	0.02 ± 0.008	-0.0012 ± 0.012	0.023 ± 0.013	0.026 ± 0.024
Vernita Bridge (d)	24		0.09 ± 0.03	0.014 ± 0.010	0.005 ± 0.010	0.0061 ± 0.015	0.009 ± 0.022
Yakima Barricade (d)	25	0.02 ± 0.02	0.02 ± 0.02	0.012 ± 0.010	0.00 ± 0.013	0.0027 ± 0.015	---
Rattlesnake Springs (d)	26		0.03 ± 0.02	0.004 ± 0.009	0.0054 ± 0.013	0.016 ± 0.014	0.81 ± 0.05
ALE (d)	27	0.04 ± 0.03	0.03 ± 0.02	0.0093 ± 0.0095	-0.0006 ± 0.012	0.022 ± 0.013	---
Prosser Barricade (d)	28	0.08 ± 0.03	0.006 ± 0.02	0.011 ± 0.008	0.012 ± 0.012	NS	0.004 ± 0.025
S of 300 Area (d)	29		0.02 ± 0.01	0.005 ± 0.012	0.0032 ± 0.013	0.013 ± 0.020	0.018 ± 0.023
Benton City	30	0.03 ± 0.02	0.06 ± 0.08	0.022 ± 0.007	0.0041 ± 0.011	0.093 ± 0.021	1.4 ± 0.1
Sunnyside	31	0.03 ± 0.02	0.04 ± 0.02	0.006 ± 0.009	0.018 ± 0.012	0.018 ± 0.015	0.34 ± 0.03
Walla Walla	32						0.006 ± 0.020
McNary Dam	33						0.014 ± 0.019
Moses Lake	34						0.85 ± 0.05
Washtucna	35						0.98 ± 0.05
Connell	36						0.027 ± 0.017
Othello	37						0.002 ± 0.019
Yakima	38						0.21 ± 0.03
OFFSITE AVERAGE		0.015 ± 0.022	0.023 ± 0.023	0.014 ± 0.0041	0.0078 ± 0.0055	0.018 ± 0.012	0.64 ± 0.29

(a) Individual results ±2 sigma counting error. Means ±2 standard error of the calculated mean.
 (b) Locations are identified in Figure 3.47.
 (c) Locations sampled every other year indicated by dashed line.
 (d) Perimeter location on Site near Site boundary.
 NS = No sample.

TABLE A.52. ^{239,240}Pu Concentrations in Vegetation

Location	Map Location (b)	Concentration pCi/g (dry weight)(a)					
		1981	1982	1983	1984	1985	1986
ON SITE							
1 Mile NE of 100N	1		-0.0009 ± 0.0006	0.00000 ± 0.00000	0.0005 ± 0.00015	0.00013 ± 0.00015	NS
1 Mile E of 100N	2		0.0012 ± 0.0010	0.00022 ± 0.00045	0.00012 ± 0.00030	0.00036 ± 0.00020	0.00048 ± 0.00026
100-Area Fire Station	3		0.0002 ± 0.0004	0.00002 ± 0.00004	0.00012 ± 0.00025	0.00032 ± 0.00018	0.00041 ± 0.00029
200E NC	4	0.001 ± 0.0004	0.00062 ± 0.00067	0.00028 ± 0.00039	0.00042 ± 0.00022	0.00067 ± 0.00026	0.00070 ± 0.00042
E of 200E	5		0.0008 ± 0.0007	0.00066 ± 0.00046	0.00074 ± 0.00066	0.00075 ± 0.0011	0.0010 ± 0.0003
200E SE	6	0.004 ± 0.001	0.0001 ± 0.0006	0.00046 ± 0.00061	0.00093 ± 0.00061	0.00096 ± 0.00032	NS
SW of BC Cribs	7		0.0004 ± 0.0006	0.00016 ± 0.00018	0.00054 ± 0.00037	0.0025 ± 0.00051	0.0017 ± 0.0004
S of 200E	8		0.0005 ± 0.0006	0.00020 ± 0.00025	0.00044 ± 0.00018	0.0060 ± 0.00083	0.0044 ± 0.0012
E of 200W	9	0.003 ± 0.001	0.004 ± 0.0008	0.0044 ± 0.0010	0.0001 ± 0.00020	0.00059 ± 0.00028	0.00094 ± 0.00036
2 Miles S of 200W	10		0.00074 ± 0.00067	0.0021 ± 0.00084	0.00036 ± 0.00039	0.00047 ± 0.00023	---
NE of FFFF	11	0.001 ± 0.0007	0.0006 ± 0.0010	0.00022 ± 0.00026	0.00083 ± 0.00063	0.00049 ± 0.00030	NS
SE of FFFF	12	0.001 ± 0.0006	-0.0003 ± 0.0004	0.00070 ± 0.00069	0.0022 ± 0.0011	0.00026 ± 0.00014	0.00053 ± 0.00025
N of 300 Area	13		0.003 ± 0.0007	0.00046 ± 0.00034	0.0022 ± 0.0011	0.00042 ± 0.00022	---
Hanford Townsite	14	0.002 ± 0.0006	0.0004 ± 0.0003	0.0007 ± 0.0010	0.00055 ± 0.00035	0.00042 ± 0.00022	---
Wye Barricade	15	0.003 ± 0.0007	0.0006 ± 0.0008	0.00026 ± 0.00024	0.00078 ± 0.00088	0.0012 ± 0.00038	---
ONSITE AVERAGE		0.0022 ± 0.0010	0.00087 ± 0.00065	0.0028 ± 0.0042	0.0010 ± 0.00085	0.0016 ± 0.0012	0.0014 ± 0.0009
OFF SITE							
Riverview	16	0.002 ± 0.0009	0.0005 ± 0.0007	0.00220 ± 0.00086	-0.00013 ± 0.00017	0.00075 ± 0.00039	0.00029 ± 0.00028
Byers Landing	17	0.0006 ± 0.0004	0.00079 ± 0.00083	0.00040 ± 0.00038	0.00010 ± 0.00010	0.00015 ± 0.00013	0.00029 ± 0.00024
Sagemoor	18	0.002 ± 0.0009	-0.00040 ± 0.0004	0.00020 ± 0.00060	0.00012 ± 0.00014	0.00022 ± 0.00017	NS
Taylor Flats #2	19	0.002 ± 0.0006	0.00004 ± 0.0004	0.00056 ± 0.00036	-0.00010 ± 0.00010	0.00036 ± 0.00028	0.00015 ± 0.00015
W End Fir Road	20	0.002 ± 0.0007	0.0007 ± 0.0009	0.00021 ± 0.00029	0.00039 ± 0.00048	0.00019 ± 0.00015	0.00007 ± 0.00015
Ringold	21	0.001 ± 0.0009	0.0001 ± 0.0004	0.00000 ± 0.00000	-0.00007 ± 0.00030	0.00019 ± 0.00017	0.00033 ± 0.00031
Berg Ranch	22	0.003 ± 0.0008	0.003 ± 0.0008	0.00050 ± 0.00030	0.00080 ± 0.00059	0.00058 ± 0.00031	NS
Wahluke Slope #2(d)	23	0.001 ± 0.0005	0.002 ± 0.0008	-0.00001 ± 0.00002	0.00017 ± 0.00028	0.00026 ± 0.00021	NS
Vernita Bridge #2(d)	24		0.002 ± 0.0009	0.00008 ± 0.00030	0.00035 ± 0.00028	0.00017 ± 0.00028	NS
Yakima Barricade(d)	25	0.002 ± 0.0008	0.001 ± 0.0010	0.00038 ± 0.00029	0.00027 ± 0.00044	0.00056 ± 0.00022	---
Rattlesnake Springs(d)	26		0.0004 ± 0.0003	0.00083 ± 0.00096	0.00022 ± 0.00022	0.00040 ± 0.00021	0.00013 ± 0.00012
ALE(d)	27	0.001 ± 0.0008	0.0005 ± 0.0006	0.00033 ± 0.00028	0.00074 ± 0.00063	0.00054 ± 0.00025	---
Prosser Barricade(d)	28	0.004 ± 0.0010	-0.00008 ± 0.0005	0.00034 ± 0.00034	0.00017 ± 0.00031	NS	0.00071 ± 0.00027
S of 300 Area(d)	29		0.001 ± 0.0007	0.00014 ± 0.00021	0.00036 ± 0.00067	0.00045 ± 0.00021	0.0026 ± 0.0005
Benton City	30	0.002 ± 0.0007	0.001 ± 0.0009	0.00070 ± 0.00050	-0.00015 ± 0.00025	0.00019 ± 0.00048	0.00013 ± 0.00016
Sunnyside	31	0.003 ± 0.0008	0.001 ± 0.0008	0.00031 ± 0.00029	0.00031 ± 0.00025	0.00017 ± 0.00014	0.00006 ± 0.00011
OFFSITE AVERAGE		0.0036 ± 0.0033	0.00077 ± 0.00045	0.00045 ± 0.00028	0.00022 ± 0.00017	0.00046 ± 0.00023	0.00047 ± 0.00049

(a) Individual results ±2 sigma counting error. Means ±2 standard error of the calculated mean.
 (b) Locations are identified in Figure 3.47.
 (c) Locations sampled every other year indicated by dashed line.
 (d) Perimeter location on Site near Site boundary.
 NS = No sample.

TABLE A.53. U Concentrations in Vegetation

Location	Map Location ^(b)	Concentration pCi/g (dry weight) ^(a)					
		1981	1982	1983	1984	1985	1986
ON SITE							
1 Mile NE of 100N Area	1		0.01 ± 0.005	0.006 ± 0.003	0.007 ± 0.0034	0.0076 ± 0.0056	NS
1 Mile E of 100N Area	2		0.02 ± 0.007	0.007 ± 0.003	0.0061 ± 0.0030	0.013 ± 0.0074	0.0060 ± 0.0017
100-Area Fire Station	3		0.008 ± 0.003	0.007 ± 0.003	0.0067 ± 0.0033	0.016 ± 0.0078	0.0054 ± 0.0016
200E NC	4	0.01 ± 0.004	0.006 ± 0.002	0.007 ± 0.004	0.0092 ± 0.0037	0.015 ± 0.0076	0.011 ± 0.003
E of 200E	5		0.01 ± 0.005	0.008 ± 0.003	0.0066 ± 0.0042	0.011 ± 0.0064	0.0046 ± 0.0013
200E SE	6	0.008 ± 0.003	0.006 ± 0.002	0.007 ± 0.003	0.0052 ± 0.0040	0.016 ± 0.0080	0.013 ± 0.004
SW of BC Cribs	7		0.01 ± 0.003	0.005 ± 0.003	0.017 ± 0.0077	0.014 ± 0.0077	NS
S of 200E	8		0.01 ± 0.004	0.009 ± 0.004	0.011 ± 0.0054	0.035 ± 0.014	0.0072 ± 0.0021
E of 200W	9	0.01 ± 0.004	0.01 ± 0.004	0.011 ± 0.004	0.016 ± 0.0065	0.022 ± 0.0096	0.016 ± 0.005
2 Miles S of 200 W	10		0.01 ± 0.003	0.007 ± 0.003	0.015 ± 0.0058	0.0096 ± 0.0063	0.0060 ± 0.0017
NE of FFTF	11	0.02 ± 0.006	0.002 ± 0.0008	0.005 ± 0.003	0.014 ± 0.005	0.0081 ± 0.0054	---(c)
SE of FFTF	12	0.008 ± 0.003	0.007 ± 0.002	0.01 ± 0.004	0.0050 ± 0.0027	0.022 ± 0.0098	NS
N of 300 Area	13		0.01 ± 0.005	0.018 ± 0.006	0.012 ± 0.0046	0.082 ± 0.027	0.018 ± 0.005
Hanford Townsite	14	0.005 ± 0.003	0.01 ± 0.004	0.011 ± 0.0048	0.0032 ± 0.0022	0.015 ± 0.0080	---(c)
Wye Barricade	15	0.01 ± 0.004	0.005 ± 0.002	0.0077 ± 0.0035	0.0045 ± 0.0036	0.021 ± 0.0095	---(c)
ONSITE AVERAGE		0.010 ± 0.0037	0.0099 ± 0.0025	0.0083 ± 0.0018	0.0093 ± 0.0026	0.021 ± 0.0099	0.0097 ± 0.0030
OFF SITE							
Riverview	16	0.02 ± 0.008	0.02 ± 0.006	0.014 ± 0.005	0.021 ± 0.0076	0.0099 ± 0.0060	0.015 ± 0.004
Byers Landing	17	0.02 ± 0.0080	0.04 ± 0.010	0.015 ± 0.006	0.022 ± 0.0078	0.19 ± 0.058	0.021 ± 0.006
Sagemoor	18	0.02 ± 0.0080	0.02 ± 0.006	0.013 ± 0.005	0.012 ± 0.0050	0.019 ± 0.0086	NS
Taylor Flats #2	19	0.03 ± 0.010	0.03 ± 0.009	0.016 ± 0.006	0.011 ± 0.0044	0.022 ± 0.0096	0.016 ± 0.005
W End Fir Road	20	0.02 ± 0.0070	0.03 ± 0.010	0.02 ± 0.007	0.036 ± 0.012	0.038 ± 0.014	0.0092 ± 0.0027
Ringold	21	0.04 ± 0.010	0.03 ± 0.010	0.027 ± 0.009	0.025 ± 0.0085	0.041 ± 0.015	0.011 ± 0.003
Berg Ranch	22	0.01 ± 0.0050	0.02 ± 0.0060	0.012 ± 0.005	0.017 ± 0.0066	0.0097 ± 0.0063	NS
Wahluke Slope #2 ^(d)	23	0.02 ± 0.0060	0.01 ± 0.005	0.011 ± 0.005	0.0088 ± 0.0039	0.015 ± 0.0079	NS
Vernita Bridge ^(d)	24		0.01 ± 0.005	0.013 ± 0.005	0.011 ± 0.0045	0.020 ± 0.0090	NS
Yakima Barricade ^(d)	25	0.12 ± 0.040	0.01 ± 0.003	0.0078 ± 0.0035	0.0037 ± 0.0020	0.020 ± 0.0090	---(c)
Rattlesnake Springs ^(d)	26		0.004 ± 0.001	0.012 ± 0.005	0.0042 ± 0.0022	0.013 ± 0.0068	0.0097 ± 0.0028
ALE ^(d)	27	0.007 ± 0.0020	0.008 ± 0.003	0.0055 ± 0.0029	0.0057 ± 0.0025	0.0075 ± 0.0054	---(c)
Prosser Barricade ^(d)	28	0.006 ± 0.0030	0.01 ± 0.003	0.011 ± 0.005	0.0042 ± 0.0023	NS	0.0097 ± 0.0028
S of 300 Area ^(d)	29		0.006 ± 0.002	0.0118 ± 0.0056	0.014 ± 0.0053	0.036 ± 0.014	0.014 ± 0.004
Benton City	30		0.01 ± 0.004	0.015 ± 0.006	0.014 ± 0.0056	0.013 ± 0.0074	0.021 ± 0.006
Sunnyside	31	0.01 ± 0.0050	0.01 ± 0.005	0.009 ± 0.004	0.0013 ± 0.0014	0.0086 ± 0.0057	0.0060 ± 0.0017
OFFSITE AVERAGE		0.027 ± 0.016	0.017 ± 0.0052	0.013 ± 0.0028	0.013 ± 0.0049	0.041 ± 0.041	0.013 ± 0.003

(a) Individual results ±2 sigma analytical error. Means ±2 standard error of the calculated mean.

(b) Locations are identified in Figure 3.47.

(c) Locations sampled every other year indicated by dashed line.

(d) Perimeter location on Site near Site boundary.

NS = No sample.

TABLE A.54. Environmental Dosimeter Measurements - Perimeter and Community Locations

Location	Map Location ^(b)	No. of Samples	Dose Rate, mrem/yr ^(a)		
			Maximum	Minimum	Average ^(c)
PERIMETER STATIONS					
Prosser Barricade	1	12	75	59	72 ± 7
ALE	2	12	80	55	69 ± 7
Rattlesnake Springs	3	12	88	67	75 ± 9
Yakima Barricade	4	12	79	61	73 ± 6
Vernita Bridge	5	11	74	64	70 ± 4
Wahluke Slope #2	6	11	80	70	74 ± 5
Berg Ranch	7	12	76	66	72 ± 5
Sagehill	8	12	70	60	65 ± 5
Ringold	9	11	80	65	71 ± 6
Fir Road	10	11	76	64	70 ± 5
Pettett	11	11	69	59	65 ± 5
Sagemoor	12	9	72	64	67 ± 4
Byers Landing	13	11	77	68	73 ± 4
RRC #64	14	11	70	59	64 ± 5
Horn Rapids Rd., Mi. 12	15	12	89	56	70 ± 12
Horn Rapids, Substation	16	12	82	56	67 ± 10

Range of annual averages 64-75 mrem/yr

NEARBY COMMUNITIES

Benton City	17	10	64	47	54 ± 7
Othello	18	12	63	52	56 ± 5
Connell	19	12	69	55	62 ± 5
Pasco	20	9	64	59	62 ± 3
Richland	21	10	64	49	58 ± 8
Etopia	22	11	63	54	60 ± 4
Prosser	23	12	71	53	61 ± 8
Mattawa	24	10	63	50	56 ± 7
Kennewick	25	11	71	53	64 ± 8

Range of annual averages 54-64 mrem/yr

DISTANT COMMUNITIES

Walla Walla	26	12	64	47	61 ± 4
McNary	27	12	72	59	64 ± 5
Sunnyside	28	11	66	52	60 ± 6
Moses Lake	29	11	60	50	54 ± 8
Washtucna	30	11	66	57	63 ± 5
Yakima	31	11	60	50	56 ± 5

Range of annual averages 54-64 mrem/yr

- (a) Monthly integrated readings in mR were converted to annual dose equivalent rates.
 (b) Locations are identified in Figure 3.52.
 (c) Averages ±2 times the standard error of the calculated mean.

TABLE A.55. Immersion Dose Rates Measured in the Columbia River

Location ^(b)	Number of Measurements	Dose Rate, mrem/h ^(a)		
		Maximum	Minimum	Average ^(c)
Coyote Rapids	4	0.006	0.005	0.005 ± 0.001
Richland Pumphouse	3	0.005	0.004	0.004 ± 0.001

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

TABLE A.56. Environmental Dosimeter Measurements at Publicly Accessible Onsite Locations

Location	Map Location ^(b)	No. of Measurements	Dose Rate, mrem/h ^(a)		
			Maximum	Minimum	Average ^(c)
100N Area Shoreline					
100N Trench Springs	1	12	0.046	0.015	0.035 ± 0.014
Below 100N Main Stack	2	12	0.037	0.008	0.023 ± 0.012
Upstream Tip 100N Berm	3	12	0.036	0.008	0.024 ± 0.012
Downstream 100N Outfall	4	12	0.032	0.010	0.024 ± 0.009
300 Area Perimeter Fence					
377S Fence	5	12	0.023	0.009	0.017 ± 0.010
3705 West Fence	6	13	0.016	0.011	0.014 ± 0.002
400 Area (FFTF) Perimeter Fence					
400 East	7	13	0.012	0.007	0.008 ± 0.0002

- (a) Monthly integrated readings in mR were converted to hourly dose equivalent rates.
 (b) Locations are identified in Figure 3.55.
 (c) Averages ±2 times the standard error of the calculated mean.

TABLE A.57. Environmental Dosimeter Measurements Along the Hanford Reach of the Columbia River

Location	Map Location ^(b)	No. of Measurements	Dose Rate, mrem/h ^(a)		
			Maximum	Minimum	Average ^(c)
Upriver 100B Area	1	4	0.009	0.006	0.007 ± 0.002
Below 100B Retention Basin	2	4	0.015	0.011	0.014 ± 0.002
Above 100K Boat Ramp	3	4	0.009	0.006	0.008 ± 0.002
Downriver from 100D	4	4	0.012	0.008	0.010 ± 0.003
Downriver Opposite 100D	5	4	0.008	0.006	0.007 ± 0.002
Lower End Locke Island	6	4	0.009	0.006	0.008 ± 0.002
White Bluffs Slough	7	3	0.015	0.009	0.012 ± 0.003
White Bluffs Ferry Landing	8	4	0.009	0.006	0.008 ± 0.002
Below 100F	9	4	0.009	0.006	0.007 ± 0.002
100F Floodplain	10	4	0.016	0.010	0.013 ± 0.004
Hanford Powerline Crossing	11	4	0.016	0.006	0.008 ± 0.003
Hanford Ferry Landing	12	4	0.008	0.005	0.007 ± 0.002
Hanford Peninsula	13	4	0.014	0.008	0.012 ± 0.004
Hanford Railroad Track	14	4	0.013	0.008	0.011 ± 0.003
Savage Island Slough	15	4	0.012	0.007	0.010 ± 0.003
Ringold Island	16	4	0.009	0.006	0.008 ± 0.002
Powerline Crossing	17	4	0.010	0.006	0.008 ± 0.002
North End Wooded Island	18	4	0.009	0.006	0.007 ± 0.002
South End Wooded Island	19	4	0.011	0.006	0.009 ± 0.003
Island Near 300 Area	20	4	0.013	0.008	0.010 ± 0.003
Below Bateman Island	21	4	0.011	0.007	0.009 ± 0.002

(a) Quarterly, integrated readings in mR were converted to hourly dose equivalent rates.

(b) Locations are identified in Figure 3.54.

(c) Averages ±2 times the standard error of the calculated mean.

TABLE A.58. Onsite External Penetrating Dose Measurements

Location	Map Location ^(b)	No. of Measurements	Dose Rate, mrem/h ^(a)		
			Maximum	Minimum	Average ^(c)
100 Area					
100K	1	13	0.008	0.006	0.007 ± 0.0007
100N	2	13	0.012	0.008	0.010 ± 0.002
100D	3	13	0.009	0.008	0.008 ± 0.0006
100-Area Fire Station	4	13	0.008	0.007	0.008 ± 0.0007
200 Area					
N of 200E	5	11	0.009	0.007	0.008 ± 0.001
E of 200E	6	11	0.009	0.007	0.008 ± 0.001
200E SE	7	11	0.011	0.007	0.008 ± 0.001
GTE Building	8	11	0.008	0.006	0.008 ± 0.0009
SW of BC Cribs	9	11	0.009	0.007	0.008 ± 0.001
S of 200E	10	11	0.010	0.007	0.008 ± 0.001
300 Area					
300 Pond	11	10	0.009	0.007	0.008 ± 0.001
3614 A Building	12	10	0.008	0.007	0.008 ± 0.001
300S Gate	13	10	0.009	0.006	0.008 ± 0.001
300SW Gate	14	6	0.009	0.007	0.008 ± 0.001
3705 West Fence	15	13	0.016	0.011	0.014 ± 0.002
377 Building South Fence	16	12	0.023	0.009	0.017 ± 0.01
400 Area					
400E	17	13	0.012	0.007	0.008 ± 0.02
400W	18	9	0.009	0.007	0.008 ± 0.0009
400S	19	10	0.009	0.007	0.008 ± 0.001
400N	20	10	0.009	0.007	0.008 ± 0.0009
FFTF North	21	8	0.009	0.007	0.008 ± 0.001
FFTF Southeast	22	10	0.009	0.007	0.008 ± 0.001
600 Area					
Rt. 11A, Mi. 9	23	11	0.011	0.007	0.008 ± 0.002
Hanford	24	13	0.007	0.006	0.007 ± 0.0008
Wye Barricade	25	12	0.008	0.007	0.007 ± 0.0007
Army Loop Camp	26	11	0.008	0.007	0.008 ± 0.001

(a) Monthly integrated reading in mR were converted to hourly dose equivalent rates.

(b) Locations are identified in Figure 3.56.

(c) Averages ±2 standard error of the mean.

TABLE A.59. U.S. Testing Analysis of National Bureau of Standards Reference Soil

Radionuclide	Concentration (pCi/g)		Normalized Deviation From the Known ^(a)
	NBS	UST $\pm 2\sigma$	
⁴⁰ K	19.5	18.8 \pm 1.1	-0.4
⁹⁰ Sr	0.206	0.21 \pm 0.03	-0.2
¹³⁷ Cs	0.476	0.43 \pm 0.05	-1.0
²²⁶ Ra	1.16	0.95 \pm 0.11	-1.2
^{239,240} Pu	0.217	0.19 \pm 0.01	-0.8

(a) Normalized deviation calculated according to Jarvis and Siu (1981) using control limits from Sanderson (1985).

TABLE A.60. Estimates of Precision Based in Terms of Coefficient of Variation on 1985-1986 Replicate Sampling and Analysis

Medium	Analysis	Coefficient of Variation (%) ^(a)
Air	Gross Alpha	25
	Gross Beta	21
	³ H	44
	⁹⁰ Sr	71
	^{239,240} Pu	40
	Uranium	20
Water	Gross Alpha	20
	Gross Beta	30
	³ H	60
	⁹⁰ Sr	56
	Uranium	47
Milk	⁹⁰ Sr	17
Wheat	⁹⁰ Sr	35
Soil on Site	¹³⁷ Cs	23
	^{239,240} Pu	43
	Uranium	28
Soil off Site	⁹⁰ Sr	16
	Uranium	24

(a) Coefficient of variation calculated from the standard deviation calculated from replicates divided by the mean, multiplied by 100. The standard deviation was calculated by $S = \sqrt{\frac{E-dz}{2n}}$ where d is the range between duplicate pairs and n is the number of pairs. (AOAC 1975).

TABLE A.61. Comparison of TLD Results with Known Exposures

<u>Month</u>	<u>% Bias^(a)</u>		
	<u>Low^(b)</u>	<u>Medium</u>	<u>High</u>
January	-1.0	-4.5	-0.4
February	-1.3	-1.7	+2.2
March	+1.9	+0.7	0.0
April	-1.0	-3.3	+1.4
May	-6.0	-6.7	-5.0
June	-6.6	-8.1	-8.8
July	-6.5	-5.5	-5.9
August	-3.3	-6.7	-2.6
September	+2.8	+2.2	+5.5
October	-4.1	-5.0	-4.4
November	+3.9	+5.4	+5.6
December	+1.3	+3.3	+2.7

(a) The percent bias was calculated by

$$100 \left(\frac{x_1 + x_2}{2} - E \right) / E$$

where x_1 and x_2 are the two measured exposures and E is the known exposure.

(b) Low, medium, and high refer to the range of known exposures. Ranges of exposure from low to high range were between 15 and 29 mR.

TABLE A.62. Washington State - DSHS and PNL Shared TLD Stations

Location	Exposure Rate mR/day)							
	First ^(a)		Second		Third		Fourth	
	DSHS ^(b)	PNL	DSHS	PNL	DSHS	PNL	DSHS	PNL
U.S. Ecology NE Corner	0.25	0.18	----	0.20	----	0.24	0.28	0.18
NW Corner	0.28	0.18	0.24	0.20	0.23	0.19	0.30	0.19
SW Corner	0.42	0.29	0.29	0.23	0.26	0.23	0.36	0.20
SE Corner	0.79	0.50	0.40	0.30	0.30	0.24	0.36	0.22
WNP-2 1	0.21	0.20	0.27	0.20	0.20	0.20	0.29	0.20
WNP-2 4	0.20	0.17	0.23	0.18	0.20	0.17	0.25	0.17
WNP-2 8	0.23	0.17	0.26	0.18	0.21	0.17	0.31	0.21
Connell	0.20	0.17	0.24	0.17	0.17	0.17	0.27	0.16
Richland	0.21	0.13	0.21	0.15	0.16	0.17	0.25	0.16
Moses Lake	0.18	0.15	0.18	0.14	0.19	0.16	0.19	0.13
200E SE	0.23	0.19	0.18	0.21	0.21	0.22	0.26	0.19
E 200E	0.32	0.21	0.19	0.21	0.24	0.22	0.28	0.19
N 200E	0.26	0.19	0.19	0.21	0.23	0.20	0.29	0.18
Rt 11A, Mi. 9	0.26	0.18	0.18	0.21	0.21	0.22	0.23	0.18
200 GTE	0.23	0.18	0.15	0.19	0.17	0.20	0.23	0.17
S 200E	0.26	0.21	0.19	0.22	0.20	0.24	0.28	0.20
SW of BC Crib	0.25	0.20	0.17	0.21	0.21	0.23	0.25	0.19
Army Loop Camp	0.26	0.19	0.20	0.20	0.23	0.20	0.25	0.18
Yakima Barricade	0.26	0.20	0.20	0.22	0.21	0.21	0.26	0.19
Wye Barricade	0.23	0.18	0.16	0.17	0.18	0.18	0.22	0.17
Sunnyside	0.21	0.16	0.17	0.17	0.19	0.17	0.22	0.15

(a) First, Second, Third and Fourth are the 1986 calendar quarters.
 (b) DSHS and PNL are the TLD results for the same location in units of milliroentgens per day.

TABLE A.63. Results of Fruit and Produce Samples Split with U.S. Food and Drug Administration Laboratory

Location	Sample Type	Results pCi/g)					
		⁹⁰ Sr		Gamma Emitters		³ H (pCi/L)	
		UST ^(a)	FDA	PNL	FDA	UST	FDA
Riverview	Melons	0.003 ± 0.003	0.0001 ± 0.0007	ND	ND	63 ± 305	200 ± 100
	Apples	0.002 ± 0.002	0.0008 ± 0.0008	ND	ND	359 ± 322	200 ± 100
	Carrots	0.006 ± 0.002	0.0021 ± 0.001	ND	ND	NA	NA
	Potatoes	0.006 ± 0.003	0.0007 ± 0.0008	ND	ND	NA	NA
	Tomatoes	0.002 ± 0.003	0.0002 ± 0.0007	ND	ND	NA	NA
Sagemoor	Apples	0.002 ± 0.003	0.0006 ± 0.0007	ND	ND	56 ± 242	200 ± 100
	Potatoes	0.005 ± 0.003	0.0004 ± 0.0007	ND	ND	NA	NA
Wahluke	Apples	0.004 ± 0.003	0.0002 ± 0.0007	ND	ND	20 ± 271	100 ± 100
	Potatoes	0.007 ± 0.016	0.00 ± 0.0008	ND	ND	NA	NA

(a) UST mean of 3 analyses.
 ND = None detected.
 NA = Not available

APPENDIX B

GLOSSARY, ABBREVIATIONS, CONVERSION TABLE

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

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

Airlift - A means of collecting water samples from wells by pumping air down the tube that is inside the well and then forcing water up the annular space between the tube and a larger pipe or the well casing.

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

Background Radiation - The radioactivity in the environment, including cosmic rays from space and radiation that exists elsewhere - in the air, in the earth, and in manmade materials that surround us. In the United States, most people receive 100 to 250 millirems (mrem) of background radiation per year.

Baller - A cylindrical steel container attached to a wire line that is lowered down a well to just below the water surface, filled with water, and then brought to the surface.

Bankstorage - A hydrologic term that describes river water that flows into and is retained in permeable stream banks during periods of high river stage. Flow is reversed during periods of low riverstage.

becquerel (Bq) - A unit of activity equal to one nuclear transformation per second ($1 \text{ Bq} = 1\text{s}^{-1}$). The former special named unit of activity, the curie, is related to the becquerel according to $1 \text{ Ci} = 3.7 \times 10^{10} \text{ Bq}$.

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

Controlled Area - An area to which access is controlled to protect individuals from exposure to radiation or radioactive materials.

Cosmic Radiation - High-energy subatomic particles from outer space, which bombard the earth's atmosphere. Cosmic radiation is part of natural background radiation.

Counting Error - The variability caused by the inherent random nature of radioactive disintegration and the detection process.

Curie (Ci) - A unit of radioactivity equal to 37 billion (3.7×10^{10}) nuclear transformations per second.

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

Derived Concentration Guide (DCG) - Concentrations of radionuclides in air and water that could be continuously consumed or inhaled and not exceed an effective dose equivalent of 100 mrem/yr.

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

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

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

Effluent - The liquid or gaseous waste streams released to the environment from a facility.

Effluent Monitoring - Sampling or measuring specific liquid or gaseous effluent streams for the presence of pollutants.

Exposure - Subjecting a target (usually living tissue) to radiation.

Evapotranspiration - A combination of evaporation from open bodies of water, evaporation from soil surfaces, and transpiration from the soil by plants.

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

"Fence-post" Dose Rate - The dose rate measured or calculated at the point of highest exposure at the boundary of the Hanford Site.

Fission (fissioned) - The splitting or breaking apart of a heavy atom into two new atoms. When a heavy atom, such as uranium, is split, large amounts of energy, radiation, and one or more neutrons are released.

Fission Products - The atoms formed when uranium is split in a nuclear reactor. Many fission products are radioactive.

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

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

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

Half-life - The length of time in which any radioactive substance will lose one-half of its radioactivity. The half-life may vary in length from a fraction of a second to thousands of years.

Ion Exchange - The reversible exchange of ions contained in a crystal for different ions in solution without destroying the crystal structure or disturbing the electrical neutrality.

Isotope - Different forms of the same chemical element that are distinguished by having different numbers of neutrons in the nucleus. A single element may have many isotopes. For example, the three isotopes of hydrogen are protium, deuterium, and tritium.

Long-lived Isotope - A radionuclide that decays at such a slow rate that a quantity of it will exist for an extended period (half-life is greater than 3 years).

Short-lived Isotope - A radionuclide that decays so rapidly that a given quantity is transformed almost completely into decay products within a short period (half-life of a day or less).

Lacustrine Sediments - A sedimentary deposit consisting of material pertaining to, produced by, or formed in a lake or lakes.

Lithology - The description of the physical characteristics of rocks that make up geologic units. This may include such characteristics as color, mineralogic composition, and grain size.

Man-rem - See "Collective Dose Equivalent" under "Radiation Dose."

Maximally Exposed Individual - A hypothetical individual who remains in an uncontrolled area and would, when all potential routes of exposure from a facility's operations are considered, receive the greatest possible dose equivalent.

Mean - The average value of a series of measurements.

Median - The middle value in a set of results when the data are ranked in increasing or decreasing order.

Millirem (mrem) - A unit of radiation dose equivalent that is equal to one one-thousandth of a rem. An individual member of the public can receive up to 500 millirems per year according to DOE standards. This limit does not include radiation received for medical treatment or the 100 to 250 millirems (mrem) that people receive annually from background radiation.

Minimum Detectable Concentration - The smallest amount or concentration of a radioactive or nonradioactive element that can be reliably detected in a sample.

Noble Gas - Any of a group of chemically and biologically inert gases that includes krypton and xenon. These gases are not retained in the

body following inhalation. The principle exposure pathways from radioactive noble gases are direct external dose from the surrounding air (see air submersion dose), and from internal irradiation while the inhaled air is in the lung.

Offsite Locations - Sampling and measurement locations outside the Hanford Site boundary.

Onsite Locations - Sampling and measurement locations within the Hanford Site boundary.

Outfall - The end of a drain or pipe that carries waste water or other effluents into a ditch, pond, or river.

Plume - The distribution of a pollutant in air or water after being released from a source.

Plutonium - A heavy, radioactive, manmade metallic element. Its most important isotope is fissionable ^{239}Pu , which is produced by the irradiation of ^{238}U . Routine analysis cannot distinguish between the ^{239}Pu and ^{240}Pu isotopes, hence, the term $^{239,240}\text{Pu}$.

Primary Cooling Loop - A closed system of piping that provides cooling water to the reactor. Heat energy is transferred to the secondary loop through a heat exchanger.

Radiation - Refers to the process of emitting energy in the form of rays or particles that are thrown off by disintegrating atoms. The rays or particles emitted may consist of alpha, beta, or gamma radiation.

Alpha Radiation - The least penetrating type of radiation. Alpha radiation can be stopped by a sheet of paper or outer dead layer of skin.

Beta Radiation - Emitted from a nucleus during fission. Beta radiation can be stopped by an inch of wood or a thin sheet of aluminum.

External Radiation - Radiation originating from a source outside the body, such as cosmic radiation or natural and manmade radionuclides.

Gamma Radiation - A form of electromagnetic, high-energy radiation emitted from a nucleus. Gamma rays are essentially the same as x-rays and require heavy shieldings, such as concrete or steel, to be stopped.

Internal Radiation - Radiation originating from a source within the body as a result of the inhalation, ingestion, or implantation of natural or manmade radionuclides in body tissues.

Radiation Dose - For the purpose of this report, radiation doses are defined as follows:

Absorbed Dose - The amount of energy deposited by radiation in a given amount of material. Absorbed dose is measured in units of "rads" (see "Dose Equivalent").

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

Committed Dose Equivalent - The total dose equivalent accumulated in an organ or tissue in the 50 years following a single intake of radioactive materials into the body.

Cumulative Dose Equivalent - The total dose one could receive in a period of 50 years following release of the radionuclides to the environment, including the dose that could incur as a result of residual radionuclides remaining in the environment beyond the year of release.

Dose Equivalent - The product of the absorbed dose, the quality factor, and any other modifying factors. The dose equivalent is a quantity for comparing the biological effectiveness of different kinds of radiation on a common scale. The unit of dose equivalent is the rem. A millirem (mrem) is one one-thousandth of a rem.

Effective Dose Equivalent - An estimate of the total risk of potential health

effects from radiation exposure. It is the sum of the committed effective dose equivalent from internal deposition and the effective dose equivalent from external penetrating radiation received during a calendar year. The committed effective dose equivalent is the sum of the individual organ committed dose equivalents (50 year) multiplied by weighting factors that represent the proportion of the total random risk that each organ would receive from uniform irradiation of the whole body.

Radioactivity - A property possessed by some elements, such as uranium, whereby alpha, beta, or gamma rays are spontaneously emitted.

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

Radionuclide - A radioactive nuclide. There are several hundred known nuclides, both man-made and naturally occurring; nuclides are characterized by the number of neutrons and protons in an atom's nucleus.

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

Sievert - An International System of Units (SI) measurement of dose equivalent which is 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 is exposed.

Unconfined Aquifer - Contains ground water that is not confined above by relatively impermeable rocks. The pressure at the top of the unconfined aquifer is equal to that of the atmosphere. At Hanford, the unconfined aquifer is the uppermost aquifer and is most susceptible to contamination from Site operations.

Uncontrolled Area - An area on or near a nuclear facility to which public access is not restricted to public access.

Watertable - A theoretical surface which is represented by the elevation of water surfaces in wells penetrating only a short distance into the unconfined aquifer.

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

Windrose - A star-shaped diagram showing how often winds of various speeds blow from different directions, usually based on yearly averages.

X/Q' (Chi over Que) - A dispersion factor calculated using an atmospheric dispersion model from average annual meteorological data. It is used to estimate the air concentration from the total airborne release of a radionuclide. The resulting estimates of average annual air concentrations at specific locations away from the source can be used to calculate potential doses.

ACRONYMS AND ABBREVIATIONS

ALARA	as low as reasonably achievable	ICRP	International Commission on Radiological Protection
ALE	Arid Lands Ecology (Reserve)	MDC	minimum detectable concentration
α	alpha	NERP	National Environmental Research Park
β	beta	NPDES	National Pollutant Discharge Elimination System
BMI	Battelle Memorial Institute	PNL	Pacific Northwest Laboratory
BWIP	Basalt Waste Isolation Project	PSD	Prevention of Significant Deterioration
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act	PUREX Plant	Plutonium and Uranium Extraction Plant
cfs	cubic feet per second	QA	Quality Assurance
DOE	U.S. Department of Energy	QC	Quality Control
DOE-RL	U.S. Department of Energy, Richland Operations Office	RCRA	Resource Conservation and Recovery Act
DCG	Derived Concentration Guide	REDOX	Reduction Oxidation Plant
DSHS	Washington State Department of Social and Health Services	Rockwell	Rockwell Hanford Operations
DWS	Drinking Water Standards	SI	International System of Units (metric)
EML	Environmental Measurements Laboratory	TLD	thermoluminescent dosimeter
EPA	U.S. Environmental Protection Agency	UNC	UNC Nuclear Industries
ERDA	U.S. Energy Research and Development Administration (predecessor to DOE)	UO₃ Plant	Uranium Oxide Plant
FFTF	Fast Flux Test Facility	UST	United States Testing Company, Inc.
γ	gamma	USGS	U.S. Geological Survey
HEDL	Hanford Engineering Development Laboratory	WDOE	Washington State Department of Ecology
HEHF	Hanford Environmental Health Foundation	WHC	Westinghouse Hanford Company

ABBREVIATIONS FOR UNITS OF MEASURE

Radioactivity	
Symbol	Name
Ci	curie
mCi	millicurie (10^{-3} Ci)
μ Ci	microcurie (10^{-6} Ci)
nCi	nanocurie (10^{-9} Ci)
pCi	picocurie (10^{-12} Ci)
fCi	femtocurie (10^{-15} Ci)
aCi	attocurie (10^{-18} Ci)
Bq	becquerel
Sv	sievert

Volume	
Symbol	Name
cm^3	cubic centimeter
L	liter
mL	milliliter (10^{-3} L)
m^3	cubic meter
ppm	parts per million
ppb	parts per billion

Length	
Symbol	Name
km	kilometer (10^3 m)
m	meter (m)
cm	centimeter (10^{-2} m)
mm	micrometer (10^{-6} m)

Mass	
Symbol	Name
g	gram
kg	kilogram (10^3 g)
μ g	microgram (10^{-6} g)
ng	nanogram (10^{-9} g)
t	metric ton (or tonne; 10^3 kg)

Area	
Symbol	Name
ha	hectare ($10,000 \text{ m}^2$)

Time	
Symbol	Name
yr	year
d	day
h	hour
m	minute
s	second

CONVERSION TABLE

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>	<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
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/cm ³	10 ⁻¹²	mCi/cm ³	mCi/cm ³	10 ¹²	pCi/cm ³
mCi/km ²	1.0	nCi/m ²	nCi/m ²	1.0	mCi/km ²
becquerel	2.7 x 10 ⁻¹¹	curie	curie	3.7 x 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

<u>Factor</u>	<u>Prefix</u>	<u>Symbol</u>
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 C

APPLICABLE STANDARDS AND PERMITS AND ENVIRONMENTAL COMPLIANCE DOCUMENTATION

Operations at the Hanford Site must conform to a variety of federal and state standards and permits designed to ensure the radiological, chemical, biological, and physical quality of the environment for either aesthetic or public health considerations. Standards and permits applicable to Hanford operations in 1986 are listed in the following tables. The State of Washington has promulgated water-quality standards for the Columbia River (WDOE 1982). Of interest to Hanford operations is the designation of the Hanford reach of the Columbia River as Class A, Excellent. This designation requires that the water be usable for substantially all needs, including drinking water, recreation, and wildlife. Class A water standards are summarized in Table C.1. Drinking water standards promulgated by EPA (USEPA 1976) are summarized in Tables C.2 and C.3. Benton-Franklin-Walla Walla Counties Air Pollution Control Authority air quality standards are shown in Table C.4. Environmental radiation protection standards are published in DOE Order 5480.1A "Environmental Protection, Safety, and Health Protection Program for DOE Operations" (USDOE 1981a). These standards are based on guidelines originally recommended by the Federal Radiation Council and other scientific groups such as the International Commission on Radiological Protection, and the National Commission on Radiation Protection and Measurements. In September 1985, DOE issued a revision to this order that incorporates a system for evaluating and controlling radiation exposures to members of the public in uncontrolled areas. The revised standards are shown in Table C.5, which also includes standards pursuant to the Clean Air Act for sources of radionuclide emissions to the air (USEPA 1983, 40 CFR 61). These standards govern allowable exposures to ionizing radiation from DOE operations.

DOE has also prepared draft tables of Derived Concentration Guides that reflect the concentrations of individual nuclides in water or air that would result in a dose equivalent of 100 mrem caused by ingestion of water or inhalation and external exposure to air. The DCGs are useful reference values but do not generally represent concentrations that ensure compliance with either the DOE or Clean Air Act dose standards (Table C.6).

Permits required for regulated releases to water and air have been issued by the EPA under the National Pollution Discharge Elimination System of the Clean Water Acts and the Prevention of Significant Deterioration requirements of the Clean Air Act. Permits for collecting wildlife for environmental sampling are issued by the Washington State Department of Game and the U.S. Fish and Wildlife Service. Current permits are listed in Table C.7.

Table C.8 lists the Environmental Impact Statements and Environmental Assessments relating to the Hanford Site that were issued during 1986 in draft or final form. These environmental compliance documents were prepared in accordance with federal, state, and regional environmental protection laws. The environmental assessment for the Basalt Waste Isolation Project, one of three sites in the U.S. being considered as a repository for commercial high-level nuclear wastes, is DOE/RW-0076 (USDOE 1986a). The environmental impact of permanently disposing of existing and future nuclear defense wastes at Hanford is assessed in the Department of Energy's HDW-EIS. The other two documents evaluate the environmental impacts of modifying existing Hanford facilities or practices.

TABLE C.1. Washington State Water-Quality Standards for the Hanford Reach of the Columbia River

<u>Parameter</u>	<u>Permissible Levels</u>
Fecal coliform organism	1) ≤ 100 organisms/100 mL 2) $\leq 10\%$ of samples may exceed 200 organisms/100 mL
Dissolved oxygen	>8 mg/L
Temperature	1) $\leq 20^{\circ}\text{C}$ (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 $^{\circ}\text{C}$ 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—Standard Candle.

TABLE C.2 Radiological Drinking Water Standards: U.S. Environmental Protection Agency, National Interim Primary Drinking Water Regulations and State of Washington, Rules and Regulations of the State Board of Health Regarding Public Water Systems

Contaminant	Limit
Gross alpha (excluding uranium)	15 pCi/L
Combined radium-226 and radium-228	5 pCi/L
Radium-226 (State of Washington only)	3 pCi/L
Gross beta and gamma radioactivity from manmade radionuclides	<p>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.</p> <p>Compliance may be assumed if annual average concentrations for gross beta activity, tritium, and strontium-90 are less than 50 pCi/L, 20,000 pCi/L, and 8 pCi/L, respectively. It should be noted that these "screening levels" are conservatively calculated and not directly equivalent to an annual dose of 4 mrem.</p>

The following list provides the annual average concentrations, with respect to the Columbia River, for selected manmade radionuclides of interest. These radionuclides are assumed to yield an annual dose of 4 mrem to the indicated organ. Data are taken from the National Interim Primary Drinking Water Regulations, Table IV-2A (USEPA 1976).

Radionuclide	Critical Organ	Concentration, pCi/L
Tritium	Whole Body	20,000
⁶⁰ Co	GI (LLI)	100
⁸⁹ Sr	Bone	20
⁸⁹ Sr	Bone Marrow	80
⁹⁰ Sr	Bone Marrow	8
⁹⁵ Zr	GI (LLI)	200
⁹⁵ Nb	GI (LLI)	300
¹⁰⁶ Ru	GI (LLI)	30
¹²⁹ I	Thyroid	1
¹³¹ I	Thyroid	3
¹³⁴ Cs	GI(s)	20,000
¹³⁷ Cs	Whole Body	200

TABLE C.3. Chemical 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 (USEPA 1976)

<u>Chemical Constituent</u>	<u>Concentration</u>
As	50 µg/L
Ba	1 mg/L
Cd	10 µg/L
CCl ₄	5 µg/L
Cr	50 µg/L
Cu	1.3 mg/L
F	2 mg/L
Pb	50 µg/L
Hg	2 µg/L
NO ₃	45 mg/L
Se	10 µg/L

TABLE C.4. Benton-Franklin-Walla Walla Counties Air Pollution Control Authority Ambient Air Quality Standards ^(a)

<u>Parameters</u>	<u>Type of Standard (b)</u>	<u>Sampling Period</u>	<u>Permissible Levels</u>
NO ₂	Secondary and primary	Annual average	0.05 ppm

(a) Benton-Franklin-Walla Walla Air Pollution Control Authority 1980.

(b) Primary ambient air quality national standards define levels of air quality to protect the public health. Secondary standards define levels of air quality to protect the public welfare from any known or anticipated adverse effects of a pollutant.

TABLE C.5. Radiation Standards for Protection of the Public in the Vicinity of DOE Facilities

DOSE LIMITS

ALL PATHWAYS

The effective dose equivalent for any member of the public from all routine DOE operations (a) (natural background and medical exposures excluded) shall not exceed the values given below:

	Effective Dose Equivalent ^(b)	
	mrem/yr	(mSv/yr)
Occasional Annual Exposures	500	(5)
Prolonged Period of Exposure (c)	100	(1)

No individual organ shall receive a committed effective dose equivalent of 5 rem/yr (500 mSv/yr) or greater.

AIR PATHWAYS ONLY (Limits of USEPA 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) Effective dose equivalent is expressed in rem (or millirem) with the corresponding value in sievert (or millisievert) in parentheses.
- (c) For the purposes of these standards, a prolonged exposure will be one that lasts, or is predicted to last, longer than 5 years.

TABLE C.6. Proposed Derived Concentration Guides (a)

Radionuclide	Water	Air
	pCi/L (10 ⁻⁹ μCi/mL)	pCi/m ³ (10 ⁻¹² μCi/mL)
³ H	2,000,000	200,000
¹⁴ C(CO ₂)	NS	500,000
⁵¹ Cr	1,000,000	60,000
⁵⁴ Mn	50,000	2,000
⁶⁰ Co	5,000	80
⁶⁵ Zn	9,000	600
⁸⁵ Kr	NS	60,000 (b)
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
²³⁸ Pu	400	0.03
²³⁹ Pu	300	0.02

- (a) Concentrations of radionuclides in water and air that could be continuously consumed or inhaled, respectively, and not exceed an effective dose equivalent of 100 mrem/yr.
- (b) DOE Order 5480.1A (USDOE 1981a).
NS = No standard.

TABLE C.7. Environmental Permits

NPDES Permits

NPDES Permit No. WA-000374-3, issued to the DOE Richland Operations Office by Region 10 of the EPA, covers nonradioactive discharges to the Columbia River from eight outfalls.

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 Uranium Oxide Plant. No expiration date.

Wildlife Sampling Permits

Scientific Study or Collection Permit No. 011 WM-008-84, issued to Pacific Northwest Laboratory, by Washington State Department of Game, 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.

TABLE C.8. Hanford Site Environmental Impact Statements and Environmental Assessments Issued During 1986

Environmental Impact Statements

U.S. Department of Energy (US DOE). 1986. Disposal of Hanford Defense High-Level Transuranic and Tank Waste. DOE/EIS-0113, U.S. Department of Energy, Washington, DC.

U.S. Department of Energy (US DOE). 1986. Draft Environmental Impact Statement: Process Facility Modification Project. DOE/EIS-0115D, U.S. Department of Energy, Washington, DC.

Environmental Assessments

U.S. Department of Energy (US DOE). 1986. Environmental Assessment: Reference Repository Location, Hanford Site, Washington. DOE/RW-0070, U.S. Department of Energy, Washington, DC.

U.S. Department of Energy (US DOE). 1986. Environmental Assessment for the Grouting and Near-Surface Disposal of Low-Level Radioactive Phosphate/Sulfate Waste from N-Reactor Operations. DOE/EA-0312, U.S. Department of Energy, Richland, Washington.

Copies of these regulations may be obtained from the following organizations:

State of Washington,
Department of Ecology
Olympia, WA 98504

U.S. Department of Energy
Richland Operations Office
Richland, WA 99352

U.S. Environmental Protection Agency
Region 10
1200 Sixth Avenue
Seattle, WA 98101

APPENDIX D

ANALYTICAL PROCEDURES AND SAMPLING SUMMARY

SURFACE MONITORING: RADIOLOGICAL SAMPLES

All routine environmental surveillance samples are analyzed according to detailed, written analytical procedures that are described in general terms in this section. Minimum detectable concentrations for the various medium/analysis combinations and other analytical information are shown in Table D.1.

AIR SAMPLES

Alpha- and Beta- Emitting Radionuclides are measured by a direct count from the glass fiber filter. Alpha radiation is counted on a low-background, gas-flow proportional counter and beta on a gas-flow proportional counter.

Gamma-Emitting Radionuclides are counted directly from the glass fiber filter 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	¹¹⁰ MAg	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 La	²³² Th Da
⁸⁵ Sr	¹⁴⁰ BaLa	²³⁸ U Da
⁹⁵ Zr	¹³⁹ Ce	
⁹⁵ Nb	¹⁴¹ Ce	
⁹⁵ ZrNb	¹⁴⁴ Ce	Da=daughters

Strontium-90 is leached from the glass fiber filters with 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 the glass fiber filters with nitric acid and extracted as tetrapropyl ammonium uranyl trinitrate, then extracted back into water. A portion of the water extract is fused with sodium and lithium fluoride and analyzed by alpha spectrometry.

Plutonium is leached from the glass fiber filters 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 tritium content of the water vapor is determined with a liquid scintillation spectrometer.

Iodine-131 is collected on activated charcoal and then counted on a Ge(Li) detector with a multichannel, pulse-height analyzer.

Carbon-14 is collected as carbon dioxide gas using soda lime. The carbon dioxide is released from the soda-lime sample with acid and injected into a "Benzene Synthesizer" instrument. The carbon dioxide is quantitatively converted to benzene through a series of catalytic reactions. The benzene product is mixed with scintillator solution and counted on a low-temperature, liquid scintillation counter.

Krypton-85 is removed from the air sample and purified using a specially constructed cryogenic chromatography instrument. The sample is passed through a series of cold traps. The purified krypton 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 concentration using a Ge(Li) detector with a multichannel pulse-height analyzer.

Strontium-90 in large-volume water samples is precipitated with fuming nitric acid, scavenged with barium chromate, precipitated as a carbonate, transferred to a stainless steel planchet, and counted with a low-background, gas-flow proportional counter. After 15 days, the yttrium-90 decay product is separated and then counted with a proportional counter.

Tritium samples can be counted directly with a liquid scintillation spectrometer, or the sample can be enriched by alkaline electrolysis and then counted with a liquid scintillation spectrometer.

Filter-Resin Samples are analyzed for gamma-emitting radionuclides using a Ge(Li) detector with a multichannel, gamma-ray spectrometer. Aliquots of the samples are analyzed by neutron-activation analysis for ^{129}I and by chemical separation and alpha spectrometry for plutonium.

MILK

Gamma-Emitting Radionuclides in milk are counted directly using a Ge(Li) detector with a multichannel, pulse-height analyzer.

Tritium in water distilled from milk is counted directly with a liquid scintillation spectrometer.

Iodine-129 is separated from milk with an anion exchange resin, purified, and analyzed by the neutron-activation method.

Iodine-131 is removed from milk with an anion-exchange resin. The iodine is eluted with sodium hypochlorite, precipitated as palladium

iodide, and beta-counted with a low-background, gas-flow proportional counter.

Strontium-89,90 is removed from milk with a cation resin, eluted with sodium chloride, precipitated as a carbonate, and transferred to a stainless steel planchet for counting with a low-background, gas-flow proportional counter.

FOODSTUFFS

Gamma-Emitting Radionuclides in foodstuffs are counted directly on a Ge(Li) detector with a multichannel, pulse-height analyzer.

Tritium in water distilled from farm produce is counted directly with a liquid scintillation spectrometer.

Plutonium in foodstuffs is measured as it is in air-filter samples, after it has been dried, ashed in a furnace, and treated with nitric acid.

Uranium in foodstuffs is measured as it is in water samples. However, the samples are dried, ashed in a furnace, and treated with nitric acid before the ether extraction step.

Strontium-90 is measured as it is in air samples, after being dried, ashed in a furnace, and treated with nitric acid, before the fuming nitric acid step.

VEGETATION AND WILDLIFE

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

SOIL

Gamma-Emitting Radionuclides are counted on a Ge(Li) detector with a multichannel, pulse-height analyzer, after the sample is placed into a Marinelli beaker.

Plutonium and Strontium-89,90 are measured after the soil sample is dried, mixed thoroughly, leached with nitric acid, and then precipitated as strontium oxalate. The sample is then precipitated as a carbonate, transferred to a planchet, and counted with a low-background, gas-flow proportional counter. After the strontium has been removed from the sample, the plutonium is coprecipitated with calcium oxalate,

dissolved, and loaded onto an ion-exchange resin column. The plutonium is eluted from the resin column with nitric and hydrofluoric acids, deposited on a stainless steel disk, and counted with an alpha spectrometer.

Uranium analysis is conducted after the sample is dried, ashed in a furnace, and leached with hot nitric acid. Uranium is extracted from the acid leachate as tetrapropyl ammonium uranyl trinitrate and then extracted back into water. A portion of the water extract is fused with sodium and lithium fluoride and analyzed with a fluorometer.

SURFACE MONITORING: NONRADIOLOGICAL SAMPLES

Surface-Water Samples

Water samples collected to monitor water quality of the Columbia River are analyzed according to standard methods. Most onsite analyses make use of the most applicable methods recommended by the American Public Health Association in their publication *Standard Methods for the Examination of Water and Wastewater* (APHA 1985). Supplemental USGS samples are analyzed according to approved USGS standard methods.

GROUND-WATER MONITORING: RADIOLOGICAL SAMPLES

All ground-water monitoring samples are analyzed according to detailed, written analytical procedures that are briefly described below. Minimum detectable concentrations for the various medium/analysis combinations and other analytical information are shown in Table D.1.

Total Alpha-Emitting Radionuclides are measured after the samples are evaporated and the salts and solids are dissolved in nitric acid and extracted from the acid by the diethyl ether method. Each sample is then evaporated, dried on a counting dish, and measured by the ZnS scintillation counter. The chemical yield is about 83%.

Total Beta-Emitting Radionuclides are measured after each sample has been evaporated onto a 1-inch counting dish. The residue is then counted with a gas-flow proportional counter.

Gamma-Emitting Radionuclides are measured by analyzing 500-mL samples in polyethylene bottles. An NaI or a Ge(Li) detector is used to count the samples. The standards are traceable to the National Bureau of Standards.

Tritium samples are first distilled from a neutralized aliquot to which holdback carriers have been added. After the first fraction of distillate is discarded, 20 mL is 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* (APHA 1985), *ASTM's Annual Book of ASTM Standards*, Part 31, and *Manual on Water*, STP 442A.

Cr⁶ samples are filtered and treated with diphenyl carbazide reagent. The optical density of the sample is measured in 10-cm cells at 540 millimicrons and compared against a similarly prepared distilled water blank. The concentrations are determined from a standard curve obtained by analyzing solutions prepared containing known amounts of Cr⁶.

To measure **Fluoride**, a 20-mL sample is filtered and 5 mL of fluoride reagent added for color development. The optical density of the sample is then measured at 620 m μ in 1-cm cells and compared against the reagent blank. The concentrations are determined from a standard curve obtained by analyzing solutions prepared containing known amounts of fluoride.

Nitrate was measured by either of three different methods during 1986. For the first 6 months of 1986, nitrate was measured with a nitrate-specific electrode. With this method, the electrode voltage is measured, and the nitrate concentration determined from a standard curve prepared by analyzing solutions containing known amounts of nitrate in distilled water. The ion chromatography method described below under "Inorganic Anions" was used for the

second half of the year. The phenoldisulphonic method was used on a limited number of samples from the confined aquifer. Only results of the ion chromatography and phenoldisulphonic methods are included in this report.

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 it is injected into the ion chromatograph, the sample is pumped through three ion exchange columns to convert the anions in the sample to their corresponding acids. The separated anions in their acid form are measured using an electrical-conductivity cell.

Volatile Organic Chemicals are determined by Gas Chromatography 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 Biphenols 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 chromatography 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 CO₂. The CO₂ is measured by means of a nondispersive infrared analyzer.

A summary of analytical methods used for chemical groundwater monitoring is shown in Table D.2.

TABLE D.1. Radiological Monitoring Sampling Summary

Medium Sampled	Type of Analysis	Frequency of Analysis	Approximate Sample Size	Count Time	Minimum Detectable Concentration (MDC)	Analysis Aliquot Size	Off Site/On Site
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
	¹⁴ C(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(e)	Quarterly	850 m ³ per station	NA	1 x 10 ⁻⁵ 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	2 x 10 ⁻⁵ 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	2 x 10 ⁻⁵ pCi/m ³	2,000-10,000 m ³	Off Site/On Site
	U (isotopic)(d)	Quarterly comp.	5,100 m ³ per station	NA	0.01 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
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	100 min	300 pCi/L	4 mL	On Site
⁶⁰ Co		M,Q,SA,A(f)	1 L	30 min	20 pCi/L	500 mL	On Site
⁹⁰ Sr		Q,SA(f)	1 L	30 min	0.6 pCi/L	500 mL	On Site
¹³⁷ Cs		M,Q,SA,A(f)	1 L	30 min	30 pCi/L	500 mL	On Site
¹²⁹ I		Annually	4 L	NA	1 x 10 ⁻⁶ pCi/L volume	<1 to >50 mL	On Site
Plutonium (gross)		Quarterly	1 L	100 min	0.10 pCi/L	1,000 mL	On Site
²³⁸ Pu		Quarterly	1 L	1,000 min	0.10 pCi/L	1,000 mL	On Site
Uranium (natural)		M,Q(f)	1 L	100 min	0.5 pCi/L	0.5 mL	On Site
River water	Gross alpha	Weekly	1 L	50 min	4.0 pCi/L	1 L	Off Site
	Gross beta	Weekly	1 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

TABLE D.1. (contd)

Medium Sampled	Type of Analysis	Frequency of Analysis	Approximate Sample Size	Count Time	Minimum Detectable Concentration (MDC)	Analysis Aliquot Size	Off Site/On Site
River water (contd)	^{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
	U	Monthly comp.	40 L	NA	0.5 pCi/L	100-1,000 mL	Off Site
River water (Resin & particulate)	^{90}Sr	Quarterly comp.	6,000 L	100 min	0.01 pCi/L	1,500-3,000 L	Off Site/On Site
(Resin)	^{129}I	Quarterly comp.	6,000 L	NA	1×10^{-6} pCi/L	1,500-3,000 L	Off Site/On Site
(Resin & particulate)	Gamma scan (^{137}Cs)	Biweekly	1,000 L	1,000 min	0.01 pCi/L	250-500 L	Off Site/On Site
(Resin & particulate)	Pu	Quarterly comp.	6,000 L	24-72 h	1×10^{-4} 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
	^3H	Quarterly	10 L	150 min	300 pCi/L	5 mL	On Site
	^{89}Sr	Quarterly	10 L	100 min	0.06 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	^3H	Monthly	10 L	150 min	300 pCi/L	5 L	Off Site
	^{89}Sr	Quarterly	10 L	100 min	5.0 pCi/L	1 L	Off Site
	^{90}Sr	Quarterly	10 L	100 min	2.0 pCi/L	1 L	Off Site
	$^{131}\text{I}(g)$	Biweekly	10 L	100 min	0.5 pCi/L	4 L	Off Site
	^{129}I	Semiannually	4 L	NA	5×10^{-5} pCi/L	3-4 L	Off Site
	Gamma scan (^{137}Cs)(g)	Biweekly	10 L	1,000 min	10 pCi/L	450 mL	Off Site
Fruit	^3H	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	0.02 pCi/g	250-500 g	Off Site
Crops and produce	^{90}Sr	Annually	2 kg	200 min	0.005 pCi/g	100 g	Off Site
	Gamma scan (^{137}Cs)	Annually	2 kg	1,000 min	0.02 pCi/g	250-500 g	Off Site
Beef	^{90}Sr	Annually	1 kg	100 min	0.005 pCi/g	100 g	Off Site
	Gamma scan (^{137}Cs)	Annually	1 kg	1,000 min	0.02 pCi/g	250-500 g	Off Site

TABLE D.1. (contd)

Medium Sampled	Type of Analysis	Frequency of Analysis	Approximate Sample Size	Count Time	Minimum Detectable Concentration (MDC)	Analysis Aliquot Size	Off Site/On Site
Poultry	^{90}Sr	Semiannually	1 chicken (breast)	100 min	0.005 pCi/g	100 g	Off Site
	Gamma scan (^{137}Cs)	Semiannually	1 chicken (breast)	1,000 min	0.02 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	0.02 pCi/g	250-500 g	Off Site
Wine	^3H	Annually	750 mL	150 min	300 pCi/L	5 mL	Off Site
	Gamma scan (^{137}Cs)	Annually	750 mL	50 min	8.0 pCi/L	750 mL	Off Site
Fish fillet	^{90}Sr	20 per year	1 fish fillet	100 min	0.005 pCi/g	100 g	Off Site/On Site
	Gamma scan (^{137}Cs)	20 per year	1 fish fillet	1,000 min	0.02 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
	Gamma scan (^{137}Cs)	20 per year	1 fish carcass	1,000 min	0.02 pCi/g	250-500 g	Off Site/On Site
Ducks	Gamma scan (^{137}Cs)	32 per year	1 duck (breast)	1,000 min	0.02 pCi/g	250-500 g	On Site
Game birds	Gamma scan (^{137}Cs)	22 per year	1 bird (muscle)	1,000 min	0.02 pCi/g	250-500 g	On Site
Deer	^{90}Sr	2 per year	500 gm (bone)	100 min	0.005 pCi/g	100 g	On Site
	Gamma scan (^{137}Cs)	8 per year	1 kg (muscle)	1,000 min	0.02 pCi/g	250-500 g	On Site
	Pu	8 per year	1 kg (liver)	1,000 min	6×10^{-4} pCi/g	100 g	On Site
Rabbits	^{90}Sr	12 per year	250 gm (bone)	100 min	0.005 pCi/g	100 g	On Site
	Gamma scan (^{137}Cs)	12 per year	500 gm (muscle)	1,000 min	0.02 pCi/g	250-500 g	On Site
	Pu	12 per year	1 liver	1,000 min	6×10^{-4} pCi/g	100 g	On Site
Soil	^{90}Sr	A,B ^(f)	1.5 kg	100 min	0.005 pCi/g	100 g	Off Site/On Site
	Gamma scan (^{137}Cs)	A,B ^(f)	1.5 kg	100 min	0.02 pCi/g	500 g	Off Site/On Site
	U	A,B ^(f)	1.5 kg	NA	0.01 pCi/g	10 g	Off Site/On Site
	Pu	A,B ^(f)	1.5 kg	1,000 min	6×10^{-4} pCi/g	100 g	Off Site/On Site
	^{241}Am	A,B ^(f)	1.5 kg	1,000 min	0.05 pCi/g	10 g	Off Site/On Site
Native vegetation	Gamma scan (^{137}Cs)	A,B ^(f)	1 kg	1,000 min	0.03 pCi/g	125 g	Off Site/On Site
	^{90}Sr	A,B ^(f)	1 kg	200 min	0.005 pCi/g	100 g	Off Site/On Site
	U	A,B ^(f)	1 kg	NA	0.01 pCi/g	10 g	Off Site/On Site
	Pu	A,B ^(f)	1 kg	1,000 min	6×10^{-4} pCi/g	100 g	Off Site/On Site
Direct radiation exposure	Thermoluminescent dosimeter	Monthly	5 TLDs per dosimeter	NA	1.0 mR ^(h)	NA	Off Site/On Site

(a) Tritiated water vapor.

(b) Four locations.

(c) Twelve locations.

(d) Eight locations.

(e) Four locations.

(f) M = Monthly, Q = Quarterly, SA = Semiannually, A = Annually, B = Biannually.

(g) Four dairies are sampled monthly.

(h) Absolute sensitivity in the manner it is used is well below one millirem.

NA = Not applicable.

TABLE D.2. List of Parameters and Analytical Methods for Monitoring Chemicals in Ground Water

Constituent	Collection ^(a) Preservation ^(b)	Method	Detection Limit, µg/L ^(c)
Chromium	P, HNO ₃ to pH <2	SW-846	10
Manganese		#6010	5
Cadmium		(USEPA 1982)	2
Barium			6
Silver			10
Sodium			100
Iron			50
Mercury	P, HNO ₃ to pH <2	SW-846 #7470 (USEPA 1982)	0.1
Lead	P, HNO ₃ to pH <2	SW-846 #7421 (USEPA 1982)	5
Arsenic	P, HNO ₃ to pH <2	SW-846 #7060 (USEPA 1982)	5
Selenium	P, HNO ₃ to pH <2	SW-846 #7740	5
Tetrachloromethane xylene 1,1,2-trichloroethylene	G, Silicon/teflon septa, no headspace	SW-846 #8240 (USEPA 1982)	10
Hydrazine	G, None	Direct aqueous injection ^(d)	3 mg/L
Polychlorinated biphenols	G, None	SW-846 #8080 (USEPA 1982)	1
Radium	P, HNO ₃ to pH <2	EPA Method #903.0 (USEPA 1980)	1 pCi/L
Gross alpha	P, HNO ₃ to pH <2	EPA Method 680/4-75-001 (Johns 1975)	4 pCi/L
Gross beta			8 pCi/L
Coliform bacteria	P, None	Std. Methods #908A (APHA 1985)	2.2 mpn ^(e)
Total organic halogen	G, Silicon/teflon septa, no headspace	SW-846 #9020 (USEPA 1982)	0.1 mg/µ
Total organic carbon	G, H ₂ SO ₄ to pH <2	Std. Methods #505 (APHA 1985)	1 mg/L
Specific conductance	Field measurement	(USDOE 1986)	1 µmho
pH	Field measurement	(USDOE 1986)	0.01 pH unit
Temperature	Field measurement	(USDOE 1986)	0.1°C
Chloride	P, None	Ion chroma- tography ^(d)	500
Fluoride			500
Sulfate			500
Nitrate			500
Ammonium	G, H ₂ SO ₄ to pH <2	Std. Methods #417-E (APHA 1985)	50
Endrin	G, None	SW-846 #8080 (USEPA 1982)	1
Lindane			
Methoxychlor			
Toxaphene			
2,4-D	G, None	SW-846 #8150 (USEPA 1982)	1
2,4,5-TP Silvex			

- (a) P = plastic, G = glass.
(b) All samples cooled to 4°C upon collection.
(c) Exceptions where indicated.
(d) In-house analytical method.
(e) Most probable number.

TABLE D.3. Chemical Constituents Analyzed in 1986

Constituents			
Thallium	Hydrogen sulfide	2-chlorophenol	Methacrylene
Thiourea	Iodomethane	Chrysene	Methionyl
1-acetyl-2-thiourea	Methacrylonitrile	Cresols	2-methylaziridine
1-(o-chlorophenyl) thiourea	Methanethiol	2-cyclohexyl-4,6-dinitrophenol	3-methylcholanthrene
Diethylstilbesterol	Pentachloroethane	Dibenz[a,h]acridine	4,4'-methylenebis(2-chloroaniline)
Ethylenethiourea	1,1,1,2-tetrachloroethane	Dibenz[a,j]acridine	2-methylacetonitrile
1-naphthyl-2-thiourea	1,1,2,2-tetrachloroethane	Dibenz[a,h]anthracene	Methyl methacrylate
N-phenylthiourea	Bromoform	7H-dibenzof[c,g]carbazole	Methyl methanesulfonate
DDD	Trichloromethanethiol	Dibenzo[a,c]pyrene	2-methyl-2-(methylthio) propionaldehyde
DDE	Trichloromonofluoromethane	Dibenzo[a,h]pyrene	Methylthiouracil
DDT	Trichloropropane	Dibenzo[a,i]pyrene	1,4-naphthoquinone
Heptachlor	1,2,3-trichloropropane	Di-n-butyl phthalate	1-naphthylamine
Heptachlor epoxide	Vinyl chloride	3,3'-dichlorobenzidine	2-naphthylamine
Dieldrin	Diethylarsine	2,4-dichlorophenol	P-nitroaniline
Aldrin	Acetonitrile	2,5-dichlorophenol	Nitrobenzine
Chlordane	Acetophenone	Diethyl phthalate	4-nitrophenol
Endosulfan I	Warfarin	Dihydroxofrole	N-nitrosodi-n-butylamine
Acrolein	2-acetylaminofluorene	3,3'-dimethoxybenzidine	N-nitrosodiethanolamine
Acrylonitrile	4-aminobiphenyl	P-dimethylaminoazobenzene	N-nitrosodimethylamine
Bis(chloromethyl) ether	5-(aminomethyl)-3-isoxazolol	7,12-dimethylbenz[a]anthracene	N-nitrosodimethylamine
Bromoacetone	Anitrole	3,3'-dimethylbenzidine	N-nitrosomethyl ethylamine
Methyl bromide	Aniline	Thiofanox	N-nitroso-N-methylurethane
Carbon disulfide	Aramite	Alpha,alpha-dimethylphenethylamine	N-nitrosomethylvinylamine
Chlorobenzene	Auramine	2,4-dimethylphenol	N-nitrosomorpholine
2-chloroethyl vinyl ether	Benz[c]acridine	Dimethyl phthalate	N-nitrosonorcotine
Chloroform	Benz[e]anthracene	Dinitrobenzene	N-nitrosopiperidine
Methyl chloride	Benzene dichloromethyl	4,6-dinitro-o-cresol and salts	Nitrosopyrrolidine
Chloromethyl methyl ether	Benzenethiol	2,4-dinitrophenol	5-nitro-o-toluidine
Crotonaldehyde	Benzidine	2,4-dinitrotoluene	Ethyl methacrylate
1,2-dibromo-3-chloropropane	Benzo[b]fluoranthene	Di-n-octyl phthalate	Fluoroacetic acid
1,2-dibromethane	Benzo[j]fluoranthene	Diphenylamine	Glycidylaldehyde
Dibromethane	P benzoquinone	1,2-diphenylhydrazine	Isobutyl alcohol
1,4-dichloro-2-butene	Benzyl chloride	Di-n-propylnitrosamine	Methyl hydrazine
Dichlorodifluoromethane	Bis(2-chloroethoxy) methane	Ethylamine	N-propylamine
1,1-dichloroethane	Bis(2-chloroethyl) ether	Ethyl methanesulfonate	2-propyl-1-ol
1,2-dichloroethane	Bis(2-ethylhexyl) phthalate	Fluoranthene	2,4,5-T
Trans-1,2-dichloroethene	4-bromophenyl phenyl ether	Hexachlorobutadiene	
1,1-dichloroethylene	Butyl benzyl phthalate	Hexachlorocyclopentadiene	
Methylene chloride	2-sec-butyl-4,6-dinitrophenol	Hexachloroethane	
1,2-dichloropropane	Chloroalkyl ethers	Indeno(1,2,3-cd)pyrene	
1,3-dichloropropane	P-chloroaniline	Isosafrole	
N,N-dimethylhydrazine	P-chloro-m-cresol	Malononitrile	
1,1-dimethylhydrazine	1-chloro-2,3-epoxypropane	Melphalan	
1,2-dimethylhydrazine	2-chloronaphthalene		
			0,0,0-triethyl phosphorothioate
			Sym-trinitrobenzene
			Tris(2,3-dibromopropyl) phosphate
			Benzo[a]pyrene
			Chloromaphazine
			Bis(2-chloroisopropyl) ether
			Hydrazine
			Tetraethylpyrophosphate
			2-methyl-2-(methylthio) propionaldehyde
			Carbophenothion
			Disulfoton
			Dimethoate
			Methyl parathion
			Parathion
			Cyanide
			Citrus red
			Cyanogen bromide
			Cyanogen chloride
			Paraldehyde
			Acrylamide
			Allyl alcohol
			Chloral
			Chloroacetaldehyde
			3-chloropropionitrile
			Cyanogen
			Dichloropropanol
			Ethyl carbamate
			Ethyl cyanide
			Ethylene oxide
			Ethyl methacrylate
			Fluoroacetic acid
			Glycidylaldehyde
			Isobutyl alcohol
			Methyl hydrazine
			N-propylamine
			2-propyl-1-ol
			2,4,5-T

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 (\pm) value, which is the uncertainty term known as a two-sigma counting error. Because measuring a radionuclide requires a process of counting random radioactive emissions from a sample, the two-sigma counting error gives information on what the measurement might be if the same sample were counted again under identical conditions. The two-sigma counting error implies that approximately 95% of the time, a recount of the same sample would give a value somewhere between the reported value minus the two-sigma counting error and the reported value plus the two-sigma counting error. Values in the tables that are less than the two-sigma counting error indicate that the reported result might have come from a sample with no radioactivity. Also note that each radioactive measurement must have the random background radioactivity of the measuring instrument subtracted; therefore, negative results are possible, especially when the sample has very little radioactivity.

Just as individual values are accompanied by two-sigma counting errors, reported means (\bar{x}) are accompanied by two standard errors (SE) of the mean. If the data fluctuate randomly, then the SE is a measure of the uncertainty in the estimated mean of the data due to this randomness. If trends or periodic (e.g., seasonal) fluctuations are present, then the SE is primarily a measure of the variability in the trends and fluctuations about the mean of the data, rather than a measure of the uncertainty of the estimated mean due to random fluctuations in the data.

The mean, \bar{x} , was computed as:

$$\bar{x} = \frac{1}{n} \sum_{i=1}^n x_i$$

where n is the number of measurements and x_i is the i th measurement, where $i=1, 2, \dots, n$.

The standard error of the mean was computed as

$$SE = \sqrt{\frac{S^2}{n}}$$

where S^2 is the variance of the n measurements, a measure of variability. S^2 was computed as the sum of the measurement variance (S_M^2) and the average counting variance (S_C^2), i.e.,

$$S^2 = S_M^2 + S_C^2$$

If $n \geq 10$, then S_M^2 was computed as

$$S_M^2 = \frac{1}{n-1} \sum_{i=1}^n (x_i - \bar{x})^2$$

If $n < 10$, then $S_M^2 = f^2 R^2$, where f is a factor [from Table A.6 in Snedecor and Cochran (1980)] that depends on the value of n , and R is the range of the n measurements (largest minus smallest measurement).

The average counting variance, S_C^2 , was computed as

$$S_C^2 = \frac{1}{m} \sum_{i=1}^m s_i^2$$

where m is the number of the n measurements for which a counting variance was reported ($m \leq n$), and s_i^2 is the counting variance for the i th measurement.

APPENDIX F

DOSE CALCULATIONS

The radiation dose to the public during 1986 from Hanford operations is assessed in terms of the "dose equivalent" and "effective dose equivalent." These dose quantities are given in units of millirems (mrem) for individuals and in units of man-rems for the collective dose to the total population within an 80-km radius of the Site. These quantities provide a way to express the radiation dose, regardless of the type or source of radiation or the means by which it is delivered. The values given in this report may be compared to standards for radiation protection (Appendix C) established by DOE. This appendix describes how the doses were calculated for this report.

The transport of radionuclides from the environment to the body is simulated by empirical exposure pathway models. These pathways account for inhalation or ingestion of radionuclides present in air, water, and foods. Radionuclides taken into the body may be distributed among different organs and retained for various time periods. In addition, long-lived radionuclides deposited on the ground become possible sources for long-term external exposure and uptake by agricultural products.

Where possible, the dose values calculated for this report were based on measured radionuclide concentrations in environmental samples. Dietary factors and exposure parameters were applied to convert the environmental concentrations to exposure in terms of cumulative dose. Ideally, such calculations would be based on a precise understanding of the amount of radionuclides taken into the body. However, radionuclide release rates from Hanford Site activities are usually too low to be measured in offsite air, drinking water, and food crops. Therefore, in most cases, the dose calculations were based on measurements made at the point of release (stacks and effluent streams). Environmental concentrations were estimated from these effluent measurements by mathematical models and computer simulations. Dietary and exposure parameters were then applied to calculate radionuclide intakes and radiation doses to man (see Figure 2.4). A set of standardized computer programs were used to perform the calculations

(Houston, Strenge and Watson 1974; Napier, Kennedy and Soldat 1980; Strenge and Watson 1973). These programs contain internally consistent mathematical models that use site-specific dispersion and uptake parameters. The assumptions and input data used in these calculations are described below.

TYPES OF DOSE CALCULATIONS PERFORMED

Radiation dose calculations for radionuclides released into the environment are performed to determine that the health and safety of the public is not being compromised and to determine compliance with applicable standards and regulations.

Revised DOE Guidance For Dose Calculations

Beginning in 1985, the Department of Energy required that estimates of radiation exposure to the general public be in terms of the "effective dose equivalent." The effective dose equivalent is a measure of the total risk of potential health effects from radiation exposure. The adoption and use of the effective dose equivalent was previously recommended by the ICRP (1979-1982).

Estimated radiological impacts from DOE operations have previously been reported in terms of the cumulative dose (or simply, radiation dose), which is a measure of the energy (rads) absorbed by tissue, multiplied by a 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 rems. The committed dose is still used for controlling the exposure to individual organs and the whole body, and for comparing the organ doses resulting from variable exposure conditions.

The new effective dose is the sum of individual 50-year committed organ doses multiplied by weighting factors that represent the proportion of the total health-effect risk that each organ would receive from uniform irradiation of the whole body. The organ committed dose may

result from irradiation by either internal or external sources, and the two sources are to be summed. The new effective dose is also expressed in rem. The reader should keep in mind that the previously used cumulative dose is a measure of potential radiation risk to individual organs, whereas the new effective dose is a measure of potential radiation risk to the individual as a whole.

In addition to implementing the effective dose requirement for offsite population dose calculations, the DOE has also adopted the revised biokinetic models and metabolic parameters for radionuclides given by the ICRP (1979-1982) for estimating radiation dose.

The calculation of the new effective dose takes into account the long-term internal exposure from radionuclides taken into the body during the current year, but not the potential exposure from future intake of radionuclides remaining in the environment from the current year's release. For these reasons, the older cumulative dose and the newer effective dose are calculated differently, and they cannot be compared directly. In this report, the effective dose equivalent is expressed in rem (or millirem), with the corresponding value in sievert (or millisievert) in parentheses.^(a)

The following types of radiation doses were estimated:

1. **"Fence-Post" Whole-Body Dose Rate (mrem/h and mrem/yr).** The maximum external radiation dose rate during the year in areas accessible by the general public was determined from measurements obtained at locations of potential public access in proximity to operating facilities.
2. **"Maximally Exposed" Individual Dose (mrem).** The maximally exposed individual is a hypothetical member of the public residing near the Hanford Site who, by virtue of his location and living habits, could receive the highest possible radiation dose from radioactive effluents. All potentially significant short- and long-term exposure pathways to this hypothetical individual were considered, including the following:

- inhalation of airborne radionuclides
- submersion in airborne radionuclides
- ingestion of foodstuffs contaminated by radionuclides deposited on vegetation and the ground by both airborne deposition and irrigation water drawn from the Columbia River downstream of the Hanford Site
- drinking sanitary water originating from the Columbia River at Pasco
- exposure to ground contaminated by both airborne deposition and irrigation water
- ingestion of fish taken from the Columbia River
- recreation along the Columbia River, including boating, swimming, and shoreline activities.

3. **80-km Population Doses (man-rem).** Regulatory limits have not been established for population doses. Nonetheless, evaluation of the collective population dose to all residents within an 80-km radius of Hanford Site operations provides an indication of the overall environmental impact of site operations. The 80-km population dose equivalent represents the summed products of the individual doses for the number of individuals involved for all potential exposure pathways.

The pathways depicted in Figure 2.4 for the maximally exposed individual were assumed to also be applicable to the offsite population. Consideration was given, however, to the fraction of the offsite population actually affected by each pathway. The river-related exposure pathways for the population are as follows:

- **Drinking Water.** The cities of Richland and Pasco obtain their municipal water from the Columbia River downstream from the Hanford Site. The city of Kennewick began drawing a portion of its municipal water from the river in late 1980. During 1986, approximately

(a) 1 rem (or 1000 mrem) = 0.01 Sv (or 10 mSv).

40% of Kennewick's drinking water was drawn from the Columbia River. The total affected population of these three cities was approximately 70,000.

- **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 2,000 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 (X/Q , in units of C/m^3 per C/sec , or sec/m^3) that, when combined with annual average release rates, will predict average radionuclide air concentrations for the year. Annual average dispersion factors for the 100, 200, 300, and 400 Areas during 1986 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 the plants and soil during irrigation can be taken into plants through their roots and leaves, and may then be eaten by man or farm animals. The numerous transfer factors required for pathway and dose calculations have been described previously (Houston, Strenge and Watson 1974; Napier, Kennedy and Soldat 1980).

Important parameters affecting the movement of radionuclides within potential exposure pathways, such as irrigation rates, growing period, and holdup period, are listed in Table F.9. Note that certain parameters are specific to either "maximally exposed" or "average" individuals.

Public Exposure

Offsite radiation dose impact is related to the extent of public exposure to or intake of radionuclides associated with Hanford Site operations. Tables F.10 through F.12 give the parameters describing the diet, residency, and river recreation assumed for "maximally exposed" and "average" individuals.

DOSE CALCULATION DOCUMENTATION

The quality of the calculated doses was determined in several ways. First, comparisons were made with doses calculated for previous annual reports, and differences were investigated. Second, the Hanford Dose Overview Committee has defined standard, documented computer codes and input parameters to be used for radiation dose calculations for the public in the vicinity of the Hanford Site. Third, all computed doses were reviewed by the Hanford Dose Overview Committee. Summaries of dose calculation documentation for this report are given in Tables F.13 through F.17.

50-YEAR CUMULATIVE DOSES

An additional quantity called the "cumulative dose" is calculated to account for the dose from continual intake of, and external exposure to residual radionuclides in soil. When calculating the cumulative dose, the long-term residency of the individual or population involved is considered.

For continuity with past practice, cumulative doses were again calculated for 1986. Cumulative doses were calculated for both the hypothetical maximally exposed individual and the 80-km population and compared with such doses estimated during the previous 5 years. The cumulative doses estimated for the maximally exposed individual are listed in Table F.18. These values include the doses received from exposure to liquid and airborne effluents during 1986 as well as potential exposure beyond 1986 to that fraction of the 1986 effluents estimated to be deposited on the ground from airborne deposition and from irrigation with Columbia River water.

All potential maximally exposed individual cumulative doses that were calculated for 1986 were

well below the applicable DOE Radiation Protection Standards. The organ receiving the largest dose was the bone (9 mrem). The calculated whole-body dose in 1986 was 2 mrem, as compared to 3 mrem in 1985. The whole-body and bone doses in 1986 were due almost entirely to the ^{90}Sr effluent released to the Columbia River at the 100N Area. The thyroid dose resulted from the gaseous emission of ^{129}I from the 200 Area.

A comparison of the cumulative doses for the maximally exposed individual from 1986 Hanford operations and estimates for the previous 5 years are shown in Table F.19. The trend of the calculated doses in Table F.19 (and in Table F.20 below) reflect the resumption of operations at the PUREX Plant in the fall of 1983.

The cumulative radiation dose to the population residing within an 80-km radius of any of the onsite operating areas during 1986 was also calculated. The results are shown in Table F.20. A comparison of the 80-km population doses attributed to 1986 Hanford operations and estimated population doses for the previous 5 years are given in Table F.21.

The primary pathways contributing to the 1986 population doses to whole-body and bone were

- air submersion in the short-lived noble gases from the N Reactor
- consumption of food irrigated with water obtained from the Columbia River.

The population dose to the thyroid resulted primarily from the consumption of food containing the long-lived radionuclide ^{129}I released with gaseous effluents at the PUREX plant.

TABLE F.1. Distribution of Population in 80-km Radius of the N Reactor by Population Grid Sector^(a)

Compass Direction	Number of People					Totals
	0-16 km	16-32 km	32-48 km	48-64 km	64-80 km	
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-Area Hanford Meteorological Tower by Population Grid Sector^(a)

Compass Direction	Number of People					Totals
	0-16 km	16-32 km	32-48 km	48-64 km	64-80 km	
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 FFTF by Population Grid Sector^(a)

Compass Direction	Number of People					Totals
	0-16 km	16-32 km	32-48 km	48-64 km	64-80 km	
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.4. Distribution of Population in 80-km Radius of 300 Area by Population Grid Sector^(a)

Compass Direction	Number of People					Totals
	0-16 km	16-32 km	32-48 km	48-64 km	64-80 km	
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.5. Annual Average Atmospheric Dispersion (\bar{X}/Q') Around the 100N Area During 1986 for an 89-Meter Release Height^(a)

Direction	\bar{X}/Q' (sec/m ³)									
	0.8 km	2.4 km	4.0 km	5.6 km	7.2 km	12 km	24 km	40 km	56 km	72 km
N	5.55 x 10 ⁻⁸	4.79 x 10 ⁻⁸	4.10 x 10 ⁻⁸	3.32 x 10 ⁻⁸	2.72 x 10 ⁻⁸	1.69 x 10 ⁻⁸	8.16 x 10 ⁻⁹	4.61 x 10 ⁻⁹	3.13 x 10 ⁻⁹	2.34 x 10 ⁻⁹
NNE	4.41 x 10 ⁻⁸	3.68 x 10 ⁻⁸	2.97 x 10 ⁻⁸	2.33 x 10 ⁻⁸	1.87 x 10 ⁻⁸	1.13 x 10 ⁻⁸	5.30 x 10 ⁻⁹	2.96 x 10 ⁻⁹	2.00 x 10 ⁻⁹	1.49 x 10 ⁻⁹
NE	7.51 x 10 ⁻⁸	4.82 x 10 ⁻⁸	4.07 x 10 ⁻⁸	3.28 x 10 ⁻⁸	2.68 x 10 ⁻⁸	1.66 x 10 ⁻⁸	7.92 x 10 ⁻⁹	4.46 x 10 ⁻⁹	3.03 x 10 ⁻⁹	2.26 x 10 ⁻⁹
ENE	7.92 x 10 ⁻⁸	5.46 x 10 ⁻⁸	4.77 x 10 ⁻⁸	3.94 x 10 ⁻⁸	3.29 x 10 ⁻⁸	2.12 x 10 ⁻⁸	1.07 x 10 ⁻⁸	6.24 x 10 ⁻⁹	4.32 x 10 ⁻⁹	3.27 x 10 ⁻⁹
E	1.73 x 10 ⁻⁷	1.09 x 10 ⁻⁷	9.35 x 10 ⁻⁸	7.67 x 10 ⁻⁸	6.37 x 10 ⁻⁸	4.08 x 10 ⁻⁸	2.06 x 10 ⁻⁸	1.21 x 10 ⁻⁸	8.44 x 10 ⁻⁹	6.42 x 10 ⁻⁹
ESE	1.19 x 10 ⁻⁷	6.83 x 10 ⁻⁸	5.85 x 10 ⁻⁸	4.79 x 10 ⁻⁸	3.96 x 10 ⁻⁸	2.51 x 10 ⁻⁸	1.24 x 10 ⁻⁸	7.13 x 10 ⁻⁹	4.91 x 10 ⁻⁹	3.70 x 10 ⁻⁹
SE	1.12 x 10 ⁻⁷	5.53 x 10 ⁻⁸	4.31 x 10 ⁻⁸	3.41 x 10 ⁻⁸	2.77 x 10 ⁻⁸	1.72 x 10 ⁻⁸	8.35 x 10 ⁻⁹	4.77 x 10 ⁻⁹	3.27 x 10 ⁻⁹	2.46 x 10 ⁻⁹
SSE	1.09 x 10 ⁻⁷	5.79 x 10 ⁻⁸	4.74 x 10 ⁻⁸	3.79 x 10 ⁻⁸	3.10 x 10 ⁻⁸	1.94 x 10 ⁻⁸	9.51 x 10 ⁻⁹	5.47 x 10 ⁻⁹	3.77 x 10 ⁻⁹	2.85 x 10 ⁻⁹
S	1.49 x 10 ⁻⁷	8.33 x 10 ⁻⁸	6.66 x 10 ⁻⁸	5.26 x 10 ⁻⁸	4.26 x 10 ⁻⁸	2.61 x 10 ⁻⁸	1.24 x 10 ⁻⁸	7.01 x 10 ⁻⁹	4.77 x 10 ⁻⁹	3.57 x 10 ⁻⁹
SSW	8.10 x 10 ⁻⁸	5.31 x 10 ⁻⁸	4.51 x 10 ⁻⁸	3.66 x 10 ⁻⁸	3.01 x 10 ⁻⁸	1.88 x 10 ⁻⁸	9.15 x 10 ⁻⁹	5.19 x 10 ⁻⁹	3.54 x 10 ⁻⁹	2.65 x 10 ⁻⁹
SW	8.86 x 10 ⁻⁸	5.31 x 10 ⁻⁸	4.51 x 10 ⁻⁸	3.73 x 10 ⁻⁸	3.10 x 10 ⁻⁸	1.99 x 10 ⁻⁸	1.01 x 10 ⁻⁸	5.89 x 10 ⁻⁹	4.10 x 10 ⁻⁹	3.11 x 10 ⁻⁹
WSW	5.11 x 10 ⁻⁸	6.32 x 10 ⁻⁸	5.42 x 10 ⁻⁸	4.38 x 10 ⁻⁸	3.60 x 10 ⁻⁸	2.26 x 10 ⁻⁸	1.10 x 10 ⁻⁸	6.25 x 10 ⁻⁹	4.27 x 10 ⁻⁹	3.20 x 10 ⁻⁹
W	1.11 x 10 ⁻⁷	1.04 x 10 ⁻⁷	8.87 x 10 ⁻⁸	7.18 x 10 ⁻⁸	5.90 x 10 ⁻⁸	3.71 x 10 ⁻⁸	1.82 x 10 ⁻⁸	1.05 x 10 ⁻⁸	7.22 x 10 ⁻⁹	5.44 x 10 ⁻⁹
WNW	7.69 x 10 ⁻⁸	7.89 x 10 ⁻⁸	6.45 x 10 ⁻⁸	5.06 x 10 ⁻⁸	4.06 x 10 ⁻⁸	2.43 x 10 ⁻⁸	1.12 x 10 ⁻⁸	6.12 x 10 ⁻⁹	4.10 x 10 ⁻⁹	3.03 x 10 ⁻⁹
NW	5.14 x 10 ⁻⁸	6.67 x 10 ⁻⁸	5.57 x 10 ⁻⁸	4.39 x 10 ⁻⁸	3.52 x 10 ⁻⁸	2.11 x 10 ⁻⁸	9.68 x 10 ⁻⁹	5.28 x 10 ⁻⁹	3.52 x 10 ⁻⁹	2.59 x 10 ⁻⁹
NNW	3.07 x 10 ⁻⁸	4.12 x 10 ⁻⁸	3.44 x 10 ⁻⁸	2.69 x 10 ⁻⁸	2.15 x 10 ⁻⁸	1.27 x 10 ⁻⁸	5.78 x 10 ⁻⁹	3.16 x 10 ⁻⁹	2.11 x 10 ⁻⁹	1.56 x 10 ⁻⁹

(a) Calculated from meteorological data collected at the 100N Area and the Hanford Meteorology Tower.

TABLE F.6. Annual Average Atmospheric Dispersion (\bar{X}/Q') Around the 200 Areas During 1986 for an 89-Meter Release Height^(a)

Direction	\bar{X}/Q' (sec/m ³)									
	0.8 km	2.4 km	4.0 km	5.6 km	7.2 km	12 km	24 km	40 km	56 km	72 km
N	6.23 x 10 ⁻⁸	3.51 x 10 ⁻⁸	3.13 x 10 ⁻⁸	2.62 x 10 ⁻⁸	2.21 x 10 ⁻⁸	1.45 x 10 ⁻⁸	7.39 x 10 ⁻⁹	4.32 x 10 ⁻⁹	3.00 x 10 ⁻⁹	2.27 x 10 ⁻⁹
NNE	1.62 x 10 ⁻⁸	1.57 x 10 ⁻⁸	1.45 x 10 ⁻⁸	1.21 x 10 ⁻⁸	1.01 x 10 ⁻⁸	6.59 x 10 ⁻⁹	3.35 x 10 ⁻⁹	1.97 x 10 ⁻⁹	1.37 x 10 ⁻⁹	1.04 x 10 ⁻⁹
NE	2.99 x 10 ⁻⁸	2.71 x 10 ⁻⁸	2.54 x 10 ⁻⁸	2.11 x 10 ⁻⁸	1.74 x 10 ⁻⁸	1.08 x 10 ⁻⁸	5.14 x 10 ⁻⁹	2.87 x 10 ⁻⁹	1.94 x 10 ⁻⁹	1.44 x 10 ⁻⁹
ENE	4.22 x 10 ⁻⁸	2.96 x 10 ⁻⁸	2.59 x 10 ⁻⁸	2.16 x 10 ⁻⁸	1.81 x 10 ⁻⁸	1.19 x 10 ⁻⁸	6.07 x 10 ⁻⁹	3.54 x 10 ⁻⁹	2.45 x 10 ⁻⁹	1.85 x 10 ⁻⁹
E	6.67 x 10 ⁻⁸	6.35 x 10 ⁻⁸	6.04 x 10 ⁻⁸	5.13 x 10 ⁻⁸	4.34 x 10 ⁻⁸	2.84 x 10 ⁻⁸	1.45 x 10 ⁻⁸	8.49 x 10 ⁻⁹	5.90 x 10 ⁻⁹	4.48 x 10 ⁻⁹
ESE	7.41 x 10 ⁻⁸	8.02 x 10 ⁻⁸	7.45 x 10 ⁻⁸	6.27 x 10 ⁻⁸	5.28 x 10 ⁻⁸	3.45 x 10 ⁻⁸	1.76 x 10 ⁻⁸	1.03 x 10 ⁻⁸	7.11 x 10 ⁻⁹	5.38 x 10 ⁻⁹
SE	1.19 x 10 ⁻⁷	8.60 x 10 ⁻⁸	7.16 x 10 ⁻⁸	5.75 x 10 ⁻⁸	4.71 x 10 ⁻⁸	2.94 x 10 ⁻⁸	1.43 x 10 ⁻⁸	8.21 x 10 ⁻⁹	5.63 x 10 ⁻⁹	4.24 x 10 ⁻⁹
SSE	9.11 x 10 ⁻⁸	5.94 x 10 ⁻⁸	4.95 x 10 ⁻⁸	3.93 x 10 ⁻⁸	3.18 x 10 ⁻⁸	1.94 x 10 ⁻⁸	9.15 x 10 ⁻⁹	5.14 x 10 ⁻⁹	3.50 x 10 ⁻⁹	2.62 x 10 ⁻⁹
S	1.89 x 10 ⁻⁷	9.53 x 10 ⁻⁸	7.29 x 10 ⁻⁸	5.56 x 10 ⁻⁸	4.37 x 10 ⁻⁸	2.52 x 10 ⁻⁸	1.11 x 10 ⁻⁸	5.88 x 10 ⁻⁹	3.87 x 10 ⁻⁹	2.82 x 10 ⁻⁹
SSW	1.09 x 10 ⁻⁷	6.44 x 10 ⁻⁸	4.80 x 10 ⁻⁸	3.61 x 10 ⁻⁸	2.82 x 10 ⁻⁸	1.61 x 10 ⁻⁸	6.99 x 10 ⁻⁹	3.70 x 10 ⁻⁹	2.42 x 10 ⁻⁹	1.76 x 10 ⁻⁹
SW	9.13 x 10 ⁻⁸	6.17 x 10 ⁻⁸	4.60 x 10 ⁻⁸	3.44 x 10 ⁻⁸	2.68 x 10 ⁻⁸	1.52 x 10 ⁻⁸	6.62 x 10 ⁻⁹	3.50 x 10 ⁻⁹	2.30 x 10 ⁻⁹	1.67 x 10 ⁻⁹
WSW	1.02 x 10 ⁻⁷	5.50 x 10 ⁻⁸	3.96 x 10 ⁻⁸	2.94 x 10 ⁻⁸	2.28 x 10 ⁻⁸	1.30 x 10 ⁻⁸	5.71 x 10 ⁻⁹	3.07 x 10 ⁻⁹	2.04 x 10 ⁻⁹	1.50 x 10 ⁻⁹
W	1.27 x 10 ⁻⁷	7.55 x 10 ⁻⁸	5.77 x 10 ⁻⁸	4.38 x 10 ⁻⁸	3.43 x 10 ⁻⁸	1.98 x 10 ⁻⁸	8.74 x 10 ⁻⁹	4.71 x 10 ⁻⁹	3.12 x 10 ⁻⁹	2.29 x 10 ⁻⁹
WNW	1.13 x 10 ⁻⁷	5.52 x 10 ⁻⁸	4.08 x 10 ⁻⁸	3.11 x 10 ⁻⁸	2.47 x 10 ⁻⁸	1.46 x 10 ⁻⁸	6.76 x 10 ⁻⁹	3.75 x 10 ⁻⁹	2.54 x 10 ⁻⁹	1.89 x 10 ⁻⁹
NW	7.88 x 10 ⁻⁸	5.39 x 10 ⁻⁸	4.18 x 10 ⁻⁸	3.25 x 10 ⁻⁸	2.61 x 10 ⁻⁸	1.60 x 10 ⁻⁸	7.70 x 10 ⁻⁹	4.41 x 10 ⁻⁹	3.04 x 10 ⁻⁹	2.29 x 10 ⁻⁹
NNW	4.29 x 10 ⁻⁸	4.19 x 10 ⁻⁸	3.61 x 10 ⁻⁸	2.91 x 10 ⁻⁸	2.38 x 10 ⁻⁸	1.48 x 10 ⁻⁸	7.19 x 10 ⁻⁹	4.10 x 10 ⁻⁹	2.81 x 10 ⁻⁹	2.12 x 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 1986 for a 10-Meter Release Height^(a)

Direction	\bar{X}/Q' (sec/m ³)									
	0.8 km	2.4 km	4.0 km	5.6 km	7.2 km	12 km	24 km	40 km	56 km	72 km
N	5.36 x 10 ⁻⁶	1.07 x 10 ⁻⁶	5.05 x 10 ⁻⁷	3.11 x 10 ⁻⁷	2.17 x 10 ⁻⁷	1.06 x 10 ⁻⁷	4.08 x 10 ⁻⁸	2.05 x 10 ⁻⁸	1.30 x 10 ⁻⁸	9.34 x 10 ⁻⁹
NNE	3.49 x 10 ⁻⁶	6.78 x 10 ⁻⁷	3.18 x 10 ⁻⁷	1.95 x 10 ⁻⁷	1.36 x 10 ⁻⁷	6.59 x 10 ⁻⁸	2.52 x 10 ⁻⁸	1.26 x 10 ⁻⁸	7.98 x 10 ⁻⁹	5.70 x 10 ⁻⁹
NE	3.50 x 10 ⁻⁶	6.84 x 10 ⁻⁷	3.21 x 10 ⁻⁷	1.97 x 10 ⁻⁷	1.37 x 10 ⁻⁷	6.68 x 10 ⁻⁸	2.56 x 10 ⁻⁸	1.28 x 10 ⁻⁸	8.13 x 10 ⁻⁹	5.81 x 10 ⁻⁹
ENE	2.69 x 10 ⁻⁶	5.13 x 10 ⁻⁷	2.39 x 10 ⁻⁷	1.46 x 10 ⁻⁷	1.02 x 10 ⁻⁷	4.91 x 10 ⁻⁸	1.87 x 10 ⁻⁸	9.26 x 10 ⁻⁹	5.87 x 10 ⁻⁹	4.19 x 10 ⁻⁹
E	2.93 x 10 ⁻⁶	5.75 x 10 ⁻⁷	2.70 x 10 ⁻⁷	1.65 x 10 ⁻⁷	1.15 x 10 ⁻⁷	5.58 x 10 ⁻⁸	2.13 x 10 ⁻⁸	1.06 x 10 ⁻⁸	6.72 x 10 ⁻⁹	4.79 x 10 ⁻⁹
ESE	2.26 x 10 ⁻⁶	4.53 x 10 ⁻⁷	2.14 x 10 ⁻⁷	1.31 x 10 ⁻⁷	9.18 x 10 ⁻⁸	4.47 x 10 ⁻⁸	1.72 x 10 ⁻⁸	8.60 x 10 ⁻⁹	5.47 x 10 ⁻⁹	3.92 x 10 ⁻⁹
SE	2.57 x 10 ⁻⁶	5.28 x 10 ⁻⁷	2.50 x 10 ⁻⁷	1.54 x 10 ⁻⁷	1.08 x 10 ⁻⁷	5.26 x 10 ⁻⁸	2.03 x 10 ⁻⁸	1.01 x 10 ⁻⁸	6.47 x 10 ⁻⁹	4.63 x 10 ⁻⁹
SSE	4.11 x 10 ⁻⁶	7.85 x 10 ⁻⁷	3.66 x 10 ⁻⁷	2.23 x 10 ⁻⁷	1.55 x 10 ⁻⁷	7.47 x 10 ⁻⁸	2.83 x 10 ⁻⁸	1.40 x 10 ⁻⁸	8.86 x 10 ⁻⁹	6.31 x 10 ⁻⁹
S	5.58 x 10 ⁻⁶	1.08 x 10 ⁻⁶	5.08 x 10 ⁻⁷	3.11 x 10 ⁻⁷	2.16 x 10 ⁻⁷	1.05 x 10 ⁻⁷	4.00 x 10 ⁻⁸	1.99 x 10 ⁻⁸	1.26 x 10 ⁻⁸	9.02 x 10 ⁻⁹
SSW	1.80 x 10 ⁻⁶	3.23 x 10 ⁻⁷	1.52 x 10 ⁻⁷	9.34 x 10 ⁻⁸	6.52 x 10 ⁻⁸	3.17 x 10 ⁻⁸	1.22 x 10 ⁻⁸	6.08 x 10 ⁻⁹	3.87 x 10 ⁻⁹	2.77 x 10 ⁻⁹
SW	7.28 x 10 ⁻⁷	1.32 x 10 ⁻⁷	6.11 x 10 ⁻⁸	3.71 x 10 ⁻⁸	2.57 x 10 ⁻⁸	1.23 x 10 ⁻⁸	4.64 x 10 ⁻⁹	2.29 x 10 ⁻⁹	1.45 x 10 ⁻⁹	1.03 x 10 ⁻⁹
WSW	5.86 x 10 ⁻⁷	1.06 x 10 ⁻⁷	4.85 x 10 ⁻⁸	2.93 x 10 ⁻⁸	2.03 x 10 ⁻⁸	9.66 x 10 ⁻⁹	3.61 x 10 ⁻⁹	1.78 x 10 ⁻⁹	1.12 x 10 ⁻⁹	8.00 x 10 ⁻¹⁰
W	1.60 x 10 ⁻⁶	2.97 x 10 ⁻⁷	1.38 x 10 ⁻⁷	8.45 x 10 ⁻⁸	5.88 x 10 ⁻⁸	2.84 x 10 ⁻⁸	1.08 x 10 ⁻⁸	5.40 x 10 ⁻⁹	3.43 x 10 ⁻⁹	2.46 x 10 ⁻⁹
WNW	3.41 x 10 ⁻⁶	6.75 x 10 ⁻⁷	3.17 x 10 ⁻⁷	1.95 x 10 ⁻⁷	1.36 x 10 ⁻⁷	6.59 x 10 ⁻⁸	2.52 x 10 ⁻⁸	1.26 x 10 ⁻⁸	7.99 x 10 ⁻⁹	5.71 x 10 ⁻⁹
NW	5.05 x 10 ⁻⁶	1.03 x 10 ⁻⁶	4.88 x 10 ⁻⁷	3.01 x 10 ⁻⁷	2.11 x 10 ⁻⁷	1.03 x 10 ⁻⁷	3.97 x 10 ⁻⁸	2.00 x 10 ⁻⁸	1.27 x 10 ⁻⁸	9.14 x 10 ⁻⁹
NNW	3.59 x 10 ⁻⁶	7.22 x 10 ⁻⁷	3.41 x 10 ⁻⁷	2.10 x 10 ⁻⁷	1.47 x 10 ⁻⁷	7.15 x 10 ⁻⁸	2.75 x 10 ⁻⁸	1.38 x 10 ⁻⁸	8.78 x 10 ⁻⁹	6.29 x 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 1986 for a 10-Meter Release Height^(a)

Direction	\bar{X}/Q' (sec/m ³)									
	0.8 km	2.4 km	4.0 km	5.6 km	7.2 km	12 km	24 km	40 km	56 km	72 km
N	5.88 x 10 ⁻⁶	1.15 x 10 ⁻⁶	5.40 x 10 ⁻⁷	3.32 x 10 ⁻⁷	2.31 x 10 ⁻⁷	1.12 x 10 ⁻⁷	4.30 x 10 ⁻⁸	2.15 x 10 ⁻⁸	1.36 x 10 ⁻⁸	9.75 x 10 ⁻⁹
NNE	4.06 x 10 ⁻⁶	7.91 x 10 ⁻⁷	3.71 x 10 ⁻⁷	2.28 x 10 ⁻⁷	1.59 x 10 ⁻⁷	7.70 x 10 ⁻⁸	2.94 x 10 ⁻⁸	1.47 x 10 ⁻⁸	9.34 x 10 ⁻⁹	6.67 x 10 ⁻⁹
NE	2.46 x 10 ⁻⁶	4.78 x 10 ⁻⁷	2.24 x 10 ⁻⁷	1.37 x 10 ⁻⁷	9.56 x 10 ⁻⁸	4.63 x 10 ⁻⁸	1.77 x 10 ⁻⁸	8.82 x 10 ⁻⁹	5.60 x 10 ⁻⁹	4.00 x 10 ⁻⁹
ENE	1.53 x 10 ⁻⁶	2.91 x 10 ⁻⁷	1.36 x 10 ⁻⁷	8.33 x 10 ⁻⁸	5.80 x 10 ⁻⁸	2.81 x 10 ⁻⁸	1.07 x 10 ⁻⁸	5.34 x 10 ⁻⁹	3.40 x 10 ⁻⁹	2.43 x 10 ⁻⁹
E	2.44 x 10 ⁻⁶	4.69 x 10 ⁻⁷	2.19 x 10 ⁻⁷	1.35 x 10 ⁻⁷	9.37 x 10 ⁻⁸	4.55 x 10 ⁻⁸	1.74 x 10 ⁻⁸	8.68 x 10 ⁻⁹	5.52 x 10 ⁻⁹	3.95 x 10 ⁻⁹
ESE	2.56 x 10 ⁻⁶	4.90 x 10 ⁻⁷	2.29 x 10 ⁻⁷	1.40 x 10 ⁻⁷	9.76 x 10 ⁻⁸	4.72 x 10 ⁻⁸	1.79 x 10 ⁻⁸	8.92 x 10 ⁻⁹	5.65 x 10 ⁻⁹	4.03 x 10 ⁻⁹
SE	4.03 x 10 ⁻⁶	8.09 x 10 ⁻⁷	3.82 x 10 ⁻⁷	2.35 x 10 ⁻⁷	1.64 x 10 ⁻⁷	7.96 x 10 ⁻⁸	3.05 x 10 ⁻⁸	1.53 x 10 ⁻⁸	9.70 x 10 ⁻⁹	6.94 x 10 ⁻⁹
SSE	3.01 x 10 ⁻⁶	6.01 x 10 ⁻⁷	2.83 x 10 ⁻⁷	1.74 x 10 ⁻⁷	1.21 x 10 ⁻⁷	5.90 x 10 ⁻⁸	2.26 x 10 ⁻⁸	1.13 x 10 ⁻⁸	7.20 x 10 ⁻⁹	5.15 x 10 ⁻⁹
S	3.74 x 10 ⁻⁶	7.53 x 10 ⁻⁷	3.55 x 10 ⁻⁷	2.19 x 10 ⁻⁷	1.53 x 10 ⁻⁷	7.44 x 10 ⁻⁸	2.86 x 10 ⁻⁸	1.43 x 10 ⁻⁸	9.12 x 10 ⁻⁹	6.53 x 10 ⁻⁹
SSW	2.09 x 10 ⁻⁶	4.10 x 10 ⁻⁷	1.93 x 10 ⁻⁷	1.18 x 10 ⁻⁷	8.27 x 10 ⁻⁸	4.02 x 10 ⁻⁸	1.54 x 10 ⁻⁸	7.73 x 10 ⁻⁹	4.93 x 10 ⁻⁹	3.53 x 10 ⁻⁹
SW	1.46 x 10 ⁻⁶	2.77 x 10 ⁻⁷	1.29 x 10 ⁻⁷	7.87 x 10 ⁻⁸	5.47 x 10 ⁻⁸	2.63 x 10 ⁻⁸	1.00 x 10 ⁻⁸	4.96 x 10 ⁻⁹	3.15 x 10 ⁻⁹	2.24 x 10 ⁻⁹
WSW	1.10 x 10 ⁻⁶	2.08 x 10 ⁻⁷	9.65 x 10 ⁻⁸	5.89 x 10 ⁻⁸	4.09 x 10 ⁻⁸	1.97 x 10 ⁻⁸	7.50 x 10 ⁻⁹	3.73 x 10 ⁻⁹	2.37 x 10 ⁻⁹	1.69 x 10 ⁻⁹
W	1.62 x 10 ⁻⁶	2.98 x 10 ⁻⁷	1.38 x 10 ⁻⁷	8.37 x 10 ⁻⁸	5.80 x 10 ⁻⁸	2.78 x 10 ⁻⁸	1.05 x 10 ⁻⁸	5.21 x 10 ⁻⁹	3.30 x 10 ⁻⁹	2.36 x 10 ⁻⁹
WNW	1.86 x 10 ⁻⁶	3.60 x 10 ⁻⁷	1.68 x 10 ⁻⁷	1.03 x 10 ⁻⁷	7.15 x 10 ⁻⁸	3.45 x 10 ⁻⁸	1.31 x 10 ⁻⁸	6.49 x 10 ⁻⁹	4.11 x 10 ⁻⁹	2.93 x 10 ⁻⁹
NW	2.25 x 10 ⁻⁶	4.12 x 10 ⁻⁷	1.90 x 10 ⁻⁷	1.15 x 10 ⁻⁷	7.99 x 10 ⁻⁸	3.82 x 10 ⁻⁸	1.43 x 10 ⁻⁸	7.07 x 10 ⁻⁹	4.46 x 10 ⁻⁹	3.17 x 10 ⁻⁹
NNW	3.31 x 10 ⁻⁶	6.58 x 10 ⁻⁷	3.10 x 10 ⁻⁷	1.90 x 10 ⁻⁷	1.33 x 10 ⁻⁷	6.43 x 10 ⁻⁸	2.46 x 10 ⁻⁸	1.23 x 10 ⁻⁸	7.81 x 10 ⁻⁹	5.58 x 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 1986 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 aboveground vegetables	1	14	60	0.7	160
Potatoes	10	14	90	4	180
Other root vegetables	1	14	90	5	150
Berries	1	14	60	2.7	150
Melons	1	14	90	0.8	150
Orchard fruit	10	14	90	1.7	150
Wheat	10	14	90	0.72	0
Other grains	1	14	90	1.4	150
Eggs	1	18	90	0.84	150
Milk	1	4	30	1.3	200
Beef	15	34	90	0.84	140
Pork	15	34	90	0.84	140
Poultry	1	34	90	0.84	140
Fish	24 h	24 h	--	--	--
Drinking water	24 h	24 h	--	--	--

(a) Holdup is the time between harvest and consumption.

TABLE F.10. Dietary Parameters Used in 1986 Dose Calculations

	Consumption, kg/yr	
	Maximally Exposed Individual	Average Individual
Leafy vegetables	30	15
Other aboveground vegetables	30	15
Potatoes	110	100
Other root vegetables	72	17
Berries	30	6
Melons	40	8
Orchard fruit	265	50
Wheat	80	72
Other grains	8.3	7.5
Eggs	30	20
Milk ^(a)	274	230
Beef	40	40
Pork	40	30
Poultry	18	8.5
Fish	40	-- ^(b)
Drinking water ^(a,c)	730	438

(a) Units L/yr.

(b) Average individual consumption not identified; radiation doses were calculated based on estimated total annual catch of 15,000 kg.

(c) 330 L/yr for infant.

TABLE F.11. Residency Parameters Used in the 1986 Dose Calculations

Parameter	Exposure, h/yr	
	Maximally Exposed Individual	Average Individual
Ground contamination	4383	2920
Air submersion	8766	8766
Inhalation ^(a)	8766	8766

(a) Inhalation rates: Adult 270 cm³/sec routine
 Infant 44 cm³/sec.

TABLE F.12. Recreational Parameters Used in the 1986 Dose Calculations

Parameter	Exposure, h/yr ^(a)	
	Maximally Exposed Individual	Average Individual
Shoreline	500	17
Boating	100	5
Swimming	100	10

(a) Assumes 8-h holdup for maximally exposed individual and 13-h holdup for average.

TABLE F.13. Documentation of 100-Area Airborne Release Dose Calculation for 1986

Facility name:	100 Area.
Releases:	See Table G.1
Meteorological conditions:	1986 annual average, calculated from data collected at the 100N Area and the Hanford Meteorology Station from January 1986 through December 1986, using the computer code HANCHI. (See Table F.5).
\bar{X}/Q' :	Maximally exposed individual, 4.1×10^{-9} sec/m ³ at 53 km SSE, 80-km population 1.5×10^{-3} person-sec/m ³ .
Release height:	89-m effective stack height.
Population distribution:	340,000 (see Table F.1).
Computer code:	DACRIN, Rev. 1.2, 1980.
Calculated dose:	Chronic inhalation, maximally exposed individual and 80-km population, 50-yr committed dose.
Files addressed:	Organ Data Library, Rev. 8-1-84. Radionuclide Library, Rev. 3-19-84.
Computer code:	PABLM, Rev. 2.2, 10-1-80.
Calculated dose:	Chronic ingestion and ground contamination exposure, maximally exposed individual and 80-km population, 50-yr cumulative dose equivalent.
Files addressed:	Radionuclide Library, Rev. 3-19-85. Food Transfer Library, Rev. 11-11-83. Organ Data Library, Rev. 8-1-84. Ground Dose Factor Library, Rev. 3-15-78.
Computer code:	KRONIC, Rev. 3-11-83.
Calculated dose:	Chronic air submersion, maximally exposed individual and 80-km population, first-year dose.
Files addressed:	OLD RND BET, OLD GISLIB.
Computer code:	PABKID, Rev. 1.0, 3-10-86.
Calculated dose:	Chronic inhalation, ingestion, and ground contamination exposure, maximally exposed individual and 80-km population, effective dose equivalent (ICRP-30 methods).
Files addressed:	Radionuclide Library, 3-19-85. Food Transfer Library, 9-24-85. ICRP-26/30 Dose Factor Library, 3-14-86. Ground Dose Factor Library, Rev. 3-15-78.

TABLE F.14. Documentation of 100-Area Liquid Release Dose Calculation for 1986

Facility name:	100 Area
Releases:	See Table G.6
Mean river flow:	108,000 ft ³ /sec.
Mixing ratio:	1
Reconcentration formula:	3
Shore-width factor:	0.2
Population:	70,000 for drinking water pathway, 125,000 for fish consumption and direct exposure, 2,000 for consumption of irrigated foodstuffs.
Computer code:	PABLM, Rev. 2.2, 10-1-80.
Calculated dose:	Chronic ingestion, direct exposure to water and shoreline, maximally exposed individual and 80-km population, and ground contamination, 50-yr cumulative dose equivalent.
Files addressed:	Radionuclide Library, Rev. 3-19-85. Organ Data Library, Rev. 8-1-84. Hanford-Specific Bioaccumulation Factor Library. Ground Dose Factor Library, Rev. 3-15-78. Food Transfer Library, Rev. 9-24-85.
Computer code:	PABLM, Rev. 2.2, 10-1-80.
Calculated dose:	Chronic ingestion and ground contamination, maximally exposed individual and 80-km population, 50-yr cumulative dose.
Computer code:	PABKID, Rev. 1.0, 3-10-86.
Calculated dose:	Chronic inhalation, ingestion, and ground contamination exposure, maximally exposed individual and 80-km population, effective dose equivalent (ICRP-30 methods).
Files addressed:	Radionuclide Library, 3-19-85. Food Transfer Library, 9-24-85. ICRP-26/30 Dose Factor Library, 3-14-86. Ground Dose Factor Library, Rev. 3-15-78. Hanford-Specific Bioaccumulation Factor Library.

TABLE F.15. Documentation of 200-Area Airborne Release Dose Calculation for 1986

Facility name:	200 Area.
Releases:	See Table G.1
Meteorological conditions:	1986 annual average, calculated from data collected at the 100N Area and the Hanford Meteorology Station from January 1986 through December 1986, using the computer code HANCHI. (See Table F.6).
\bar{X}/Q' :	Maximally exposed individual, 7.7×10^{-9} sec/m ³ at 43 km SE, 80-km population 1.5×10^{-3} person-sec/m ³ .
Release height:	82.3 m effective (61 m actual) stack height.
Population distribution:	341,000 (see Table F.2).
Computer code:	DACRIN, Rev. 1.2, 1980.
Calculated dose:	Chronic inhalation, maximally exposed individual and 80-km population, 50-yr committed dose.
Files addressed:	Organ Data Library, Rev. 8-1-84. Radionuclide Library, Rev. 3-19-85.
Computer code:	PABLM, Rev. 2.2, 10-1-80.
Calculated dose:	Chronic ingestion and ground contamination exposure, maximally exposed individual and 80-km population, 50-yr cumulative dose equivalent.
Files addressed:	Radionuclide Library, Rev. 3-19-85. Food Transfer Library, Rev. 9-24-85. Organ Data Library, Rev. 8-1-84. Ground Dose Factor Library, Rev. 3-15-78.
Computer code:	KRONIC, Rev. 3-11-83.
Calculated dose:	Chronic air submersion, maximally exposed individual and 80-km population, first-year dose.
Files addressed:	OLD RNOBET, OLD GISLIB.
Computer code:	PABKID, Rev. 1.0, 3-10-86.
Calculated dose:	Chronic inhalation, ingestion, and ground contamination exposure, maximally exposed individual and 80-km population, effective dose equivalent (ICRP-30 methods).
Files addressed:	Radionuclide Library, 3-19-85. Food Transfer Library, 9-24-85. ICRP-26/30 Dose Factor Library, 3-14-86. Ground Dose Factor Library, Rev. 3-15-78.

TABLE F.16. Documentation of 300-Area Airborne Release Dose Calculation for 1986

Facility name:	300 Area.
Releases:	See Table G.1
Meteorological conditions:	1986 annual average, calculated from data collected at the 300 Area and the Hanford Meteorology Station from January 1986 through December 1986, using the computer code HANCHI. (See Table F.7).
\bar{X}/Q' :	Maximally exposed individual, 7.1×10^{-8} sec/m ³ at 13 km SSE, 80-km population 7.2×10^{-3} person-sec/m ³ .
Release height:	Ground level.
Population distribution:	265,000 (see Table F.4).
Computer code:	DACRIN, Rev. 1.2, 1980.
Calculated dose:	Chronic inhalation, maximally exposed individual and 80-km population, 50-yr committed dose.
Files addressed:	Organ Data Library, Rev. 8-1-84. Radionuclide Library, Rev. 3-19-85.
Computer code:	PABLM, Rev. 2.2, 10-1-80.
Calculated dose:	Chronic ingestion and ground contamination exposure, maximally exposed individual and 80-km population, 50-yr cumulative dose equivalent.
Files addressed:	Radionuclide Library, Rev. 3-19-85. Food Transfer Library, Rev. 9-24-85. Organ Data Library, Rev. 8-1-84. Ground Dose Factor Library, Rev. 3-15-78.
Computer code:	KRONIC, Rev. 3-11-83.
Calculated dose:	Chronic air submersion, maximally exposed individual and 80-km population, first-year dose.
Files addressed:	OLD RNBET, OLD GISLIB.
Computer code:	PABKID, Rev. 1.0, 3-10-86.
Calculated dose:	Chronic inhalation, ingestion, and ground contamination exposure, maximally exposed individual and 80-km population, effective dose equivalent (ICRP-30 methods).
Files addressed:	Radionuclide Library, 3-19-85. Food Transfer Library, 9-24-85. ICRP-26/30 Dose Factor Library, 3-14-86. Ground Dose Factor Library, Rev. 3-15-78.

TABLE F.17. Documentation of 400-Area Airborne Release Dose Calculation for 1986

Facility name:	400 Area.
Releases:	See Table G.1
Meteorological conditions:	1986 annual average, calculated from data collected at the 400 Area and the Hanford Meteorology Station from January 1986 through December 1986, using the computer code HANCHI. (See Table F.8).
\bar{X}/Q' :	Maximally exposed individual, 2.9×10^{-8} sec/m ³ at 22 km SSE, 80-km population 5.7×10^{-3} person-sec/m ³ .
Release height:	Ground level.
Population distribution:	264,000 (see Table F.3).
Computer code:	DACRIN, Rev. 1.2, 1980.
Calculated dose:	Chronic inhalation, maximally exposed individual and 80-km population, 50-yr committed dose.
Files addressed:	Organ Data Library, Rev. 8-1-84. Radionuclide Library, Rev. 3-19-85.
Computer code:	PABLM, Rev. 2.2, 10-1-80.
Calculated dose:	Chronic ingestion and ground contamination exposure, maximally exposed individual and 80-km population, 50-yr cumulative dose equivalent.
Files addressed:	Radionuclide Library, Rev. 3-19-85. Food Transfer Library, Rev. 9-24-85. Organ Data Library, Rev. 8-1-84. Ground Dose Factor Library, Rev. 3-15-78.
Computer code:	KRONIC, Rev. 3-11-83.
Calculated dose:	Chronic air submersion, maximally exposed individual and 80-km population, first-year dose.
Files addressed:	OLD RNOBET, OLD GISLIB.
Computer code:	PABKID, Rev. 1.0, 3-10-86.
Calculated dose:	Chronic inhalation, ingestion, and ground contamination exposure, maximally exposed individual and 80-km population, effective dose equivalent (ICRP-30 methods).
Files addressed:	Radionuclide Library, 3-19-85. Food Transfer Library, 9-24-85. ICRP-26/30 Dose Factor Library, 3-14-86. Ground Dose Factor Library, Rev. 3-15-78.

TABLE F.18. Calculated Cumulative Doses to the Hypothetical Maximally Exposed Individual from 1986 Hanford Operations

Pathway	50-Year Cumulative Doses (m-rem)					
	Whole Body	GI ^(a)	Bone	Lung	Thyroid	
					Adult	Infant
Air - Direct ^(b)	0.01	0.01	0.01	0.02	0.02	0.02
- Foods ^(c)	<0.01	<0.01	<0.01	<0.01	2	2
Water - Foods ^(d)	2	0.2	9	<0.01	<0.01	<0.01
- Drinking Water	0.01	<0.01	0.05	<0.01	<0.01	0.03
- River Recreation ^(e)	0.1	0.04	0.4	<0.01	<0.01	--
Total	2	0.3	9	0.03	2	2

- (a) Gastrointestinal tract (lower large intestine).
 (b) Includes inhalation, air submersion, and direct exposure to ground deposition.
 (c) Includes consumption of all foodstuffs contaminated via dry deposition.
 (d) Includes consumption of all foodstuffs contaminated via irrigation water.
 (e) Includes consumption of fish taken from the Columbia River.

TABLE F.19. Calculated Cumulative Doses to the Hypothetical Maximally Exposed Individual from Hanford Operations, 1981 Through 1986

Organ	50-Year Cumulative Doses (m-rem) ^(a)					
	1981	1982	1983	1984	1985	1986
Whole Body	0.5	0.7	1	2	3	2
GI ^(b)	0.06	0.07	0.2	0.3	0.3	0.3
Bone	2	2	4	8	10	9
Lung	0.01	0.02	0.01	0.02	0.04	0.03
Thyroid	0.2	0.2	0.2	0.8	2	2

- (a) Total dose to each organ from exposure to all available pathways.
 (b) Gastrointestinal tract (lower large intestine).

TABLE F.20. Calculated Cumulative Doses to the 80-km Population from 1986 Hanford Operations

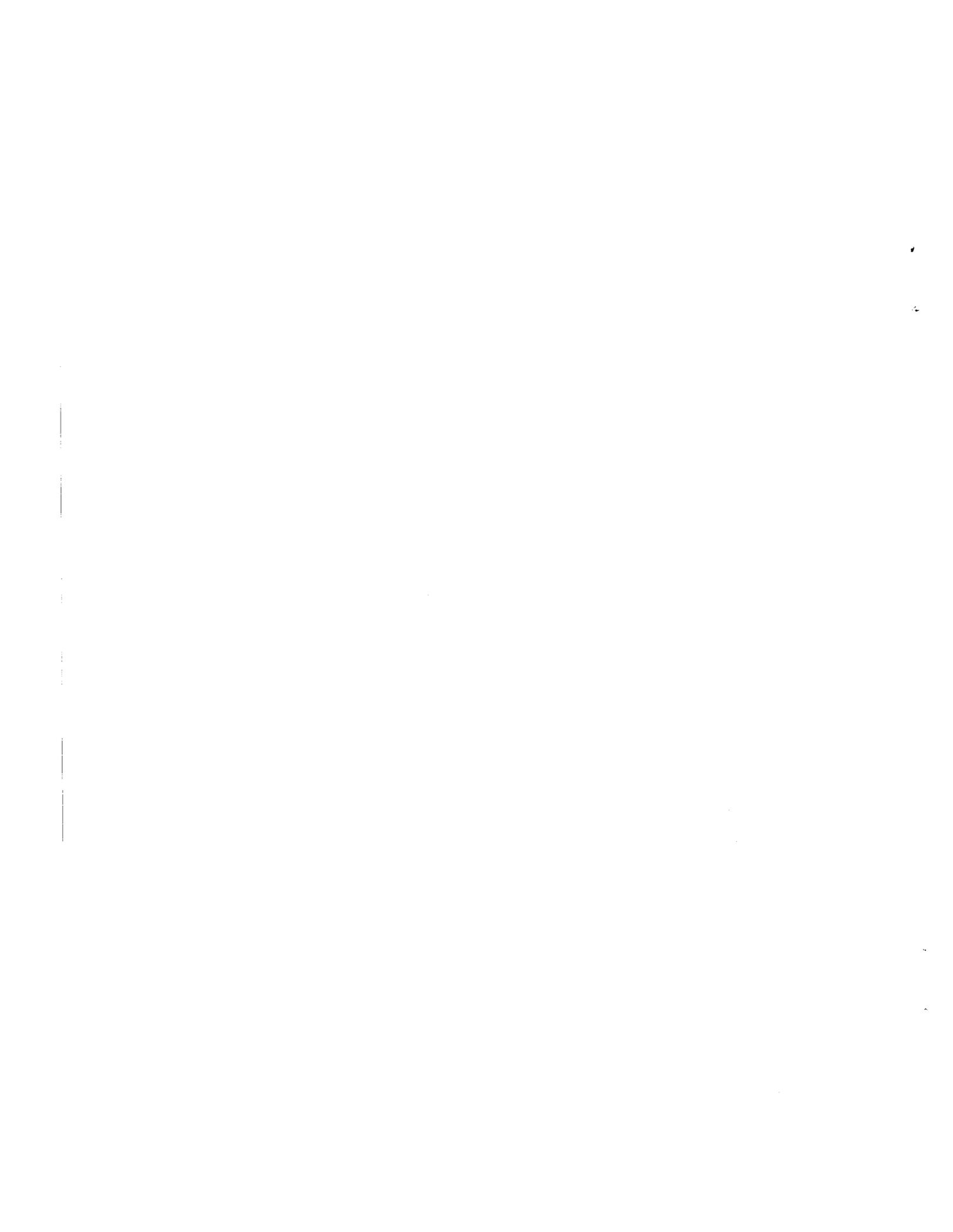
Pathway	50-Year Cumulative Doses (man-rem)				
	Whole Body	GI ^(a)	Bone	Lung	Thyroid
Air - Direct ^(b)	5	4.7	7	6	6
- Foods ^(c)	0.4	0.1	0.3	0.02	240
Water - Foods ^(d)	2	0.2	.7	<0.01	<0.01
- Drinking Water	0.5	0.1	2	<0.01	0.07
- River Recreation ^(e)	<u>0.05</u>	<u>0.2</u>	<u>0.2</u>	<u><0.01</u>	<u><0.01</u>
Total	8	5	17	6	250

- (a) Gastrointestinal tract (lower large intestine).
 (b) Includes inhalation, submersion, and direct exposure to ground deposition.
 (c) Includes consumption of all foodstuffs contaminated via dry deposition.
 (d) Includes consumption of all foodstuffs contaminated via irrigation water.
 (e) Includes consumption of fish taken from the Columbia River.

TABLE F.21. Calculated Cumulative Doses to the 80-km Population from Hanford Operations, 1981 Through 1986

Organ	50-Year Cumulative Doses (man-rem) ^(a)					
	1981	1982	1983	1984	1985	1986
Whole Body	3	4	4	5	7	8
GI ^(b)	3	3	3	3	4	5
Bone	5	7	7	13	19	17
Lung	3	4	3	4	8	6
Thyroid	5	7	17	43	200	250

- (a) Total dose to each organ from exposure to all available pathways.
 (b) Gastrointestinal tract (lower large intestine).



APPENDIX G

EFFLUENTS, WASTE DISPOSAL, AND UNUSUAL OCCURRENCES

The operating contractors at Hanford have the responsibility to control, monitor, sample, and report effluents released into the environment from their facilities. This section briefly summarizes the planned and unplanned releases of effluents that occurred at Hanford during 1986 as reported by the contractors.

EFFLUENTS AND WASTE DISPOSAL

Radioactive and nonradioactive materials were released to the environment during operations at Hanford in 1986. 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 the NPDES.

Airborne Releases

Radioactive and nonradioactive effluents discharged to the atmosphere during 1986 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 UO₃ Plant, and the PUREX Plant.

Liquid Releases

Liquid wastes generated at Hanford were managed in several ways. They were stored, converted to solids, discharged to the ground through cribs, ditches, ponds, or septic systems, or discharged directly into the Columbia River. Radioactive and nonradioactive effluents (except sanitary wastes) discharged to ground disposal facilities during 1986 are summarized in Tables G.3 and G.4.

Radioactive liquids discharged into the Columbia River from operating facilities during 1986 are listed in Table G.5. The reported discharges are from liquid effluent systems in the 100 Area and include seepage into the river from the 1301N/1325N Liquid Waste Disposal Facilities. The ³H and ¹²⁹I that may have entered the Columbia River through springs from the unconfined aquifer are not included in the releases listed in Table G.5. Nonradioactive liquids released to the Columbia River were monitored according to the individual requirements of each NPDES-permitted discharge point.

Solid-Waste Burial

Solid radioactive wastes were buried in trenches or special retrievable storage facilities within the 200 Area. Radioactive materials in solid wastes included fission and activation products, uranium, and transuranics. Solid wastes containing ²³³U 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 1986.

Nonradioactive solid wastes were buried in sanitary landfills near the 200 Area. The quantities of nonradioactive solid wastes buried during 1986 are also included in Table G.6.

ENVIRONMENTALLY RELATED UNUSUAL OCCURRENCES

Unusual occurrences were reported to DOE during 1986 by onsite contractors. Several of these occurrences involved the inadvertent release of radioactive or nonradioactive pollutants to the environment. Generally, the pollutants were dispersed naturally, stabilized in existing waste disposal sites, or controlled and cleaned up with no permanent environmental impact noted. In some cases, particularly where

the contaminants may have reached the ground water, the environmental impact is under continuing observation and evaluation. Summaries, including event descriptions and corrective actions, are available for review in the Public Reading Room at the Hanford Science Center, Richland, Washington. The occurrences with the most potential environmental impacts are summarized below.

**Release of Sodium Hydroxide (NaOH)
From B Plant to Chemical Sewer (UOR
No. RHO-86-20)**

On April 15, 1986, 10,000 L of NaOH solution with a pH greater than 12.5 was discharged to the chemical sewer during regeneration of a demineralizer at B Plant. The quantity released exceeded state standards for pH and a WDOE Hazardous Substance Release Report was filed. An alternative neutralization system has been implemented and has been shown to be an effective means of preventing a recurrence of an environmental release.

**Atmospheric Release of Anhydrous
Ammonia From B Plant (UOR No. RHO-
86-42)**

An atmospheric discharge of greater than 63 kg of anhydrous ammonia occurred on May 26, 1986, through a vessel pressure-relief system in a storage tank. Another leak in the tank liquid level indicator resulted in the release of 1600 kg of anhydrous ammonia to the atmosphere over a 2-month period. The contents of the storage tank were removed and transported back to the vendor. Further use of the tank was suspended until an upgrade of the liquid level indicator and the heating/cooling systems could be completed. WDOE and the EPA were notified of the release.

**163-N Regeneration Waste Spill to
Ground (UOR No. UNI-86-12)**

On June 14, 1986, a leak occurred in the demineralized water-treatment plant (163-N)

waste-transport pipe. Approximately 25,000 of regeneration waste with a pH of 1.4 was released to the ground, exceeding the Washington State reportable quantity for dangerous waste. Appropriate notifications were made to DOE-RL. The spill was neutralized, and the fiberglass piping in the 163-N Plant waste-transport system was replaced.

**163-N Regeneration Waste Spill to
Ground (UOR No. UNI-86-15)**

Nonradioactive regeneration waste from the demineralized treatment plant (163-N) spilled to the ground on June 30, 1986. Approximately 4000 L of waste with pH of 1.1 was spilled. The reportable quantity for a corrosive dangerous waste was exceeded and DOE-RL was notified. The spill was neutralized.

**Discharge of Hydrazine to the PUREX
Chemical Sewer (UOR No. RHO-86-36)**

While hydrazine from a 55-gal drum was being pumped into the hydrazine head tank on July 7, 1986, the head tank began to overflow to the chemical floor drain; an estimated 8 L of hydrazine solution flowed into the PUREX chemical sewer. Chemically absorbent pillows were used to contain the spill. The release was reported to WDOE as required. A new manometer for liquid level indication in the head tank was installed and the tank calibration chart was modified.

**Release of Nitric Acid to the UO₃
Chemical Sewer (UOR No. RHO-86-46)**

Approximately 3028 L of recovered nitric acid containing approximately 16 g/L uranium was released to the chemical sewer during a transfer from the 211U Area storage tank to a railroad tank car on August 6, 1986. It was discovered that the vent/drain valve was stuck in the open position and had been open during the transfer. The appropriate WDOE notifications were made.

TABLE G.1. Radionuclides in Gaseous Effluents Discharged to the Atmosphere in 1986

Radionuclide ^(b)	Half-Life	Release, Ci ^(a)			
		100 Area	200 Area	300 Area	400 Area
³ H	12.3 yr	12	60	5.0	(c)
¹⁴ C	5730 yr		90		
²⁴ Na	15.0 h	0.039			
⁴¹ Ar	1.8 h	120,000			24
⁵¹ Cr	27.7 d	0.0035			
⁵⁴ Mn	312 d	0.0018			
⁵⁶ Mn	2.6 h	100			
⁵⁹ Fe	44.6 d	0.0024			
⁵⁸ Co	70.8 d	0.001			
⁶⁰ Co	5.3 yr	0.011		8.0 x 10 ⁻⁶ (d)	
⁷⁶ As	26.3 h	0.37			
^{85m} Kr	4.5 h	320			
⁸⁵ Kr	10.7 yr	45,000	500,000		4.0
⁸⁷ Kr	76.3 min	860			
⁸⁸ Kr	2.8 h	710			
⁸⁹ Sr	50.5 d	0.0022			
⁹⁰ Sr	28.8 yr	0.0001	0.00021	0.00014(e)	0.000013
⁹¹ Sr	9.5 h	33			
⁹⁵ Zr	64.0 d	0.0026	0.002		
⁹⁹ Mo	66.0 h	0.1			
⁹⁹ Tc	2.1 x 10 ⁵ yr			0.0002	
¹⁰³ Ru	39.4 d	0.00093	0.02		
¹⁰⁶ Ru	367 d	0.0088	0.4		
¹¹³ Sn	115 d		0.21		
¹²⁵ Sb	2.7 yr		<0.008		
¹²⁹ I	1.6 x 10 ⁷ yr		0.5		
¹³¹ I	8.0 d	0.38	<0.2	0.0002	8 x 10 ⁻⁶
¹³² I	2.3 h	1.8			
¹³³ I	20.9 h	2.4			
¹³⁵ I	6.6 h	2.6			
¹³³ Xe	5.25 d	210			
¹³⁵ Xe	9.1 h	1,300			
¹³⁴ Cs	2.1 yr	0.0011	ND		
¹³⁷ Cs	30.2 yr	0.0011	0.0087		
¹³⁸ Cs	32.2 min	1,900			
¹⁴⁰ Ba	12.8 d	0.038			
¹⁴¹ Ce	32.5 d	0.00086			
¹⁴⁴ Ce	284 d	0.0041	ND		
¹⁴⁷ Pm	2.62 yr		0.01		
²⁰⁸ Tl	3.1 min		0.04		
²¹² Pb	10.6 h		0.2		
²¹² Bi	60.6 min		0.12		
²¹² Po	3 x 10 ⁻⁷ sec		0.08		
²¹⁶ Po	0.15 sec		1.8		
²²⁰ Rn	55.6 sec		1.8		
²³⁴ U	2.4 x 10 ⁵ yr		6.7 x 10 ⁻⁶	0.000063(f)	
²³⁵ U	7.0 x 10 ⁸ yr		2.4 x 10 ⁻⁷	4.9 x 10 ⁻⁶ (f)	
²³⁶ U	2.3 x 10 ⁷ yr		5.4 x 10 ⁻⁷		
²³⁸ U	4.5 x 10 ⁹ yr		4.5 x 10 ⁻⁶	0.000036(f)	
²³⁸ Pu	87.7 yr	2.8 x 10 ⁻⁷	0.0002		
^{239,240} Pu	2.4 x 10 ⁴ yr	8.5 x 10 ⁻⁷	0.003	0.000016	2 x 10 ⁻⁶
²⁴¹ Pu	14.4 yr		0.01		
²⁴¹ Am	433 yr		<0.0006		

- (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 curie quantities of radioactivity are for the listed radionuclides only. For those radionuclides with radioactive daughters, the daughter activity is added in during the dose calculations.
- (c) Blank entry indicates no value reported by the operating contractor.
- (d) Includes 3.2 x 10⁻⁷ Ci reported as mixed activation products, assumed to be ⁶⁰Co for dose calculations.
- (e) Includes 8.4 x 10⁻⁵ Ci reported as mixed fission products, assumed to be ⁹⁰Sr for dose calculations.
- (f) Includes fractional contribution from 3.3 x 10⁻⁵ Ci originally reported as natural uranium.
- ND = Not detected.

TABLE G.2. Nonradioactive Constituents in Gaseous Effluents Discharged to the Atmosphere in 1986

Constituent	Release, kg ^(a)			
	100 Area	200 Area	300 Area	1100 Area
Particulates	54,000	32,000	21,000	610
Nitrogen oxides	160,000	820,000	190,000	3,300
Sulfur oxides	740,000	1.2 x 10 ⁶	440,000	2,100
Carbon monoxide	14,000	89,000		200
Hydrocarbons	2,800	44,000		41

(a) Values are those reported by operating contractors.

TABLE G.3 Radionuclides in Liquid Effluents Discharged to Ground Disposal Facilities in 1986

Radionuclide	Half-Life	Release, Ci ^(a)		
		100 Area	200 Area	300 Area
³ H	12.3 yr	220	7000	(b)
³² P	14.3 d	14		
⁵¹ Cr	27.7 d	69		
⁵⁴ Mn	312 d	270		
⁵⁹ Fe	44.6 d	170		
⁵⁸ Co	70.8 d	16		
⁶⁰ Co	5.3 yr	390		
⁶⁵ Zn	244 d	10		
⁸⁹ Sr	50.5 d	200		
⁹⁰ Sr	28.8 yr	36	<3.0	
⁹⁵ Zr	64.0 d	250		
⁹⁹ Tc	210,000			0.01
⁹⁹ Mo	66.0 h	890		
¹⁰³ Ru	39.4 d	43	2.4	
¹⁰⁶ Ru	367 d	49	24	
¹¹³ Sn	115 d	ND	1.6	
¹²⁴ Sb	60.2 d	4.7		
¹²⁵ Sb	2.7 yr	12		
¹²⁹ I	1.6 x 10 ⁷ yr	ND	<0.021	
¹³¹ I	8.0 d	430		
¹³³ Xe	5.25 d	1,000		
¹³⁴ Cs	2.1 yr	7.4		
¹³⁷ Cs	30.2 yr	210	<1.6	
¹⁴⁰ Ba	12.8 d	3,400		
¹⁴¹ Ce	32.5 d	55		
¹⁴⁴ Ce	284 d	94		
¹⁴⁷ Pm	2.62 yr		2.2	
Unidentified beta				0.2
Short-lived radionuclides ^(c)		49,000		
²³⁴ U	2.4 x 10 ⁵ yr		0.018	0.06
²³⁵ U	7.0 x 10 ⁸ yr		0.00066	0.003
²³⁶ U	2.3 x 10 ⁷ yr		0.0015	
²³⁸ U	4.5 x 10 ⁹ yr		0.012	0.04
²³⁸ Pu	87.7 yr	0.035	0.062	
^{239,240} Pu	24,000	0.24	0.82	
²³⁹ Np	2.4 d	3,100		
²⁴¹ Pu	14.4 yr		7.6	
²⁴¹ Am	433 yr		<0.51	

(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.

ND = Not detected

TABLE G.4. Nonradioactive Constituents in Liquids Discharged to Ground Disposal Facilities in 1986

Constituent	Release, kg ^(a)		
	100 Area	200 Area	300 Area
Total organic carbon		16,000	
Nitrates		110,000	66,000
Copper			270
Fluoride			1,400
Chromium			34
Aluminum sulfate	210,000		
Polyacrylamide	520		
Sodium hydroxide	590,000		
Sulphuric acid	870,000		

(a) Values are those reported by operating contractors.

TABLE G.5 Radionuclides in Liquid Effluents Discharged to the Columbia River in 1986

<u>Radionuclide</u>	<u>Half-Life</u>	<u>Release, Ci^(a)</u>
³ H	12.3 yr	220
²⁴ Na	15.0 h	ND
³² P	14.3 d	0.0052
⁵¹ Cr	27.7 d	0.61
⁵⁴ Mn	312 d	0.11
⁵⁹ Fe	44.6 d	0.16
⁵⁸ Co	70.8 d	ND
⁶⁰ Co	5.3 yr	0.53
⁸⁹ Sr	50.5 d	1.8
⁹⁰ Sr	28.8 yr	8.0
⁹⁵ Zr	64.0 d	0.076
⁹⁹ Mo	66.0 h	0.064
¹⁰³ Ru	39.4 d	0.13
¹⁰⁶ Ru	367 d	0.12
¹²⁴ Sb	60 d	ND
¹²⁵ Sb	2.7 yr	0.37
¹³¹ I	8.0 d	0.13
¹³³ I	20.9 h	0.11
¹³³ Xe	5.25 d	0.026
¹³⁷ Cs	30.2 yr	0.095
¹⁴⁰ Ba	12.8 d	0.086
¹⁴¹ Ce	32.5 d	ND
¹⁴⁴ Ce	284 d	ND
²³⁸ Pu	87.7 yr	2.8 x 10 ⁻⁶
^{239,240} Pu	24,000	0.0009

(a) Values are those reported by contractors.
 ND = Not detected

TABLE G.6. Composition of Solid Wastes Buried on the Site During 1986

<u>Constituent</u>	<u>Quantities^(a)</u>
Radioactive	
Uranium	1.1 x 10 ⁷ g
Plutonium	19,000 g
Americium	0.00003 g
Strontium	29,000 Ci
Ruthenium	3.8 Ci
Cesium	31,000 Ci
Other fission and activation products	64,000 Ci
Nonradioactive	
Nonhazardous trash, refuse	43,000 m ³
Asbestos	970 m ³
Septic sludge	238 m ³

(a) Values are those reported by the operating contractors.



APPENDIX REFERENCES

- American Public Health Association (APHA). 1985. **Standard Methods for the Examination Water and Wastewater**. American Public Health Association, Washington, D.C.
- Association of Official Analytical Chemists (AOAC). 1975. **Statistical Manual of the AOAC**. AOAC Arlington, Virginia.
- Benton-Franklin-Walla Walla Counties Air Pollution Control Authority. 1980. General Regulation 80-7.
- Department of Social and Health Services (DSHS) (Washington State). **Rules and Regulations of the State Board of Health Regarding Public Water Systems**. Washington Administrative Code, Chapter 248-254, Olympia, Washington.
- Houston, J. R., D. L. Strenge and E. C. Watson. 1974. **DACRIN--A Computer Program for Calculating Organ Dose from Acute or Chronic Radionuclide Inhalation**. BNWL-B-389, Pacific Northwest Laboratory, Richland, Washington.
- International Commission on Radiological Protection (ICRP). 1979 - 1982. **ICRP Publication 30, Limits for Intakes of Radionuclides by Workers: Part 1 (1979) Annals of the ICRP, 2, No. 3/4. Supplement to Part 1 (1979) Annals of the ICRP, 3, Part 2 (1980) Annals of the ICRP, 4, No. 3/4. Supplement to Part 2 (1981) Annals of the ICRP, 5, Part 3 (1981) Annals of the ICRP, 6, No. 2/3. Supplement A to Part 3 (1982) Annals of the ICRP, 7, Supplement B to Part 3 (1982) Annals of the ICRP, 8**, Pergamon Press, Elmsford, New York.
- Jarvis, A. N., and L. Sui. 1981. **Environmental Radioactivity Laboratory Intercomparison Studies Program**. EPA-600/4-81-004, U.S. Environmental Protection Agency, Las Vegas, Nevada.
- Johns, F. B., Ed. 1975. **Handbook of Radiochemical Analytical Methods**. EPA-680/4-75-001, National Environmental Research Center, Office of Research and Development, Las Vegas, Nevada.
- McGhan, V. L., P. J. Mitchell and R. S. Argo. 1985. **Hanford Wells**. PNL-5397, Pacific Northwest Laboratory, Richland, Washington.
- Napier, B. A., W. E. Kennedy, Jr., and J. K. Soldat. 1980. **PABLM--A Computer Program to Calculate Accumulated Radiation Doses from Radionuclides in the Environment**. PNL-3209, Pacific Northwest Laboratory, Richland, Washington.
- Sanderson, C. G. 1985. **Semi-Annual Department of Energy Quality Assessment Program Data Evaluation Report**. EML-349, Environmental Measurements Laboratory, U.S. Department of Energy, New York.
- Snedecor, G. W., and W. G. Cochran. 1980. **Statistical Methods**. 7th ed., Iowa State University Press, Ames, Iowa.
- Sommer, D. J., R. G. Rau and D. C. Robinson. 1981. **Population Estimates for the Area Within a 50-mile Radius of Four Reference Points on the Hanford Site**. PNL-4010, Pacific Northwest Laboratory, Richland, Washington.
- Strenge, D. L., and E. C. Watson. 1973. **KRONIC--A Computer Program for Calculating Annual Average External Doses from Chronic Atmospheric Releases of Radionuclides**. BNWL-B-264, Pacific Northwest Laboratory, Richland, Washington.
- U.S. Department of Energy (USDOE). 1981a. "Environmental Protection, Safety, and Health Protection Information Reporting Requirements." In **DOE Order 5484.1**, Washington, D.C.
- U.S. Department of Energy (USDOE). 1981b. "Environmental Protection, Safety, and Health Protection Program for DOE Operations." In **DOE Order 5480.1A**. Washington, D.C.
- U.S. Department of Energy (USDOE). 1986a. **Environmental Assessment, Reference**

Repository Location, Hanford Site, Washington. DOE/RW-0076, Washington D.C.

U.S. Department of Energy (USDOE). 1986b. **Revised Ground-Water Monitoring Compliance Plan for the 183-H Solar Evaporation Basins.** Prepared by the Pacific Northwest Laboratory for the U.S. Department of Energy, Richland, Washington.

U.S. Environmental Protection Agency (USEPA). 1976. **National Interim Primary Drinking Water Regulations.** EPA-570/976-003, Washington, D.C.

U.S. Environmental Protection Agency (USEPA). 1980. **Prescribed Procedures for Measurement of Radioactivity in Drinking Water.** EPA-6004-80-032, Eds. H. L. Krieger and E. L. Wittaker, Environmental

Monitoring and Support Office of Research and Development, Cincinnati, Ohio.

U.S. Environmental Protection Agency (USEPA). 1982. **Test Methods for Evaluation Solid Waste.** SW-846, Washington, D.C.

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

Washington State Department of Ecology (WDOE). 1982. **Water Quality Standards,** Washington Administrative Code, Chapter 172-201, Olympia, Washington.

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