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SUBJECT: HANFORD SITE ENVIRONMENTAL REPORT FOR CALENDAR YEAR 1989 (PNL-7346), PACIFIC NORTHWEST LABORATORY (PNL), RICHLAND, WASHINGTON, JUNE 1990

Enclosed is a copy of the Environmental Report for 1989 for the U.S. Department of Energy (DOE) Hanford Site. The purpose of the report is to present summary environmental data. This data characterizes site environmental management performance and confirms the success of the continuing efforts to achieve compliance with environmental standards and requirements. In addition, significant environmental programs and efforts are highlighted.

This report is prepared and published annually for distribution to local, state, and federal government agencies; Congress; the public; and the news media. The report was prepared for DOE by Pacific Northwest Laboratory.

Also enclosed is an addendum summarizing significant changes to our compliance status, current issues and actions, and conformance to environmental permit requirements for the period January 1 through May 1, 1990. We prepared this addendum as part of our continuing efforts to upgrade the quality of the report.

If you have any questions or desire additional information, please contact Mr. R. F. Brich of the Department of Energy Safety and Environment Division at (509) 376-9031.

John D. Wagoner
Manager

Enclosures:
1. Hanford Site Environmental Report for 1989
2. Compliance Summary

ENVIRONMENTAL COMPLIANCE SUMMARY
U.S. DEPARTMENT OF ENERGY'S HANFORD SITE
RICHLAND, WASHINGTON
MAY 1990

This summary updates the environmental compliance status and environmental issues and actions at the Hanford Site from January 1 through May 1, 1990. The summary is in the same format as in the Environmental Report: 1) compliance self-assessment, 2) current issues and actions, and 3) environmental permits.

1. COMPLIANCE SELF-ASSESSMENT

COMPREHENSIVE ENVIRONMENTAL RESPONSE, COMPENSATION, AND LIABILITY ACT (CERCLA)

Through April 1990, no notifications were required to the National Response Center under Section 103(a), the Emergency Release Notification provision of CERCLA.

CLEAN AIR ACT

Subpart H of the Clean Air Act was revised and issued as a final rule December 15, 1989. It requires that radionuclide emissions from all point sources (stacks, vents, pipes, or other release points) be analyzed, measured, and reported in accordance with several new requirements. All of these emission points on the Hanford Site became technically out of compliance with some portion of the detailed measurement requirements as of the March 15, 1990, compliance deadline. Because of the time needed to document exemptions, procure equipment, develop procedures, and train personnel, DOE requested a two-year extension of the compliance deadline.

RESOURCE CONSERVATION AND RECOVERY ACT (RCRA)

Dangerous Waste Tanks

The DOE is reevaluating the dangerous waste tanks at Hanford against more stringent federal requirements adopted in 1989 by the Washington Department of Ecology (WDOE). Potential deficiencies include lack of certified tank integrity assessments and inadequate secondary containment systems. On March 27, 1990, DOE submitted background information to WDOE and began negotiations for corrective action schedules to be included in the Tri-Party Agreement (TPA).

183-H Solar Evaporation Basins

From 1973 to 1980, four sedimentation basins were used as evaporation ponds for liquid chemical and radioactive wastes from 300 Area fuel fabrication processes. After evaporation, low-level mixed wastes remained. The residual sludges have been removed and are contained in barrels. These have been stabilized and stored for future disposal. Although all of the basins have been decontaminated, some crystallized salts remain in one of the basins. The final closure plan and permit application have been prepared.

The basins will be closed by clean closure or by landfill with an engineered cover. Cleanup of the four basins near the Columbia River took seven years and cost $28.6 million.

Enforcement Actions

The WDOE conducted several inspections through April 1990. No enforcement actions resulted. All corrective actions from earlier enforcement actions have been completed.

Two spills of acid from used batteries are the only reportable spills through April 1990. These spills were reported to WDOE as required by the state's Dangerous Waste Regulations.

NATIONAL ENVIRONMENTAL POLICY ACT (NEPA)

On January 12, 1990, Secretary Watkins released his decision that DOE will prepare a programmatic environmental impact statement (EIS) to address the activities proposed by the Environmental Restoration and Waste Management Five-Year Plan (DOE/S-0070). This DOE-Headquarters (DOE-HQ) plan describes DOE's long-term strategy in environmental restoration and waste management. The plan was first issued in August 1989 and will be updated annually. This programmatic EIS will support future site-specific NEPA documents and implementation plans for the Hanford Site.

In January 1990, the Natural Resources Defense Council filed a Notice of Intent to sue DOE, asserting the restart of the PUREX plant should require a supplemental EIS. This Notice of Intent contends, among other items, that significant new information about safety and environmental concerns must be considered before restart. The DOE is evaluating these assertions.

2. CURRENT ISSUES AND ACTIONS

HANFORD FEDERAL FACILITY AGREEMENT AND CONSENT ORDER (TRI-PARTY AGREEMENT)

All parties have approved the annual update to the Tri-Party Agreement (TPA). The update is being issued as Volume 2, with the existing Legal Agreement and Action Plan identified as Volume 1. The public was given the opportunity to review and comment on all modifications. A major modification was the incorporation of land disposal restriction compliance actions into the TPA. The update also includes 30 new interim milestones.

Hanford continues to efficiently complete activities scheduled in the TPA. All 10 milestones scheduled through April 1990 have been completed on or ahead of schedule. The completion of 10 RCRA ground water monitoring wells achieved two milestones eight months ahead of schedule. It must be noted that substantial budget commitments are needed for successful implementation of the TPA. DOE will continue to work with the regulatory agencies to ensure continued progress towards full cleanup and compliance at Hanford.

ENVIRONMENTAL RESTORATION AND WASTE MANAGEMENT FIVE-YEAR PLAN

The site-specific plan for DOE-Richland Operations (DOE-RL) was released in April following DOE-HQ approval. This plan implements the DOE-HQ five-year plan issued in August 1989. The site-specific plan consists of four separate documents: a vision statement, a general overview, a detailed plan, and a set of activity data sheets that provides detailed descriptions of current and planned activities. The detailed plan has been distributed to about 300 individuals in the Northwest.

The 25-page overview document, which was prepared for a more general audience, was distributed to about 1,200 individuals in the Northwest. The 90-day public comment period will last from April 20 to July 19, 1990. Nine public meetings are being held in Washington and Oregon between May 22 and June 14, 1990, to answer questions and receive comments.

HANFORD SITE WASTE STORAGE TANKS

Concerns have been raised about the potential of a ferrocyanide explosion and hydrogen gas accumulation in Hanford waste tanks. One issue is that under certain conditions of chemical concentration, moisture, and temperature, ferrocyanide and nitrates in the single-shell tanks could release heat and potentially become explosive. The DOE has analyzed the conditions and concludes that the probability of a ferrocyanide explosion is low under current operating conditions. Several outside agencies have studied the issue and reached this same conclusion in their preliminary reports.

The other issue is that flammable hydrogen gases may be trapped beneath the crust in five double-shell tanks and 18 single-shell tanks. One tank in particular, 101-SY (a double-shell tank), shows the largest accumulation of trapped gases. In the 22 other tanks, the problem is much less. The DOE and external oversight groups have concluded there is no imminent danger to the public from a hydrogen explosion; however, additional work is needed to increase understanding of the hazards of hydrogen generation.

Westinghouse Hanford Company has formed a Waste Tank Safety Team to identify any hazards associated with the waste tanks and implement the necessary actions to mitigate those hazards. The DOE is overseeing this effort. The EPA, WDOE, State of Washington Department of Health, State of Oregon Water Resources Department, Defense Nuclear Facility Safety Board, and Advisory Committee on Nuclear Facility Safety also provide oversight.

UNITED STATES TESTING COMPANY, INC., (UST) SUSPENSION

The UST performed all radiochemical analyses contained in the Environmental Report with the exception of the penetrating radiation measurements which were conducted by Pacific Northwest Laboratory (PNL), and the nonradiological surface water quality analyses conducted by the US Geological Survey.
On April 25, 1990, EPA suspended UST Inc., from receiving future federal contracts and assistance awards. The EPA Region 10 in Seattle, Washington, and EPA Headquarters initiated the action. They alleged that two UST laboratories supporting the EPA's Superfund program submitted unreliable and falsified data. These laboratories are in Richland, Washington, and Hoboken, New Jersey.

Based on an extensive review of UST, PNL determined that quality problems occurred in the Hoboken laboratory, not the Richland laboratory that does the radiochemical analyses that appear in the Environmental Report. These problems resulted in PNL's termination of the UST contract on June 1, 1990.

More importantly, however, quality control checks of data generated by UST's Richland laboratory have been performed routinely by PNL. Some of these comparisons were made without UST's knowledge. The UST was required by contract to participate in interlaboratory comparison programs conducted by the Environmental Protection Agency and DOE's Environmental Measurements Laboratory. The results from these programs, as well as analytical results from samples split with the States of Washington and Oregon, were in all cases within the range of normal variability. In addition to the past checks, PNL is forming an independent panel to review the reliability of past data generated by UST.

Based on these comparisons, we have a high level of confidence in the environmental data and the conclusions reached in the Environmental Report.

242-A EVAPORATOR

The 242-A Evaporator is used to reduce the volume of dilute waste from the double-shell tanks. In the past, concentrated waste was returned to the double-shell tanks, while the condensate, after treatment by ion exchange, was discharged to a crib. Some constituents in the tanks are "listed" as dangerous wastes. Also, an evaluation indicates that the condensate stream is regulated as a toxic dangerous waste due to the presence of ammonia. Because dangerous waste regulations preclude discharge of dangerous wastes into cribs, discharge was ceased.

A Liquid Effluent Retention Facility (LERF) is being installed for temporarily storing the evaporator condensate. On March 15, 1990, WDOE issued a Determination of Nonsignificance for the LERF in accordance with the State Environmental Policy Act. The current schedule shows operation of the storage units beginning in December 1990. Permanent treatment and disposal systems are scheduled for operation in June 1992.

Operation of the 242-A Evaporator is critical to the cleanup of Hanford because of double-shell tank space limitations. Inability to restart the evaporator will adversely impact several TPA milestones.

SUBMARINE REACTOR COMPARTMENTS

The DOE-RL continues to work with the Department of Navy, EPA, and WDOE to address management of the submarine reactor compartments disposed of in the burial grounds at Hanford. In March, the second phase of cleanup began on the compartments to remove all accessible internal polychlorinated biphenyl (PCB) and ballast lead wastes. The EPA and DOE have signed a Federal Facility Compliance Agreement addressing compliance of the compartments to the Toxic Substances Control Act and also providing for continuation of future shipments to Hanford.

An Interim Approval Request for a chemical landfill permit covering the disposal of the PCBs remaining in the compartments was submitted to EPA on February 23, 1990. A request is being prepared to waive the liner and leachate collection system requirements applicable to the trench under the Washington Dangerous Waste Regulations. This waiver request will be submitted to WDOE in July 1990.

GROUND WATER MANAGEMENT

Ground water monitoring wells are being drilled at many hazardous waste sites around Hanford. The purgewater, water pumped from these wells during well development or sampling, is potentially contaminated. Two hundred to several thousand gallons of water are generated from each well. Because purgewater has the potential to contain dangerous waste or contain hazardous substances in concentrations exceeding predetermined health-based risk levels, a method for storage and treatment of the water is needed.

Purgewater is now stored in modular tanks so that new ground water monitoring wells can be installed, developed, and completed and ground water sampling can continue. One 1,000,000-gallon modular tank is being used and a second is ready for use.

STORAGE OF SPECIAL NUCLEAR MATERIALS

In response to a notice of violation DOE received for the storage of special nuclear material at the Rocky Flats Plant near Denver, the material now stored at the Plutonium Finishing Plant at Hanford is under evaluation. Radioactive materials containing dangerous waste constituents will be regulated under the state's dangerous waste regulations for storage and disposal if they are considered waste materials. Should the evaluation determine a need for state regulation, it is anticipated that TPA milestones can be negotiated which establish schedules for required corrective actions.

3. ENVIRONMENTAL PERMITS

PREVENTION OF SIGNIFICANT DETERIORATION (PSD)

The nitrogen oxide emissions from the Hanford Site chemical processing facilities (PUREX and UO3 Plant) are permitted under the PSD program under the Clean Air Act. Through April 1990, there were no PSD permit violations.

NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM (NPDES) PERMIT

The NPDES permit regulates eight discharges to the Columbia River. In accordance with the NPDES permit, monthly parameter reports were sent to EPA Region 10 and WDOE. Compliance was achieved with all permit conditions.

RCRA PERMITTING

The DOE submitted one hazardous waste facility permit application and three closure plans for Hanford Site waste treatment, storage, and disposal facilities to WDOE.

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Hanford Site Environmental Report for Calendar Year 1989

R. E. Jaquish, Editor
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Richland, Washington 99352

MASTER

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SUMMARY

This report is a summary of the environmental status of the Hanford Site in 1989. It includes descriptions of the Site and its mission, the status of compliance with environmental regulations, planning and activities to accomplish compliance, environmental protection and restoration activities, and environmental monitoring.

SITE MISSION

From 1945 through the 1960s, Hanford Site facilities were primarily dedicated to the production of plutonium for national defense and management of the wastes generated by chemical processing operations. Since the 1960s, programs at the Hanford Site have become increasingly diverse. The current Hanford Site mission includes defense production, defense waste management, environmental restoration, advanced reactor development, and research and development.

COMPLIANCE SUMMARY

A significant environmental compliance event in 1989 was the completion of the Hanford Federal Facility Agreement and Consent Order, known as the Tri-Party Agreement. This agreement among the U.S. Environmental Protection Agency (EPA), the State of Washington Department of Ecology (WDOE), and the U.S. Department of Energy (DOE) provides planning and scheduling for achieving full compliance with the Resource Conservation and Recovery Act (RCRA) and for cleaning up inactive waste sites under either Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) or RCRA authority.

Environmental standards at Hanford fall into three categories: 1) those imposed by federal statutes, regulations, and requirements; 2) those imposed by state and local statutes, regulations, and requirements; and 3) those imposed by DOE directives. This summary addresses the status of compliance with applicable regulations at the Hanford Site. (For detailed compliance information see "Compliance Summary," Section 2.0.)

Compliance with Environmental Regulations

Clean Air Act—The EPA has established National Ambient Air Quality Standards under the authority of the Clean Air Act. They have also established Prevention of Significant Deterioration (PSD) regulations. The Hanford Site radioactive stacks were registered with the State of Washington Department of Health (WDOH), and a permit has been received. Radionuclide emissions from DOE facilities and the disposal of asbestos on the Hanford Site are also regulated by the Clean Air Act. For 1989, the Hanford Site was in compliance with the applicable regulations of the Clean Air Act.

Clean Water Act—The Clean Water Act applies to all nonradioactive discharges to navigable surface water. At the Hanford Site, the regulations are applied through a National Pollutant Discharge Elimination System permit for effluent discharges to the Columbia River. There was one reportable deviation from the permit requirements in 1989.

Safe Drinking Water Act—The EPA National Interim Primary Drinking Water Regulations of

the Safe Drinking Water Act and the WDOH regulation regarding public water systems apply to the drinking water supplies at the Hanford Site. Sanitary water quality surveillance was conducted by the Hanford Environmental Health Foundation and Pacific Northwest Laboratory (PNL). In 1989, with one exception, all water supplies were in compliance with regulatory requirements.

Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA)/Superfund Amendments and Reauthorization Act of 1986 (SARA)—The CERCLA/SARA legislation established a program to identify sites from which hazardous substances have been released into the environment. This program also ensures the cleanup of these sites, evaluates damages to natural resources, and creates a claims procedure. All DOE sites must comply with applicable sections of CERCLA/SARA. Currently, the Hanford Site does not fully comply with CERCLA/SARA; however, the Tri-Party Agreement established a schedule for achieving full compliance with CERCLA/SARA. Hanford operable units were selected for remedial investigation/feasibility studies as the result of negotiations conducted in establishing plans and schedules for the Tri-Party Agreement. All Tri-Party Agreement milestones were achieved, providing compliance with this portion of the CERCLA requirements. In compliance with emergency release notification provisions, the National Response Center was notified of all reportable incidents.

Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA)—The FIFRA and the Washington Administrative Code pesticide regulations (WAC 16-228) apply to storage and use of herbicides and pesticides at the Hanford Site. In 1989, the Hanford Site was in compliance with these requirements.

Resource Conservation and Recovery Act of 1976 (RCRA)—RCRA establishes regulatory standards for the generation, transportation, storage, treatment, and disposal of hazardous waste. Compliance with RCRA requirements is a major regulatory effort. During 1989, 22 underground storage tanks that had been used to store either petroleum or noncontaminated chemical products were removed from the ground and disposed of. The treatment, storage, and disposal units were managed under interim status requirements of Washington State regulations. Schedules for corrective action were developed for identified deficiencies, and those not corrected at the end of the year were incorporated as milestones and target dates under the Tri-Party Agreement. The Hanford Site was given a dangerous waste identification number by the EPA and WDOE that encompasses all treatment, storage, and disposal waste-management units on the Site.

Endangered Species Act—A few rare species of native plants and animals are known to occur on the Hanford Site. The status of these species was reported to the U.S. Fish and Wildlife Service and the State of Washington as information was available. The Hanford Site has two permits for wildlife and fish sampling issued by the Washington State Department of Wildlife and the U.S. Fish and Wildlife Service.

Toxic Substance Control Act (TSCA)—The application of TSCA requirements to Hanford involves regulation of polychlorinated biphenyl (PCB). The Hanford Site was in compliance with regulations for PCBs that are not

radioactively contaminated. In two instances, PCB materials were not in compliance because of radioactive contamination.

National Environmental Policy Act (NEPA)—NEPA requires that projects with potentially significant impacts be carefully reviewed and reported to the public in documents such as environmental assessments (EAs) or environmental impact statements (EISs). All EAs and EISs required by NEPA were prepared for Hanford Site projects.

National Historic Preservation Act, Archaeological Resources Protection Act, and American Indian Religious Freedom Act—Compliance with these acts was accomplished through a program of 1) reviewing all proposed land-disturbing projects to assess potential impacts on cultural resources and 2) periodic inspections of known archaeological and historical sites to determine their condition and the effects of land management policies on the sites.

OPERATIONAL HIGHLIGHTS

The N Reactor has not operated since January 1987 and is on standby status. All fuel elements have been removed from the reactor core. The Plutonium Uranium Extraction (PUREX) Plant operated in December 1989 for fuel charge stabilization. The Plutonium Finishing Plant operated for a total of 3 months in 1989. The Plutonium Recovery Facility did not operate during the year. The Grout Treatment Facility operated from June through July to complete processing of sulfur-phosphate decontamination waste from the N Reactor. The Grout Treatment Facility was placed in standby mode. The Fast Flux Test Facility (FFTF) achieved a 99.0% efficiency factor while operating during 1989.

ENVIRONMENTAL OCCURRENCES

Environmental occurrences (spills, leaks, etc.) of radioactive and nonradioactive chemical wastes were reported to DOE by the onsite contractors and to other federal and state agencies as required by law. Occurrence reports, including event descriptions and corrective actions, are available for review in the DOE Richland Operations Office (DOE-RL) Public Reading Room at the Federal Building, Richland, Washington. The occurrences with the greatest potential for impacting the environment are summarized in this report. (See "Environmental Occurrences," Section 2.6.)

ENVIRONMENTAL PROGRAMS

Environmental programs were conducted at Hanford to enhance environmental quality, to improve understanding of the effects of environmental pollutants from Site operations, and to comply with laws and regulations. These programs included the following:

Environmental Restoration and Waste Management—This activity included identifying and characterizing inactive waste sites. More than 1100 inactive waste management units have been identified at Hanford. These units have been grouped into four aggregate areas that are listed on EPA's National Priorities List. Of these 1100, 115 facilities are scheduled for decontamination and decommissioning (D&D) and are managed by the Hanford surplus facilities program. Activities included cleanup of the 183-H Solar Evaporation Basins, D&D of the 201-S Strontium Semiworks, and D&D of several ancillary facilities in the 100 Areas. Waste management consists of the safe and effective management of active and standby facilities and the treatment, storage, and disposal of radioactive

hazardous, and mixed wastes. A plan and schedule were prepared for discontinuing the disposal of contaminated liquids into the soil at Hanford. A waste minimization and pollution prevention awareness program was implemented. The major effort for cleanup at the Hanford Site will be the disposal of stored wastes resulting from past production operations. The strategies for disposing of these wastes were described in *Final Environmental Impact Statement; Disposal of Hanford Defense High-Level Transuranic and Tank Wastes* (DOE 1987a). The Grout Treatment Facility completed the processing and disposal of 1 million gallons of nonhazardous radioactive waste from double-shelled tanks. This was the first time wastes had been moved out of liquid storage and converted into a solid for safe disposal. (See "Environmental Restoration and Waste Management," Section 3.1.)

Environmental Studies—Studies were conducted to monitor rare, threatened, or endangered species; to monitor species of wildlife and fish that are valued as commercial, recreational, or aesthetic resources; and to monitor those species that can be used as biological indicators of the presence of toxic and hazardous materials in the environment. The Cultural Resources Project manages the archaeological, historical, and cultural resources of the Hanford Site in a manner consistent with the National Historic Preservation Act, the Archaeological Resources Protection Act, and the American Indian Religious Freedom Act. A meteorology program was maintained to document meteorological conditions at Hanford for emergency response purposes and for use in dose calculations. The Hanford Environmental Dose Reconstruction (HEDR) Project was initiated in 1988 to develop estimates of the radiation doses people could have received from past operations at Hanford. In 1989, the HEDR effort included developing the technical approach and compiling historical information that can be used to estimate past radiation doses. (See "Environmental Studies and Programs," Section 3.3.)

ENVIRONMENTAL MONITORING RESULTS

Air—In 1989, the annual average Hanford Site downwind perimeter concentration of ^{90}Sr was numerically greater than the concentration measured at a distant upwind location, but the difference was not statistically significant (at the 5% significance level). Tritium, ^{129}I, uranium, gross alpha, and gross beta concentrations were greater at the downwind perimeter than at a distant upwind location, and the differences were statistically significant (beyond 5% significance level). The differences in tritium and ^{129}I are likely due to site operations. The differences in gross alpha, gross beta, and uranium are predominately due to the effects of natural geographic variations. However, even the maximum single perimeter sample for any radionuclide was only 0.1% of the applicable DOE Derived Concentration Guide (DCG) (Table B.6, Appendix B). The total dose from air emissions is compared to Clear Air Act and DOE dose standards in Section 4.8, "Potential Radiation Doses from 1989 Hanford Operations." Annual average NO_2 concentrations at all sampling locations were less than 14% of federal and Washington State ambient air standards.

Surface Water—The Columbia River was one of the primary environmental exposure pathways to the public during 1989 as a result of past operations at Hanford. Water samples were collected from the river at various locations throughout the year to determine compliance with applicable standards. Although radionuclides associated with Hanford operations continued to be routinely identified in Columbia River water, concentrations remained extremely low at all locations and were well below applicable standards. Nonradiological constituents measured in Columbia River water were in compliance with applicable water quality standards. Three onsite ponds were sampled to determine radionuclide concentrations. Results were similar to those observed in past years. Radionuclide levels in Columbia

River surface sediments were measured at two offsite and three onsite locations. Sampling in 1989, as in previous years, showed slightly elevated levels of some radionuclides in sediments behind McNary Dam. (See "Surface Water Surveillance," Section 4.2.)

Food and Farm Products—Alfalfa and a number of foodstuffs including milk, vegetables, fruits, wine, wheat, beef, chickens, and eggs were collected at several locations surrounding the Hanford Site during 1989. Samples were collected primarily from locations in the prevailingly downwind directions (i.e., to the south and east of the Site) where airborne effluents from Hanford could be expected to be deposited. Samples were also collected in generally upwind directions somewhat distant from the Site to provide information on levels of radioactivity that could be attributed to worldwide fallout.

Low levels of ^{3}H, ^{90}Sr, ^{129}I and ^{137}Cs were found in a number of foodstuff samples collected during 1989; however, the concentrations in samples collected near the Hanford Site were similar to those in samples collected away from the Site. Thus, measured values in foodstuffs were not attributed to Hanford effluents. (See "Food and Farm Product Surveillance," Section 4.2.)

Wildlife—Wildlife sampling was performed in areas where the potential exists for wildlife to ingest radionuclides. Fish were collected from the Hanford Reach of the Columbia River. Analyses provided an indication of the radionuclide concentrations in local game fish and were used to evaluate the potential dose to humans from this pathway. Analytical results were similar to those observed in recent years. Although there are no radionuclide concentration limits for wildlife, the potential dose to a person who consumed any of the wildlife sampled, even at the maximum radionuclide concentrations measured, was well below applicable standards for radiation dose. (See "Wildlife Surveillance," Section 4.4.)

Soil and Vegetation—Surface soil and rangeland vegetation samples were collected at 28 locations during 1989, both on and off the Hanford Site. The purpose of sampling was to detect the possible build-up of radionuclides from the deposition of airborne effluents released from Hanford facilities. Samples were collected at nonagricultural, relatively undisturbed sites so that natural deposition and build-up processes would be represented. The results provided no indication of trends or increases in the concentrations of radionuclides in the offsite environment that could be attributed to Hanford operations. (See "Soil and Vegetation Surveillance," Section 4.5.)

Penetrating Radiation—Dose rates from penetrating radiation (gamma rays) were measured at numerous locations in 1989 using thermoluminescent dosimeters (TLDs). Penetrating radiation from naturally occurring sources, including cosmic radiation and natural radioactive materials in the air and ground, as well as from worldwide fallout, was recorded by all dosimeters. Results obtained both on and off the Site were within statistical variability of those of the previous 5 years. The observed variability is attributed to variability in naturally occurring dose rates from year to year and statistical uncertainty in conducting low-level environmental dose measurements. Dose rates near waste storage and handling facilities were somewhat higher than natural background rates. (See "Penetrating-Radiation Surveillance," Section 4.6.)

Effluent Monitoring—Westinghouse Hanford Company, the prime operating and engineering

contractor at Hanford, and PNL quantify and document the amounts of radioactive and non-radioactive liquids, gases, and solids released to, or disposed of, in the environment from Hanford operations. These efforts are performed to determine the degree of compliance with applicable federal, state, and local regulations and permits. Monitoring data are also used in pollution abatement programs that assess the effectiveness of effluent treatment and control. (See "Effluent Monitoring," Section 4.7.)

Potential Radiation Doses—The potential radiation doses to the public from Hanford operations during 1989 were calculated for the hypothetical maximally exposed individual and for the general public residing within 80 km of the Hanford Site. (See "Potential Radiation Doses from 1989 Hanford Operations," Section 4.8, for the definition of hypothetical maximally exposed individual.)

The dose to the maximally exposed individual from 1989 operations was 0.05 mrem, less than the 0.08 mrem reported for 1988. The potential dose to the local population of 340,000 persons from 1989 operations was 1 person-rem, less than the 5 person-rem reported for 1988. These values are well below the current DOE radiation standards of 100 mrem per year for an individual. (See "Potential Radiation Doses from 1989 Hanford Operations," Section 4.8.)

GROUND-WATER PROTECTION AND MONITORING PROGRAM

Radiological and chemical constituents in ground water were monitored throughout the Hanford Site during 1989. During 1989, a total of 567 Hanford Site wells were sampled to satisfy ground-water monitoring needs.

Radiological monitoring results indicated that gross alpha, gross beta, ^{3}H, ^{60}Co, ^{90}Sr, ^{99}Tc, ^{129}I, and ^{137}Cs concentrations in wells in or near operating areas were at levels above the drinking water standards (DWS). Concentrations of uranium in the 200-West Area were above the derived concentration guides. Concentrations of ^{3}H in the 200 Areas and ^{90}Sr in the 100-N and 200-East Areas were also above the derived concentration guides. Iodine-131 and ^{103}Ru in ground water remained below detectable levels as a result of the N Reactor continuing in standby mode. Tritium continued to move slowly with the general ground-water flow and discharge to the Columbia River.

Certain chemicals regulated by the EPA and the State of Washington were also present in Hanford ground water near operating areas. Nitrate concentrations exceeded the DWS at isolated locations in the 100, 200, and 300 Areas and in several 600 Area locations. Chromium concentrations were above the DWS at 100-D, 100-H, and 100-K Areas, and at surrounding areas. Chromium concentrations above the DWS were also found in the 200-East and 200-West Areas. Cyanide was detected in ground water north of the 200-East Area. High concentrations of carbon tetrachloride were found in wells in the 200-West Area. Trichloroethylene concentrations exceeded DWS at wells in and near the 100-F Area, 300 Area, and Solid Waste Landfill. Sampling at monitoring wells near Richland water supply wells showed that concentrations of regulated ground-water constituents in this area are below the DWS and in general below

detection levels. (See "Ground-Water Protection and Monitoring Program," Section 5.0.)

QUALITY ASSURANCE

A comprehensive quality assurance (QA) program is maintained to ensure the quality of data collected through the surveillance programs. Quality assurance plans were developed for all surveillance activities that defined appropriate controls and documentation required to meet DOE orders and the American Society of Mechanical Engineers (ASME) NQA-1 QA program document.

In the surface- and ground-water surveillance programs, extensive environmental data were obtained to eliminate unrealistic reliance on only a few results. Newly collected data were compared both with recent results and historical data to ensure that deviations from previous conditions were identified and promptly evaluated. Samples at all locations were collected using well-established and documented procedures to ensure consistency. Samples were analyzed by documented standard analytical procedures. Data quality was verified by a continuing program of analytical laboratory quality control, participation in interlaboratory cross-checks, replicate sampling and analysis, and exchanging samples with other laboratories. (See "Quality Assurance," Section 6.0.)

ACKNOWLEDGMENTS

A number of personnel were responsible for a productive environmental surveillance program during 1989. Important contributions were made by those people who collected samples, maintained equipment, provided laboratory analysis, managed data, evaluated results, and provided clerical support. Westinghouse Hanford Company staff provided information on current Hanford environmental issues, effluents, and environmental compliance.

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HELPFUL INFORMATION

The following information is provided to assist the reader in understanding the report.

ACRONYMS AND ABBREVIATIONS

ALARA	as low as reasonably achievable
ALE	Arid Lands Ecology (Reserve)
APHA	American Public Health Association
ARPA	Archaeological Resources Protection Act
ASTM	American Society for Testing and Materials
BCSR	Boeing Computer Services Richland
BMI	Battelle Memorial Institute
BWIP	Basalt Waste Isolation Project
CAA	Clean Air Act
CEQ	Council of Environmental Quality
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
cfs	cubic feet per second
CLP	Contract Laboratory Program
CY	calendar year
D&D	decontamination and decommissioning
DCE	dichloroethylene
DCG	Derived Concentration Guide
DOE	U.S. Department of Energy
DOE-HQ	U.S. Department of Energy-Headquarters
DOE-RL	U.S. Department of Energy-Richland Operations Office
DWS	Drinking Water Standards
EIS	environmental impact statement
EIS/ODIS	Effluent Information System/ Onsite Discharge Information System
EML	Environmental Measurements Laboratory
EPA	U.S. Environmental Protection Agency
FCP	Fuel Cycle Plant
FFTF	Fast Flux Test Facility
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
FY	fiscal year
GC/MS	Gas Chromatography and Mass Spectrometry
HAZWRAP	Hazardous Waste Remedial Action Program
HEHF	Hanford Environmental Health Foundation

HMS	Hanford Meteorology Station
IC	ion chromatography
ICP	Inductively Coupled Plasma
ICRP	International Commission on Radiological Protection
INEL	Idaho National Engineering Laboratory
KEH	Kaiser Engineers Hanford Company
LEPD	low-energy photon detector
LWDF	Liquid Waste Disposal Facility
MASF	Maintenance and Storage Facility
MCL	maximum contaminant level
MDA	minimum detectable amount
MDC	minimum detectable concentration
MI	maximally exposed individual
NCRP	National Council on Radiation Protection
NEPA	National Environmental Policy Act
NERP	National Environmental Research Park
NESHAP	National Emissions Standards for Hazardous Air Pollutants
NPDES	National Pollutant Discharge Elimination System
NRC	U.S. Nuclear Regulatory Commission
NTU	nephelometric turbidity unit
ORNL	Oak Ridge National Laboratory
PCB	polychlorinated biphenyl
PFP	Plutonium Finishing Plant
PNL	Pacific Northwest Laboratory
PSD	Prevention of Significant Deterioration
PUREX	Plutonium Uranium Extraction (Plant)
QA	Quality Assurance
QC	Quality Control
RCRA	Resource Conservation and Recovery Act
REDOX	Reduction Oxidation (Plant)
RI/FS	remedial investigation/feasibility study
RQ	Reportable Quantity
SARA	Superfund Amendments and Reauthorization Act
SE	standard error
SEM	standard error of the mean

SI	International System of Units (metric)
TCE	trichloroethylene
TLD	thermoluminescent dosimeter
TOX	total organic halogens
TSCA	Toxic Substances Control Act
TSD	treatment, storage, or disposal (facility)
UO_3 Plant	Uranium Oxide Plant
USGS	U.S. Geological Survey
UST	United States Testing Company, Inc.
VOA	volatile organic analyses
WAC	Washington Administrative Code
WDOE	State of Washington Department of Ecology
WDOH	State of Washington Department of Health
WIPP	Waste Isolation Pilot Plant

ABBREVIATIONS FOR UNITS OF MEASURE

Radioactivity	
Symbol	Name
Ci	curie
mCi	millicurie (10^{-3} Ci)
µCi	microcurie (10^{-6} Ci)
nCi	nanocurie (10^{-9} Ci)
pCi	picocurie (10^{-12} Ci)
fCi	femtocurie (10^{-15} Ci)
aCi	attocurie (10^{-18} Ci)
Bq	becquerel

Volume	
Symbol	Name
cm^3	cubic centimeter
L	liter
mL	milliliter (10^{-3} L)
m^3	cubic meter
ppmv	parts per million volume
ppb	parts per billion

Length	
Symbol	Name
km	kilometer (10^3 m)
m	meter
cm	centimeter (10^{-2} m)
mm	millimeter (10^{-3} m)
µm	micrometer (10^{-6} m)

Mass	
Symbol	Name
g	gram
kg	kilogram (10^3 g)
µg	microgram (10^{-6} g)
ng	nanogram (10^{-9} g)
t	metric ton (or tonne; 10^3 kg)

Area	
Symbol	Name
ha	hectare (10,000 m^2)

Time	
Symbol	Name
yr	year
d	day
h	hour
min	minute
s	second

CONVERSION TABLE

Multiply	By	To Obtain	Multiply	By	To Obtain
in.	2.54	cm	cm	0.394	in.
ft	0.305	m	m	3.28	ft
mi	1.61	km	km	0.621	mi
lb	0.454	kg	kg	2.205	lb
liq qt	0.946	L	L	1.057	liq qt
ft^2	0.093	m^2	m^2	10.76	ft^2
acres	0.405	ha	ha	2.47	acres
mi^2	2.59	km^2	km^2	0.386	mi^2
ft^3	0.028	m^3	m^3	35.7	ft^3
nCi/mi^2	0.386	mCi/km^2	mCi/km^2	2.57	nCi/mi^2
dpm	0.450	pCi	pCi	2.22	dpm
nCi	1000	pCi	pCi	0.001	nCi
pCi/L	10^{-9}	µCi/mL	µCi/mL	10^{9}	pCi/L
pCi/m^3	10^{-12}	Ci/m^3	Ci/m^3	10^{12}	pCi/m^3
pCi/m^3	10^{-12}	mCi/cm^3	mCi/cm^3	10^{12}	pCi/m^3
mCi/km^2	1.0	nCi/m^2	nCi/m^2	1.0	mCi/km^2
becquerel	2.7×10^{-11}	curie	curie	3.7×10^{10}	becquerel
gray	100	rad	rad	0.01	gray
sievert	100	rem	rem	0.01	sievert
ppb	0.001	ppm	ppm	1000	ppb
ppm	1.0	mg/L	mg/L	1.0	ppm

RADIONUCLIDE NOMENCLATURE

Radionuclide	Symbol	Half-Life
Tritium	^{3}H	12.3 yr
Carbon-14	^{14}C	5730 yr
Sodium-22	^{22}Na	2.6 yr
Argon-41	^{41}Ar	1.8 h
Chromium-51	^{51}Cr	27.7 d
Manganese-54	^{54}Mn	312 d
Cobalt-60	^{60}Co	5.3 yr
Nickel-63	^{63}Ni	92 yr
Krypton-85	^{85}Kr	10.7 yr
Strontium-89	^{89}Sr	52 d
Strontium-90	^{90}Sr	28.8 yr
Niobium-95	^{95}Nb	36 d
Zirconium-95	^{95}Zr	64.0 d
Molybdenum-99	^{99}Mo	66.0 h
Technetium-99	^{99}Tc	212,000 yr
Ruthenium-103	^{103}Ru	39.4 d
Ruthenium-106	^{106}Ru	367 d
Tin-113	^{113}Sn	115 d
Antimony-125	^{125}Sb	2.7 yr
Iodine-129	^{129}I	16,000,000 yr
Iodine-131	^{131}I	8.0 d
Cesium-134	^{134}Cs	2.1 yr
Cesium-137	^{137}Cs	30.2 yr
Cerium-144	^{144}Ce	284 d
Promethium-147	^{147}Pm	2.62 yr
Europium-152	^{152}Eu	12 yr
Europium-154	^{154}Eu	16 yr
Europium-155	^{155}Eu	1.8 yr
Thallium-208	^{208}Tl	3.1 min
Bismuth-212	^{212}Bi	60.6 min
Lead-212	^{212}Pb	10.6 h
Polonium-212	^{212}Po	0.0000003 s
Polonium-216	^{216}Po	0.15 s
Radon-220	^{220}Rn	55.6 s
Uranium Total	U or uranium	---
Uranium-234	^{234}U	240,000 yr
Uranium-235	^{235}U	70,000,000 yr
Uranium-236	^{236}U	23,000,000 yr
Uranium-238	^{238}U	4,500,000,000 yr
Plutonium-238	^{238}Pu	87.7 yr
Neptunium-239	^{239}Np	2.4 d
Plutonium-239,240	$^{239,240}Pu$	24,000 yr
Plutonium-241	^{241}Pu	14.4 yr
Americium-241	^{241}Am	433 yr

ELEMENTAL AND CHEMICAL CONSTITUENT NOMENCLATURE

Constituent	Symbol
Aluminum	Al
Ammonia	NH_3
Ammonium	NH_4^+
Antimony	Sb
Arsenic	As
Barium	Ba
Beryllium	Be
Bicarbonate	HCO_3^-
Boron	B
Cadmium	Cd
Calcium	Ca
Carbon	C
Carbonate	CO_3^{2-}
Carbon Tetrachloride	CCl_4
Chloride	Cl^-
Chromium (species)	Cr^{6+}
Chromium (total)	Cr
Copper	Cu
Fluoride	F^-
Iron	Fe
Lead	Pb
Magnesium	Mg
Manganese	Mn
Mercury	Hg
Nickel	Ni
Nitrate	NO_3^-
Nitrogen	N
Nitrogen Dioxide	NO_2
Phosphate	PO_4^{3-}
Phosphorus	P
Potassium	K
Selenium	Se
Silver	Ag
Sodium	Na
Strontium	Sr
Sulfate	SO_4^{2-}
Vanadium	V
Zinc	Zn

1.0 Introduction

1.0 INTRODUCTION

Various nuclear and non-nuclear activities have been conducted at the Hanford Site since 1943. The most environmentally significant activities have been the production of nuclear materials for national defense and the associated chemical processing and management of the waste.

This report is a summary of the environmental status of the Hanford Site in 1989. It includes a description of the Site and its mission, the status of compliance with environmental regulations, planning and activities to accomplish compliance, environmental protection and restoration activities, and environmental monitoring.

Environmental monitoring consists of two activities: effluent monitoring and environmental surveillance. The environmental surveillance program is conducted by Pacific Northwest Laboratory (PNL), which is operated for the U.S. Department of Energy (DOE) by Battelle Memorial Institute. The operations and engineering contractor, Westinghouse Hanford Company, performs effluent monitoring for its facilities. Pacific Northwest Laboratory performs effluent monitoring of its research activities. The Hanford Environmental Health Foundation performs surveillance of nonradiological air pollutants and monitors Hanford drinking water.

REPORT BACKGROUND

From 1946 through 1957, environmental surveillance results were recorded in quarterly reports. Since 1958, results have been made publicly available as annual reports (groundwater surveillance reports began in 1956). Results through 1984 were published as separate reports under the following titles:

- *Environmental Surveillance at Hanford for Calendar Year* (monitoring results for the offsite environs)

- *Environmental Status of the Hanford Site for Calendar Year* (monitoring results for the onsite environs; discontinued in 1984)

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

Beginning in 1985, these three reports were combined into one document that summarizes all the data collected during each calendar year. Changes in the title and format of reports since 1988 reflect new guidance contained in DOE Order 5400.1. This report also contains information on the compliance status of the Hanford Site and environmental protection and restoration activities.

This report is a single, comprehensive source of offsite and onsite environmental data collected

during 1989 and a description of the environmental activities and compliance status of the Hanford Site. The report contains data on Hanford effluents, the surface environment, and ground water. Also included is an assessment of the 1989 radiological doses to the hypothetical maximally exposed individual and the local population.

Radionuclide data are expressed as curies, microcuries, picocuries, or attocuries. The curie (Ci) is the fundamental unit used to express radioactivity and defines the amount of a substance present based on its rate of radioactive disintegration. [A curie is 37 billion nuclear disintegrations per second. A microcurie (μCi) is one millionth (10^{-6}) of a curie. A picocurie (pCi) is one millionth-millionth (10^{-12}) of a curie. An attocurie (aCi) is one millionth-millionth-millionth (10^{-18}) of a curie.] Environmental monitoring results often involve extremely small numbers that are best expressed as picocuries or attocuries.

Concentrations of chemicals in water are expressed as the mass of the chemical or solute per liter of solution. Because chemical concentrations in ground water and surface water are often very low, they are expressed in micrograms per liter (μg/L) or, occasionally, milligrams per liter (mg/L). The concentration of nitrogen dioxide (NO_2) in air is expressed in units of parts per million (ppm). This is the volume of NO_2 per volume of air (v/v).

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

A glossary is presented in Appendix A. Acronyms are spelled out the first time they are used in each section, except commonly used acronyms, such as DOE and EPA. Applicable standards and environmental permits are described in Appendix B. Environmental surveillance data for 1989 are listed in Appendix C. Information in Appendix C is intended for readers with a scientific interest or for those who wish to evaluate the results in more detail. Those interested in reviewing the raw data can do so at the Department of Energy-Richland Operations' Public Reading Room at the Federal Building, Richland, Washington. Sample analysis procedures are described in Appendix D. Methods used for data analysis are summarized in Appendix E. Methods used for dose calculation in 1989 are discussed in Appendix F. Appendix G contains the 1989 Hanford effluent data.

1.1 SITE MISSION

The Hanford Site was acquired by the federal government in 1943 for the construction and operation of facilities to produce plutonium for the atomic weapons program during World War II. For over 20 years, Hanford Site facilities were dedicated primarily to the production of plutonium for national defense and management of the wastes generated by chemical processing operations. In later years, programs at the Hanford Site have become increasingly diverse, involving research and development for advanced reactors, renewable energy technologies, waste disposal technologies, and cleanup of contamination from past practices.

The current Hanford Site mission includes:

- Defense Production: N Reactor is currently not operating, and the fuel has been removed. The Plutonium Uranium Extraction (PUREX) Plant is to complete an in-process production run in early 1990 and will then be shut down for approximately 1 year for environmental upgrades. The Plutonium Finishing Plant (PFP) operates to process plutonium scrap. The 300 Area fuel fabrication facilities are not operating.

- Defense Waste Management: Management of radioactive waste, hazardous waste, mixed waste, and sanitary waste.

- Environmental Restoration: Restoration of approximately 1100 inactive waste sites and about 100 surplus facilities.

- Advanced Reactor Development: Management of the Fast Flux Test Facility (FFTF) test reactor and the SP-100 Space Reactor Program.

- Research and Development: Research and development in basic energy sciences, health and environmental sciences, and magnetic fusion.

1.2 MAJOR ACTIVITIES

Four major DOE operating areas exist at the Hanford Site [i.e., 100, 200, 300, and 400 Areas (Figure 1.1)]. The 100 Areas include facilities for the N Reactor and the eight deactivated production reactors along the Columbia River. The reactor fuel reprocessing plant (PUREX), PFP, and waste management facilities are on a plateau about 11.3 km from the river, in the 200 Areas. The 300 Area, just north of the city of Richland, contains the reactor fuel fabrication facilities and research and development laboratories. The FFTF is located in the 400 Area, approximately 8.8 km northwest of the 300 Area.

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

Major DOE contractors at Hanford in 1989 were:

- Westinghouse Hanford Company--responsible for operating the Hanford Engineering Development Laboratory, including the FFTF test reactor; maintaining N Reactor and its fuel fabrication facilities; reprocessing fuel and managing waste; conducting effluent monitoring; decommissioning old facilities; and providing Site support services, such as security, fire protection, central stores, and electrical power distribution

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

- Kaiser Engineers Hanford Company--responsible for providing architectural, construction, and engineering services

- Hanford Environmental Health Foundation--responsible for providing occupational medicine and environmental health support services

- Boeing Computer Services Richland--responsible for providing computer operations and support services.

The 1989 operating history for the major facilities is summarized below:

- The N Reactor has not operated since January 7, 1987, and has been placed on standby status. All fuel elements have been removed from its core. The major piping systems will be purged with dehumidified air to prevent corrosion and sealed to keep moist air out. This procedure will help preserve the restart capability of the plant should it be needed for another nuclear materials production mission. The irradiated fuel elements stored in the 100-N fuel storage basin were transferred to the 100-K East and -K West fuel storage basins. Support operations at the 300 Area fuel fabrication facilities were also on standby status.

- In the PUREX Plant, only one fuel-charge stabilization run was done, in December 1989. The inventory of N Reactor fuel elements is being stored underwater in the two 100-K Area fuel storage basins pending a decision on whether to process more of these elements at the PUREX facility.

- At the PFP, the Remote Mechanical-C Line operated for a total of 3 months in 1989. The Plutonium Recovery Facility did not operate during the year.

- The Grout Treatment Facility operated from June through July in 1989 to complete the processing of the N Reactor phosphate/sulfur decontamination waste. Following this 1-million-gallon run, the facility was placed in standby mode until additional facilities are constructed.

- The 242-A Evaporator, which is used to treat dilute waste from the double-shell tanks, operated from January 1 to April 4, 1989. The facility is now in standby, awaiting construction of a retention facility for condensate discharge.

- The FFTF achieved a record 99.0% efficiency factor while operating during 1989. The test reactor also operated at a capacity factor of 47.6% and an availability factor of 49.7%. Several research and laboratory facilities operated to support FFTF and other Hanford activities.

1.3 SITE DESCRIPTION

The Hanford Site is located in a rural region of southeastern Washington State and occupies an area of about 1450 km^2. The Site (Figure 1.1) lies about 320 km northeast of Portland, Oregon, 270 km southeast of Seattle, Washington, and 200 km southwest of Spokane, Washington.

SURFACE CHARACTERISTICS OF THE SITE

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

The Columbia River, which originates in the mountains of eastern British Columbia, Canada, flows through the northern edge of the Hanford Site and forms part of the Site's eastern boundary. The river drains a total area of approximately 70,800 km^2 enroute to the Pacific Ocean. Flow of the Columbia River is regulated by 11 dams within the United States, 7 upstream and 4 downstream of the Site. Priest Rapids is the nearest dam upstream of the Site, and McNary is the nearest dam downstream. The Hanford Reach of the Columbia River extends from Priest Rapids Dam to the head of Lake Wallula (created by McNary Dam) near Richland and is the last stretch of the Columbia River above Bonneville Dam that remains unimpounded. The width of the river varies from approximately 300 m to 1000 m within the Hanford Site.

Flows in the Hanford Reach fluctuate significantly because of the relatively small storage capacities and the operational practices of upstream dams. Flow rate of the Columbia River through the Site is regulated primarily by Priest Rapids Dam. Typical daily flows range from 1000 cubic meters per second (m^3/s) to 7000 m^3/s, with peak spring runoff flows of up to 12,600 m^3/s. The minimum regulated flow is 1000 m^3/s. Typical annual average flows at Priest Rapids Dam are 2800 m^3/s to 3400 m^3/s. Monthly mean flows typically peak from April through June and are lowest from September through October.

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

The Columbia River 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

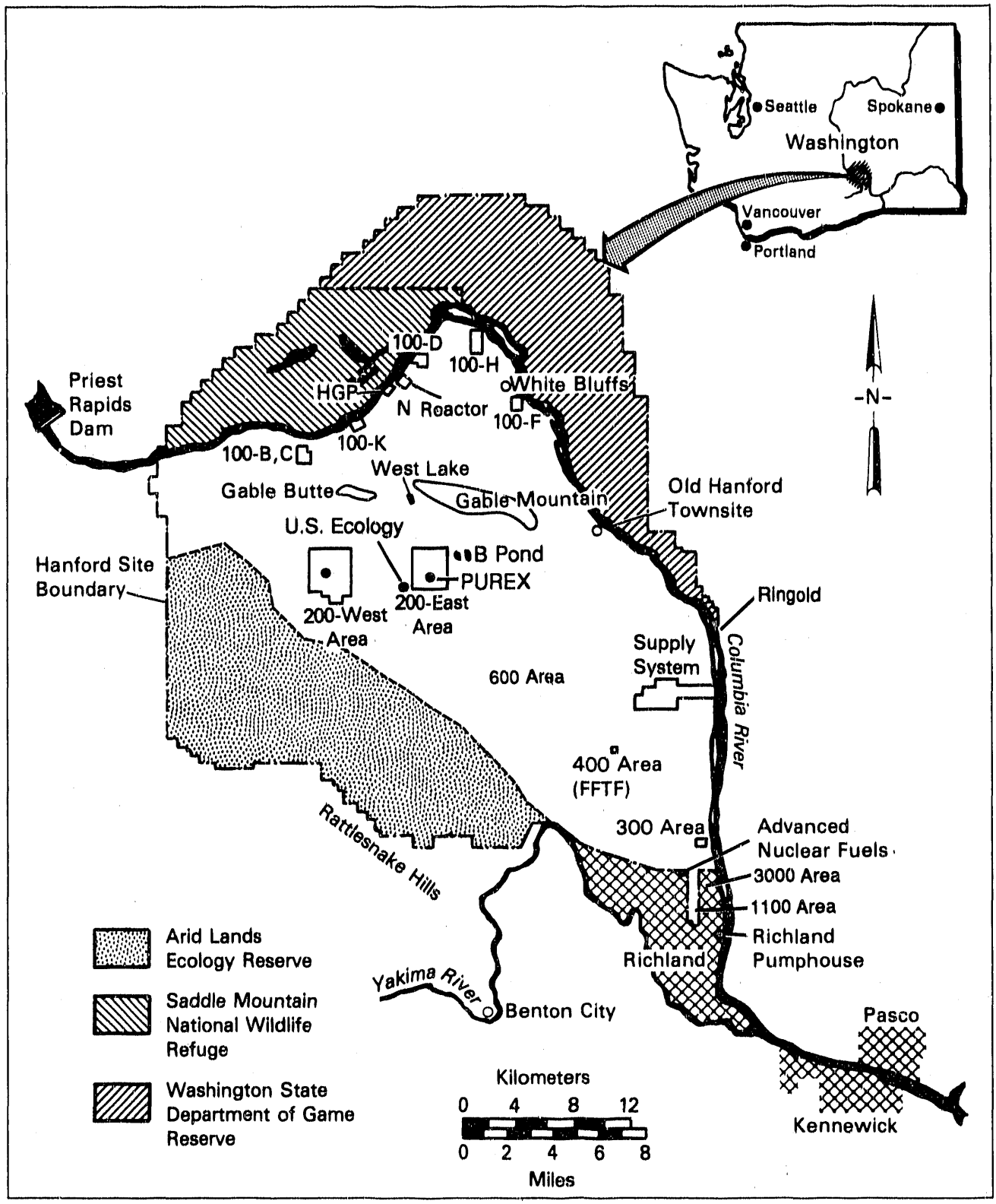

FIGURE 1.1. DOE's Hanford Site

of the Columbia River from the Washington-Oregon border to Grand Coulee Dam (which includes the Hanford Reach) as Class A (Excellent) and has established water quality criteria and water use guidelines for this class designation. Other surface water on the Site consists of West Lake (a small, natural pond), Rattlesnake Springs, Dry Creek, and a number of ditches and artificial ponds created for routine disposal of waste water.

Hanford's climate is dry and mild; the area receives approximately 16 cm of precipitation annually (see Section 3.3). About 40% of the total precipitation occurs during November, December, and January; only 10% falls in July, August, and September. Approximately 45% of all precipitation from December through February is snow. The average minimum and maximum temperatures in July are 16°C and 32°C. For January, the average minimum and maximum temperatures are -6°C and 3°C.

Monthly average wind speeds range from about 15 km/h in summer to 10 km/h in winter (see Section 3.3). The prevailing regional winds are from the northwest, with occasional cold-air drainage into valleys and strong crosswinds. The region is a typical desert basin, where frequent strong temperature inversions occur at night and break during the day, resulting in unstable and turbulent wind conditions.

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

More detail on Site characteristics and activities is available in the Hanford defense waste environmental impact statement (DOE 1987a).

DEMOGRAPHY

The most recent data on the population surrounding the Hanford Site are from the 1980 census (Sommer et al. 1981). The population in the area surrounding the Site is rural, with the exception of the area near the southeast boundary where the cities of Kennewick, Pasco, and Richland are located. Sommer et al. described the population around the Site relative to reference points at major Hanford facilities. The 200 Areas meteorological tower is a reference point used that is approximately in the center of the Site. The total population out to a distance of 50 miles (80 km) from the meteorological tower was 340,943 in 1980. The number of people in this area who resided in incorporated cities was 210,999. The greatest population density was in the southeast sector, 20 to 30 miles (32 to 48 km) from the meteorological tower, which had a density of 899.1 persons per square mile.

SUBSURFACE CHARACTERISTICS OF THE SITE

The DOE operations on the Site have resulted in the production of large volumes of waste water that historically have been discharged to the ground through cribs, ditches, and ponds. These discharges have greatly influenced

ground-water flow and contaminant movement in the unconfined aquifer beneath the Site. Discharge of waste water to the ground at Hanford began in the mid-1940s and reached a peak in 1955. After 1955, discharge to cribs declined because of improved treatment of waste streams and deactivation of various facilities (Graham et al. 1981). Since restart of the PUREX Plant and related facilities in late 1983, discharge of PUREX-related effluents has resumed.

Subsurface structures, such as cribs, were primarily used for the disposal of water containing radioactive wastes; surface ponds and ditches were primarily used for disposal of uncontaminated cooling water (Graham et al. 1981). A crib is an underground structure designed to receive liquid waste and allow it to percolate into the ground directly or through a connected tile field. Sanitary wastes were discharged to the ground via tile fields. Most liquid disposal occurred in the Separations Areas, which include the 200-East and 200-West Areas (Figure 1.1). Approximately 1.7 billion L of liquid effluent in the 200 Areas were disposed to the ground during 1989, including process cooling water and water containing low-level radioactive and hazardous wastes. This disposal to the ground is a decrease from the 28 billion L discharged during 1988, which was erroneously reported as 2.42 billion L in the 1988 report (Jaquish and Bryce 1989). Approximately 1.3 billion L of liquid effluent in the 100 N Area were disposed to liquid-waste disposal facilities and the sanitary sewer. Additional amounts of process and sanitary waste water were disposed of in the 100 and 300 Areas. Discharges of process and sanitary waste water to the ground in the 400 Area were minimal.

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

Geology

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

Emplacement of Columbia River basalt flows, which ended in the Pasco Basin approximately 8.5 million years ago, was followed by a period of river and lake sedimentation. These deposits, which belong to the Ringold Formation, contain a wide range of sediment types, with beds ranging from weakly cemented coarse sandy gravel to compacted silt and clay. The Hanford formation was deposited later as a result of giant floods associated with the sudden draining of glacier-dammed lakes located northeast of the Columbia Plateau. Cataclysmic floods occurred several times over the last million years (Bjornstad and Fecht 1989). Within the Pasco Basin, the Hanford formation

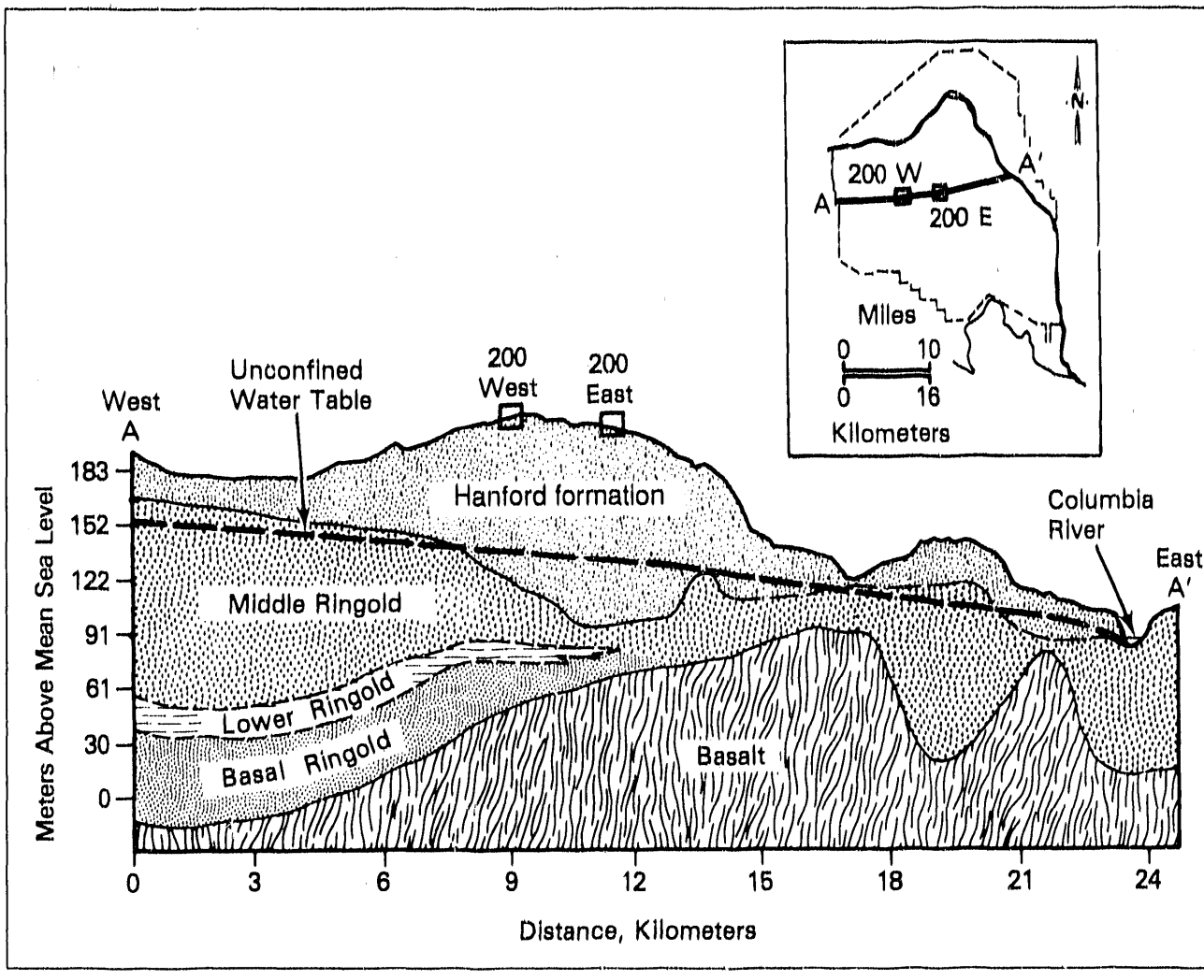

FIGURE 1.2. Geologic Cross Section of the Site (modified from Tallman et al. 1979)

consists of mostly coarse gravel and sand, and overlies the eroded surface of the Ringold Formation, but in places the Hanford formation directly overlies basalt. Near the 200-West Area, the Ringold and Hanford formations are separated by a well-developed buried soil (Plio-Pleistocene unit) and fine-grained wind deposits (early "Palouse" soil) (Last et al. 1989).

Hydrology

Both confined and unconfined aquifers are present beneath the Site. The confined aquifers, where ground water is under greater pressure 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 have 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 Ringold Formation. The water table defines the upper boundary of the unconfined aquifer. Laterally, the unconfined aquifer is bounded by the basalt ridges that surround the basin and by the Yakima and Columbia rivers. The basalt ridges have a low permeability and act as a barrier to lateral flow of ground water (Gephart et al. 1979) where they rise above the water table. The saturated thickness of the unconfined aquifer is greater than 61 m in some areas of the Hanford Site and pinches out along the flanks of the basalt ridges. Depth from the ground surface to the water table ranges from less than 0.3 m near the Columbia River to over 106 m in the center of the Site. Elevation of the water table above mean sea level for June 1989 is shown in Figure 1.3.

Recharge to the unconfined aquifer originates from several sources (Graham et al. 1981). Natural recharge occurs from precipitation at higher elevations and runoff from intermittent streams, such as Cold Creek and Dry Creek to the west. The Yakima River recharges the unconfined aquifer as it flows along the southwest boundary of the Hanford Site. The Columbia River recharges the unconfined aquifer during high stages when river water is transferred to the aquifer along the river bank. The unconfined aquifer receives little, if any, recharge from precipitation directly on vegetated areas of the Hanford Site because of a high rate of evapotranspiration from native soil and vegetation. However, studies described by Gee (1987) suggest that precipitation may contribute recharge to the ground water in areas where soils are coarse textured and bare of vegetation.

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

The operational discharge of water has created ground-water mounds near each of the major waste-water disposal facilities in the 200 Areas. These mounds have altered the aquifer's local flow pattern, 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 continually 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.

Ground-water mounding also occurs in the 100 and 300 Areas. Ground-water mounding in these areas is not as significant as in the 200 Areas because of differences in discharge volumes and subsurface geology. In the 100 and 300 Areas, water levels are also greatly influenced by river stage.

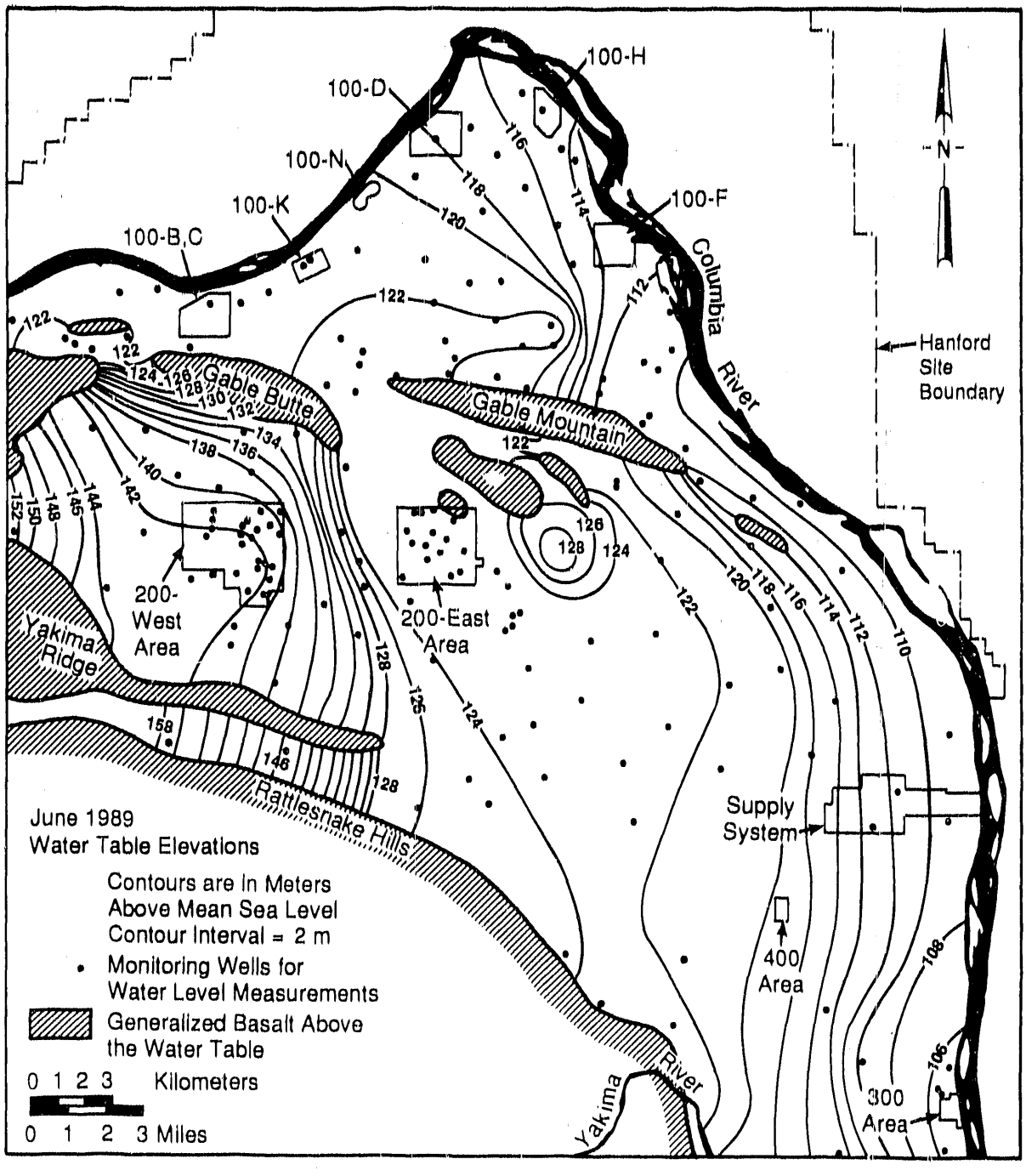

FIGURE 1.3. Water Table Elevations at Hanford for June 1989

Liquid Effluent Movement

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

2.0 Compliance Summary

2.0 COMPLIANCE SUMMARY

The DOE Order 5400.1, "General Environmental Protection Program," defines the mandatory environmental standards that are in effect at DOE operations. These environmental standards fall into three categories: 1) those imposed by federal statutes, regulations, and requirements, 2) those imposed by state and local statutes, regulations, and requirements applicable to DOE, and 3) those imposed by DOE directives. This compliance summary section addresses those standards that are significant for Hanford Site environmental compliance.

Several federal, state, and local agencies are responsible for enforcing environmental regulations at the Hanford Site. The DOE, itself, through its directives to field offices and compliance audits, is the initiating organization. Principal among other agencies are the EPA, the State of Washington Department of Ecology (WDOE), the State of Washington Department of Health (WDOH), and the Benton-Franklin-Walla Walla Counties Air Pollution Control Authority. These agencies issue permits, review compliance reports, participate in joint monitoring programs, inspect facilities and operations, and oversee compliance with applicable regulations.

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

The May 15, 1989, signing of the Hanford Federal Facility Agreement and Consent Order (Tri-Party Agreement) by the DOE, EPA, and WDOE was one of the most significant environmental compliance accomplishments of the year. The Tri-Party Agreement establishes schedules for achieving compliance with requirements for hazardous waste management facilities and provides the framework for the cleanup of Hanford over the next 30 years.

Although progress has been made toward achieving full regulatory compliance at the Hanford Site, much remains to be done. Ongoing self-assessments of the compliance status and implementation of the Tri-Party Agreement continue to identify environmental issues. These issues are being discussed openly with the regulatory agencies to ensure that compliance with all environmental regulations will be attained.

2.1 COMPLIANCE SELF-ASSESSMENT

CLEAN AIR ACT

The purposes of the Clean Air Act are to protect public health and welfare by safeguarding air quality, to bring dirty air into compliance, and to protect clean air from degradation. The provisions of the act are implemented by EPA, WDOH, WDOE, and local air authorities.

Under authority of the Clean Air Act, the EPA has established National Ambient Air Quality Standards at 40 CFR 50 to protect public health and welfare from ambient (criteria) pollutants (oxides of nitrogen and sulfur, carbon monoxide, lead, ozone, and particulates). For clean air areas, EPA has established the Prevention of Significant Deterioration (PSD) program at 40 CFR 51 to protect air quality while allowing a margin for future growth. The EPA has approved the State of Washington's implementation plan for regulating these standards.

The EPA has retained regulatory authority for subparts of the National Emissions Standards for Hazardous Air Pollutants that pertain to Hanford activities. These standards are designed to protect the public from particularly dangerous pollutants (arsenic, asbestos, beryllium, mercury, radionuclides, and vinyl chloride).

The local air authority, the Benton-Franklin-Walla Walla Counties Air Pollution Control Authority, enforces General Regulation 80-7. This regulation pertains to detrimental effects, fugitive dust, incineration products, odor, opacity, and sulfur oxide emissions.

The Hanford Site operates under a PSD permit issued by the EPA in 1980. The permit provides specific limits for emissions of oxides of nitrogen from the Plutonium Uranium Extraction (PUREX) and Uranium Oxide (UO_3) plants. Significant increases in emissions from the Hanford Site of any Clean Air Act regulated pollutant also require agency review of potential impacts to regional air quality and any additional limits that may be necessary in the PSD permit. To date, no additional limits have been added.

On April 28, 1989, all Hanford Site radioactive stacks were registered with the WDOH Office of Radiation Protection. Under authority of the Clean Air Act, Washington Administrative Code (WAC) 402-80 requires such registration for issuance of a radioactive air emissions permit by the State. The State has issued its first permit to the DOE-Richland Operations Office (RL) for the Hanford Site.

During 1989, the Hanford Site air emissions remained below all regulatory limits concerning radioactive and other regulated pollutants. Routine reporting of air emissions is provided to each air quality agency in compliance with requirements.

Asbestos

Approximately 1400 facilities on the Hanford Site have asbestos-containing material. Asbestos construction materials were widely used during the 1940s through 1950s, when many of the Site's facilities were constructed.

All contractors have programs for the control of asbestos-containing material. Primarily, these programs are to provide a safe environment for workers. Activities include the removal and disposal of previously released or damaged asbestos, as well as asbestos removal from

structures being demolished. During 1989, 1006 m^3 of asbestos were removed and disposed in the Hanford Site Central Landfill.

CLEAN WATER ACT

The Clean Water Act applies to all nonradioactive discharges to navigable surface waters. At the Hanford Site, the regulations are applied through a National Pollutant Discharge Elimination System (NPDES) permit for effluent discharges to the Columbia River. The permit holder is DOE-RL; however, Westinghouse Hanford Company and PNL are responsible for operating and monitoring their respective discharges from eight outfalls in compliance with the NPDES permit. The permit was issued in 1981 and is being renegotiated with EPA at this time. For details of this permit, see "Environmental Permits," Section 2.3.

There was only one reportable occurrence, in December 1989, in which a 300 Area discharge sample exceeded the settleable solids parameter. The Hanford Site is in substantive compliance of the discharge limits.

SAFE DRINKING WATER ACT

The National Interim Primary Drinking Water Regulations of the Safe Drinking Water Act apply to the drinking water supplies at the Hanford Site. Sample analysis required to meet sanitary water quality standards is conducted as a joint effort by the Hanford Environmental Health Foundation and PNL. This analysis monitors the quality of the drinking water on the Hanford Site and evaluates compliance with applicable regulations. There are 15 individual drinking water systems on the Site. Ten of the systems use Columbia River water as a raw water source, four systems use ground water, and one system uses a combination of the two. The water supplies are monitored for the contaminants indicated in the regulations and the rules and regulations of the WDOH regarding public water systems. In 1989, with one exception, all water supplies were in compliance with the requirements of the applicable regulations. The one exception concerns the requirement for the correct number of certified operators. An agreement with the WDOH allows for use of noncertified operators as long as they are under constant supervision of certified operators.

COMPREHENSIVE ENVIRONMENTAL RESPONSE, COMPENSATION AND LIABILITY ACT OF 1980/SUPERFUND AMENDMENTS AND REAUTHORIZATION ACT OF 1986 (CERCLA/SARA)

The CERCLA/SARA legislation established a program to identify sites from which releases of hazardous substances into the environment might occur or have occurred, to ensure that such sites are cleaned up by responsible parties or the government, to evaluate damages to natural resources, and to create a claims procedure for parties who have cleaned up sites or spent money to restore natural resources. Hanford must comply with applicable sections of CERCLA/SARA.

The CERCLA/SARA legislation requires that specific procedures be implemented to assess inactive waste sites for the release of hazardous substances. The evaluation procedure is divided into three tiers of activity: preliminary assessments, remedial investigations and feasibility studies (RI/FS), and remedial action(s). Congress has delegated enforcement authority to the EPA to establish procedure manuals to conduct the three-tiered assessment. The EPA procedures are the evaluation standards with which the Hanford Site must comply.

The preliminary assessments conducted for the Hanford Site revealed that there are approximately 1100 known individual waste sites where hazardous substances may have been disposed in an environmentally unsound manner. These 1100 sites have been grouped into 78 operable units, which have been further grouped into 4 aggregate areas using identifiable geographic boundaries on the Hanford Site. The four aggregate areas have been listed on the National Priorities List.

Hanford is actively pursuing the RI/FS process at selected operable units on the Site. The selection of the operable units currently under investigation is a result of negotiations conducted in establishing the plan and schedule contained in the Action Plan of the Tri-Party Agreement. All milestones established for 1989 were achieved. Therefore, the Hanford Site was in compliance with these CERCLA/SARA requirements.

Also, within the SARA, Title III provides for a free-standing law, which is known as the Emergency Planning and Community Right-to-Know Act of 1986. The purpose of Title III is to provide the public with information on the hazardous chemicals in their community and to establish emergency planning and notification procedures to protect the public in the event of a release of hazardous chemicals.

Field representatives throughout the Hanford Site were trained on the regulatory requirements of the SARA Title III community-right-to-know reporting and on supplying information to the newly developed Hazardous Material Inventory Database. The Hanford *Tier Two Emergency and Hazardous Chemical Inventory* (DOE 1989a) was issued on March 1, 1989, to the State of Washington Department of Community Development, local county emergency management committees, and the local fire department. The Hanford *Toxic Chemical Release Inventory* (DOE 1989b) was issued to EPA and WDOE on July 1, 1989.

Under Section 103(a), the Emergency Release Notification provision of CERCLA, releases exceeding reportable quantity limits for regulated chemicals must be appropriately reported. The following four notifications, as required, were made to the National Response Center during CY 1989:

- Approximately 29 kg of uranium were released to two cribs and one pond between May 22 and July 12, 1989. This amount was above the reportable quantity of 0.45 kg per day.

- On May 10, 1989, an estimated 0.9 to 5.4 kg of hydrazine were discharged to the 1325-N Liquid Waste Disposal Facility in the 100-N Area. This release exceeded the CERCLA reportable quantity of 0.45 kg per day.

- On August 8, 1989, an estimated 0.6 kg of hydrazine were discharged to the 1325-N Liquid Waste Disposal Facility, again exceeding the reportable quantity limit.

- Releases of dissolved ammonia that exceeded CERCLA and WAC 173-303 limits were reported to the National Response Center after the fact.

Note: These four releases, which required reporting to the National Response Center, are summarized in "Environmental Occurrences," Section 2.6.

The Hanford Site was in compliance with the reporting and notification requirements contained in the SARA, Title III Emergency Planning and Community Right-to-Know Act of 1986.

FEDERAL INSECTICIDE, FUNGICIDE, AND RODENTICIDE ACT (FIFRA)

Herbicides and pesticides are used on the Hanford Site to control revegetation growth on waste sites. The FIFRA and WAC 16-228 apply to storage and use of herbicides and pesticides at the Hanford Site. Herbicides and pesticides are applied by personnel licensed by the State of Washington as commercial pesticide operators. The Hanford Site is in compliance with FIFRA and WAC 16-228 regulations pertaining to application of pesticides.

RESOURCE CONSERVATION AND RECOVERY ACT OF 1976 (RCRA)

The RCRA establishes regulatory standards for the generation, transportation, storage, treatment, and disposal of hazardous waste. The WDOE has been authorized by EPA to implement RCRA in the State of Washington. While the State of Washington's Dangerous Waste Regulations (WAC 173-303) must follow the RCRA requirements, the State's regulations are consistently more stringent.

The Hanford Site has identified more than 50 treatment, storage, and disposal units that must be permitted or closed in accordance with RCRA and WAC 173-303. Some of the treatment, storage, and disposal units contain numerous individual components (e.g., the single-shell tank treatment, storage, and disposal unit includes 149 separate tanks). The treatment, storage, and disposal units are being operated under interim-status compliance requirements of the State's regulations. Approximately one third of the units will be closed under RCRA interim status; applications for RCRA's Part B operating permits will be made for those units remaining.

During 1989, 22 underground storage tanks used to store either petroleum or noncontaminated chemical products were removed from the ground and disposed of. This work was performed in accordance with 40 CFR 280 and 40 CFR 281. These regulations are required by RCRA Subtitle I. In addition to removing the 22 tanks, 11 other tanks were also inspected and tested for integrity. Notification of leaking tanks was made to WDOE.

Compliance with RCRA requirements has become the major regulatory effort. Examples of compliance issues include the following: inconsistencies between RCRA requirements associated with the management of mixed waste and as-low-as-reasonably-achievable (ALARA) prohibitions promulgated by the Atomic Energy Act, management of special nuclear material scrap as RCRA-regulated waste, storage of liquid mixed waste in underground tanks that do not meet underground storage tank requirements, and onsite storage activities in violation of the land disposal restriction rule.

From 1987 to 1989, self-assessments were completed at each interim-status treatment, storage, and disposal unit to ensure that RCRA interim-status requirements were being met. Corrective action schedules were developed for identified deficiencies. Those deficiencies not corrected at the end of the year were incorporated as Tri-Party Agreement-enforceable milestones and target dates. One exception is that corrective actions for dangerous waste tanks are still to be negotiated.

The RCRA corrective action requirements for inactive waste sites are being complied with under the Tri-Party Agreement. In many cases, it is not clear whether CERCLA or RCRA, or both, requirements are applicable for site remediation. The Tri-Party Agreement allows a determination of the required cleanup actions and the responsible regulatory agency.

ENDANGERED SPECIES ACT

A few rare species of native plants and animals are known to occur on the Hanford Site. Some of these are listed by the U.S. Fish and Wildlife Service as endangered or threatened (federally listed). Others are listed by the State of Washington as endangered, threatened, or sensitive species. The status of the bald eagle and ferruginous hawk is reported each year to various regulating agencies. The status of other species is reported as information becomes available.

TOXIC SUBSTANCE CONTROL ACT

The application of Toxic Substance Control Act requirements to Hanford essentially involves regulation of polychlorinated biphenyl (PCB). Federal regulations for use, storage, and disposal of PCBs are found in 40 CFR 761. State of Washington dangerous waste regulations for managing PCB waste are listed in WAC 173-303.

Varyingly concentrated PCBs are found in electrical equipment throughout the Site. All transformers have been characterized, and all large capacitors containing PCBs have been identified. Many PCB (>500-ppm) transformers and large capacitors have been replaced or retrofilled, and a risk assessment has been completed for all remaining transformers to aid in removal of the PCBs.

Decommissioned submarine reactor compartments, shipped by the U.S. Navy to Hanford for burial, were found to contain PCB-contaminated sound-dampening and electrical wiring. The U.S. Navy is removing most of the contaminated material from those already at Hanford and newly decommissioned compartments. However, sufficient residual PCBs remain to cause the disposal trench to be regulated by EPA. A Memorandum of Agreement between EPA and DOE will form the basis for compliance. Waivers from chemical waste landfill requirements for PCBs (and lead) in the compartments are required, or it will be necessary to reconstruct the disposal trench for hazardous waste disposal.

The Hanford Site is currently in compliance with regulations for nonradioactive PCBs. Instances exist at Hanford in which PCB materials are not in compliance due to radioactive contamination. Hydraulic oils from processing facilities contaminated with small quantities of plutonium are being stored until an acceptable treatment and disposal process is identified. The EPA is periodically notified of this continued practice.

NATIONAL ENVIRONMENTAL POLICY ACT (NEPA)

The NEPA requires that projects with potentially significant impacts are carefully reviewed and reported to the public in documents, such as environmental assessments or environmental impact statements. The NEPA documents are prepared and reviewed according to the procedures in DOE Order 5440.1C, "National Environmental Policy Act," and DOE-RL Order DOE-RL 5440.1A, "Implementation of National Environmental Policy Act."

The DOE complies with the requirements of NEPA by implementing the Council on Environmental Quality regulations. Regulations covering DOE's NEPA activities are found in 10 CFR 1021 and 40 CFR 1022. The DOE NEPA guidelines are in 52 FR 47662, December 15, 1987.

Preparation of the environmental impact statement, *Decommissioning the Eight Shutdown Production Reactors Located at the Hanford Site, Richland, Washington* (DOE 1989e), began in FY 1985. This document addresses the decommissioning alternatives for the eight surplus production reactors in the 100 Areas. The alternatives being considered include no action, immediate one-piece removal, safe storage followed by deferred dismantlement, and in situ (in-place) decommissioning. The draft environmental impact statement was released to the public for a 90-day review that ended July 28, 1989; preparation of the final is in progress.

One environmental assessment for Hanford, *SP-100 Ground System Test Site* (DOE 1988c), was issued in September 1989.

A self-assessment of NEPA application to Hanford activities has established that all major projects are in compliance, but NEPA requirements have not been consistently applied to small projects.

THE NATIONAL HISTORIC PRESERVATION ACT, THE ARCHAEOLOGICAL RESOURCES PROTECTION ACT, AND THE AMERICAN INDIAN RELIGIOUS FREEDOM ACT

Cultural resources on the Hanford Site are subject to the provisions of the National Historic Preservation Act, the Archaeological Resources Protection Act, and the American Indian Religious Freedom Act. Compliance with the applicable regulations is accomplished through an active monitoring program that includes 1) review of all proposed land-disturbing projects to assess potential impacts on cultural resources and 2) periodic inspections of known archaeological and historical sites to determine their condition and the effects of land management policies on the sites. The 1989 program activities are described in "Environmental Permits," Section 2.3.

2.2 CURRENT ISSUES AND ACTIONS

COMPLIANCE AGREEMENT AND PUBLIC INVOLVEMENT

Tri-Party Agreement

The Hanford Federal Facility Agreement and Consent Order (Tri-Party Agreement) is an agreement among the EPA Region 10, WDOE, and DOE for achieving full compliance with CERCLA/SARA and RCRA. The Tri-Party Agreement 1) defines and ranks RCRA and CERCLA cleanup commitments with the regulatory agencies, 2) establishes responsibilities and integrates complex and overlapping regulations, 3) provides a basis for obtaining funding for cleanup, and 4) reflects a concerted effort to achieve full regulatory compliance and cleanup, with enforceable milestones, in an aggressive but achievable manner. The Tri-Party Agreement was established with considerable input from the public, and any changes are made only after consideration of public review and comment. The agreement and quarterly progress reports are made available at the DOE-RL Public Reading Room in Richland, Washington, and at information repositories in Seattle and Spokane, Washington, and Portland, Oregon.

The Tri-Party Agreement consists of two parts, a legal agreement and an Action Plan. The legal agreement establishes jurisdictions, authorities, and other legal determinations among the parties. The Action Plan implements the Tri-Party Agreement by defining how the parties will work together, describing the processes and procedures to be followed, defining the units to be addressed, and scheduling the work.

The five specific areas of involvement defined by the Tri-Party Agreement include

1. identifying treatment, storage, and disposal units that require permits and establishing schedules to comply with interim- and final-status requirements; as applicable, RCRA Part B applications will be completed, closures accomplished, and post-closure care implemented

2. identifying interim action alternatives appropriate to implement final RCRA corrective and CERCLA remedial actions

3. establishing requirements for performing investigations to determine the nature and extent of threats to public health or the environment caused by releases and for studies to identify, evaluate, and select alternatives for controlling possible release

4. identifying the nature, objective, and schedule of response actions for cleanup of hazardous materials

5. implementing the selected interim and final RCRA corrective and CERCLA remedial actions.

The Action Plan, through enforceable milestones, establishes a plan and schedule for bringing the Hanford Site into compliance with applicable requirements of RCRA and all remedial action requirements of CERCLA. During 1989, the first 30 milestones were met as scheduled. Included in these milestones were the following activities:

- submitted three RCRA permit applications and three closure plans for Hanford treatment, storage, and disposal facilities

- submitted seven CERCLA RI/FS or RCRA facility investigation/corrective measures study (RFI/CMS) work plans for inactive waste sites

- stabilized three single-shell waste storage tanks

- obtained 15 core samples from 2 single-shell waste storage tanks for analysis

- completed design of an expanded laboratory for high-level radioactive mixed waste sample analysis

- completed a project to upgrade the PUREX demineralizer regeneration neutralization system

- completed assessments of all facilities operating under interim status for compliance with RCRA and WAC 173-303 interim-status requirements, and established enforceable milestones for meeting interim-status requirements of RCRA

- installed 29 RCRA ground-water monitoring wells.

Negotiations are currently under way to amend the Tri-Party Agreement by adding compliance agreements for extended storage of land disposal restricted waste and compliance schedules for dangerous waste tanks.

Community Relations Plan

A community relations plan was developed and negotiated among DOE, WDOE, and EPA Region 10 to lay out plans for community relations and public involvement that will be conducted in conjunction with the Tri-Party Agreement. The plan is required as part of CERCLA. The plan was issued in August 1989, following a public comment period. Changes to the community relation plan were also developed during 1989 and were submitted for public comment. These changes updated information contained in the plan and will be approved by the three parties during 1990.

The goal of the community relations plan is to provide the public with timely and accurate information about cleanup, permitting, and closure activities at the Hanford Site. To meet this goal, DOE, WDOE, and EPA have been conducting activities to inform and involve citizens of the Northwest in the hazardous waste management activities at Hanford. Specific meeting dates are announced about 3 weeks in advance through the *Hanford Update* newsletter, which is mailed to more than 1200 people. These dates are also announced in news releases and paid newspaper advertisements.

OTHER ENVIRONMENTAL ISSUES

Alternatives to Disposal to Soil Column

Disposal of contaminated liquid effluents to the soil column is being phased out according to a plan and schedule developed in 1987 and revised in succeeding years based on altered missions, changing regulatory positions, and experience gained. Replacement technologies are being developed and include several new facilities for liquid waste treatment and disposal.

Presented below is a summary of activities and changes that have occurred as reported in the

Annual Status Report for the Plan and Schedule to Discontinue Disposal of Contaminated Liquid into the Soil Column at the Hanford Site (Millikin 1989):

- completed the PUREX Plant chemical sewer demineralizer regeneration neutralization system

- completed the PUREX Plant process condensate final neutralization system and the diversion record pH monitor

- completed various engineering and design documents for all Phase I and Phase II streams.

U.S. NUCLEAR REGULATORY COMMISSION (NRC) DETERMINATION THAT GROUTED WASTE IS LOW-LEVEL WASTE

In the spring of 1988, the NRC raised the concern that some of the double-shell tank waste to be grouted might be high-level waste and, therefore, would be under their licensing jurisdiction. Their concern centered on the high-level waste definition of 10 CFR 50 Appendix F, which is a source-based definition rather than a concentration- or risk-based definition. Subsequently, the NRC agreed with DOE that grout is low-level waste and not high-level waste because the waste qualified as "incidental waste" (i.e., while some of the waste may have originated as a high-level waste source, it had been treated and primarily reflected chemicals used in the process that were contaminated with only small residual amounts of radionuclides).

The State of Washington expressed concern about the manner in which NRC made the decision and the level of public participation. Hence in December 1989, the states of Washington and Oregon and the Yakima Indian Nation filed a Notice of Intent to petition the NRC to amend 10 CFR 50 to add language clarifying that all Hanford double-shell tank wastes are high-level waste, unless the DOE could demonstrate on a tank-by-tank basis that they are not.

POTENTIAL FOR FERROCYANIDE EXPLOSION IN UNDERGROUND WASTE TANKS

During October 1989, a concern was raised that the ferrocyanide nitrate, which was added to 22 of the 149 single-shell tanks in the 1950s as part of a waste-volume reduction program, may pose an explosion hazard. Under certain conditions of chemical concentration, moisture, and temperature, ferrocyanide and nitrates in the tanks may undergo exothermic reactions and potentially become explosive. The ferrocyanide nitrate issue has been discussed before (e.g., the Oregonian story "N-Waste tanks pose threat of blast" reported on July 2, 1986, and DOE 1987a).

The WDOE sent a preliminary team to Hanford on October 17, 1989, to investigate this issue. They concluded that no immediate explosive potential exists, but they did make the following preliminary recommendations:

- repair or replace temperature probes in all tanks containing ferrocyanide nitrate

- conduct additional tests to determine the conditions necessary for a reaction of ferrocyanide nitrate

- assess the feasibility of tank chemical reaction detection methods

- conduct detailed reviews of the effects of organic materials decomposition, the potential for gas pocket generation, and associated pressure and temperature increases.

On October 23, 1989, Governor Booth Gardner directed WDOE and the WDOH to conduct an in-depth independent investigation of the explosive potential of single-shell tanks. This investigation will continue during 1990.

LAND DISPOSAL RESTRICTIONS

Land disposal of hazardous wastes that are considered by the EPA to be harmful to human health and the environment is prohibited by RCRA. The land disposal restrictions also prohibit storage of restricted hazardous waste unless such storage is to accumulate sufficient quantities of the waste to facilitate proper treatment, recovery, or disposal.

Until 1987, all radioactive wastes were exempt from RCRA requirements; therefore, radioactive wastes that contained hazardous waste (i.e., mixed waste) were not considered during statutory development and promulgation of earlier land disposal restrictions for solvents, dioxins, and other RCRA-listed wastes. This has created a situation in which the short-term statutory dates for wastes covered by land disposal restrictions conflict with the realities of long-term development of treatment capacity for DOE mixed waste.

The major land disposal restriction compliance issue for mixed waste is prohibition on storage of restricted waste. A large majority of Hanford's mixed waste is stored in tanks and containers awaiting treatment technology development and subsequent treatment. Storage for this purpose does not appear to be allowed by RCRA land disposal restrictions. A revision to the Tri-Party Agreement is being negotiated with EPA and WDOE to incorporate land disposal compliance actions for mixed waste.

2.3 ENVIRONMENTAL PERMITS

PREVENTION OF SIGNIFICANT DETERIORATION (PSD) PERMIT

Section 110 of the Clean Air Act is implemented in part through the PSD rules addressed in 40 CFR 52. The PSD regulations were originally implemented by EPA on August 7, 1980, to ensure that air quality does not significantly deteriorate, while maintaining a margin for future industrial growth. The WDOE operates under an EPA-approved State Implementation Plan to administer and enforce the PSD requirements. The WAC 173-403-80, as in effect on July 1, 1988, provides the state PSD regulations and adopts the requirements specified in 40 CFR 52.21.

The Hanford Site PSD permit (PSD-X80-14) was issued by the EPA on September 30, 1980, with no specified expiration date for the permit. The permit provides specific mass emission limits for oxides of nitrogen from the PUREX and UO_3 plants. The PSD regulations also require review and preconstruction approval of any significant new or increased emissions of pollutants regulated under the Clean Air Act. One condition of such approval is demonstration that best available control technology will be utilized for significant pollutants.

REGISTRATION OF RADIOACTIVE AIR EMISSION STACKS

Because the Hanford Site is considered as one "major source" of air emissions under terms of the PSD regulations, all proposed new or increased air emissions on Site must be tracked and summed to determine if a significant increase in emissions will occur and trigger the requirement for PSD review and approval. Any additional limits determined by WDOE to be necessary to protect air quality will be written into the existing PSD permit.

The WDOH Division of Radiation Protection regulatory controls for radioactive air emissions are provided in Section 116 of the Clean Air Act. The WAC 402-80 requires registration with the WDOH of all radioactive air emission point sources. All stacks that are routinely monitored for radionuclide releases have been registered with the WDOH, and on August 15, 1989, the WDOH issued its first radioactive source registration permit (FF-01) to DOE-RL. The permit is issued for a 2-year period of limited radioactive air emissions from Hanford operations. A total of 130 stacks are currently registered with the WDOH and are operated under the permit.

NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM (NPDES) PERMIT

An NPDES permit for the Hanford Site (WA-000374-3) governs discharges to the Columbia River. This permit is required by the Clean Water Act. The permit was issued December 7, 1981, expired December 31, 1985, and is currently being renegotiated. Until a new permit is issued, conditions of the expired permit remain in effect.

The NPDES permit specifies discharge points (of which there are eight), effluent limitations, and monitoring requirements. Above-limit conditions are detected by a routine sampling and analysis program for each of the eight discharge points. Sampling requirements include temperature, flow, pH, free available chlorine, total suspended solids, oil and grease, iron, ammonia, and chromium. The results of

sampling are reported to EPA Region 10 and WDOE on a monthly basis.

The eight separate discharge points included in the Hanford Site NPDES permit are as follows:

003	181-KE inlet screen backwash (100-K Area)
004	1908-K outfall (100-K Area)
005	Tank farm storage water overflow (100-N Area)
006	182-N building drain (100-N Area)
007	181-N inlet screen backwash (100-N Area)
009	Raw water return (100-N Area)
013	PNL fish laboratory facility (300 Area)
N-Springs	A nonpoint source along the Columbia River bank emanating from the 1301-N and 1325-N cribs (100-N Area)

RESOURCE CONSERVATION AND RECOVERY ACT (RCRA) PERMIT

The Hanford Site has been assigned a single dangerous waste permit identification number by the EPA and WDOE. This identification number (WA7890008967) encompasses all treatment, storage, and disposal waste management units on the Hanford Site. The 58 treatment, storage, and disposal units on the Hanford Site are co-operated by DOE-RL and two of its major contractors (50 by Westinghouse Hanford Company and 8 by PNL). Approximately one third of these units will be closed; the remaining will be permitted for operation. The plan, approach, and schedule for meeting RCRA requirements for treatment, storage, and disposal waste management units operating at the Hanford Site are outlined in the Action Plan of the Tri-Party Agreement.

Because all treatment, storage, and disposal waste management units cannot be permitted simultaneously, WDOE and the EPA will issue the initial permit for less than the entire facility. Each operating unit will be added as a major modification to the permit as documentation is completed in accordance with the Action Plan schedule. The initial permit for the Hanford Site has not been issued but is expected by December 1990.

WILDLIFE COLLECTION PERMITS

The Hanford Site has three permits for wildlife and fish sampling. Scientific study or collection permits 131 and 101 have been issued to PNL and Westinghouse Hanford Company, respectively, by Washington State Department of Wildlife for the collection of wildlife, including fish for environmental monitoring purposes. A federal fish and wildlife permit No. 671877 has been issued to PNL by the U.S. Fish and Wildlife Department.

2.4 U.S. DEPARTMENT OF ENERGY DIRECTIVES

RADIATION PROTECTION STANDARDS

Operations at the Hanford Site are controlled to conform to various federal and state standards and permits. Radiological releases are regulated by DOE orders pursuant to the Atomic Energy Act, the Clean Air Act, and the Safe Drinking Water Act.

In 1985, DOE issued revised radiation protection standards that incorporate a system for evaluating and controlling radiation exposures to members of the public in uncontrolled areas. The revisions are based on recommendations of the International Commission on Radiation Protection (ICRP 1977, 1979-1982).[a] The standards limit the whole-body dose equivalent to members of the public to 100 mrem/yr for prolonged exposures and to 500 mrem/yr for occasional noncontinuous exposure (not to exceed 5 consecutive years). This standard limits the dose equivalent to 25 mrem/yr whole body dose and 75 mrem/yr to any organ for air pathways, in compliance with 40 CFR 61.92 Subpart H (EPA 1988e).

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

DOE ORDER 5400.1, GENERAL ENVIRONMENTAL PROTECTION PROGRAM

The DOE Order 5400.1, "General Environmental Protection Program," directs all DOE sites to comply with applicable environmental regulations. The order became effective November 9. 1988, and combines several predecessor orders into a single document for environmental compliance. The order provides direction for the effluent monitoring program, environmental surveillance, ground-water monitoring, waste minimization, occurrence reporting, quality assurance, independent verification, and compliance and program reporting. DOE Order 5400.1 also provides guidance on the preparation of the Site environmental report, submission of A-106 pollution abatement reports, long-range environmental protection plans, ground-water protection plans, and waste minimization/pollution prevention awareness plans. The Hanford Site complied with requirements of the order in calendar year (CY) 1989.

DOE ORDER 5820.2A, RADIOACTIVE WASTE MANAGEMENT

A DOE Order 5820.2A, "Radioactive Waste Management," establishes policies and guidelines for managing radioactive waste and contaminated facilities. Many of the requirements are similarly contained in DOE Order 5400.1, such as effluent monitoring and waste minimization programs. The DOE-RL has implemented the DOE Order 5820.2A for the Hanford Site, as described in *Implementation Plan*

(a) These revisions are contained in a DOE guidance memorandum, "Radiation Standards for Protection of the Public in the Vicinity of DOE Facilities," Revision 1, September 3, 1985 (see Table B.5, Appendix B).

for Hanford Site Compliance with U.S. Department of Energy Order 5820.2A (DOE 1989d). The Hanford Site is in compliance with most of the provisions of the order; full compliance with the provisions contained in DOE Order 5820.2A will take several years to accomplish. For example, the requirement to dispose of retrievable high-level waste cannot be fully implemented until a national repository is constructed to receive high-level waste.

2.5 ENVIRONMENTAL AUDITS

FACILITY COMPLIANCE ASSESSMENTS

Beginning in 1987, Hanford implemented an aggressive self-assessment program for dangerous waste management facilities. Self-assessments were performed from mid-1987 through mid-1989 for permitted dangerous waste facilities and all major operating facilities with significant environmental effluents.

During 1989, 11 major operating facilities were assessed to evaluate compliance with environmental requirements. In addition, all significant interim-status waste management units have now been assessed for compliance with RCRA requirements. By the end of 1989, 65% of the findings of these audits had been corrected. The remaining findings have been included as enforceable milestones for the Tri-Party Agreement.

U.S. ENVIRONMENTAL PROTECTION AGENCY INSPECTION

The EPA Region 10 conducted the annual inspection for compliance with hazardous waste regulations from August 28 through 31, 1989. The EPA has been conducting these annual inspections since 1985. The 1989 inspection was the most successful inspection to date, with no findings (significant violations) noted and only a dozen observations (minor violations, such as faded labeling of waste containers). Corrective actions for all but two of the observations were completed in 1989, and actions were under way to correct the remaining two.

NOTICES OF VIOLATION

Three Notices of Violation were issued by WDOE concerning treatment, storage, and disposal facilities. Corrective actions required by these Notices of Violation were all completed in 1989.

- A WDOE inspection of B Pond and the nonradioactive dangerous waste landfill on April 10 and 11, 1989, resulted in a Notice of Violation. The notice cited a lack of security and warning signs around B Pond, a 7.6 m breach in the security fence surrounding the nonradioactive dangerous waste landfill, and questioned the stability of the wooden pier over the 216-A-29 ditch.

- A WDOE inspection of the 183-H Solar Evaporation Basins and the S-10 pond and ditch on June 12, 1989, resulted in a second Notice of Violation. The notice cited lack of security around the S-10 pond and ditch and two corroded and potentially leaking drums containing mixed waste located at the 183-H Solar Evaporation Basins.

- A WDOE inspection of the 216-A-29 ditch, 216-B pond, and the Central Waste Landfill Complex on June 20, 1989, also resulted in a Notice of Violation. The notice cited lack of security and need to construct a chain fence with warning signs around the 216-A-29 ditch; lack of radiation warning signs near the 216-A-29 ditch and 216-B pond facilities; and 10 waste drums at the Central Waste Landfill Complex that had exceeded the 90-day accumulation period.

2.6 ENVIRONMENTAL OCCURRENCES

Onsite and offsite environmental occurrences (spills, leaks, etc.) of radioactive effluent materials during 1989 were reported to DOE by onsite contractors. Environmental occurrences of nonradioactive chemical wastes were reported to other federal and state agencies as required by law. The specific agencies notified depended on the type, amount, and location of the individual occurrences. Generally, effluents were dispersed naturally, stabilized in existing waste disposal sites, or controlled and cleaned up. In some cases, particularly where the contaminants may have reached the ground water, the environmental impact is under continuing observation and evaluation. Occurrence reports, including event descriptions and corrective actions, are available for review in the DOE-RL Public Reading Room at the Federal Building, Richland, Washington. The 1989 occurrences with the greatest potential environmental impacts are summarized below.

URANIUM RELEASE (WHC-UO-89-053-PUREX-11)

The DOE environmental radiation protection standards were inadvertently cancelled on January 1, 1989, when the DOE order (5480.1B) containing these standards was revised. This cancellation resulted in the loss of the federally permitted environmental release exemption under CERCLA. Regulations in CERCLA restrict the discharge of unregulated radionuclides to less than 0.45 kg (1.0 lb) per day. The DOE exemption was reinstated on July 20, 1989; however, a review of Hanford releases on November 3, 1989, revealed that uranium discharge violations had occurred in late May when the CERCLA exemption was not in effect. Although the events were reported promptly when it was realized that a violation had occurred, reporting to the National Response Center is mandatory at the time of occurrence. These events went unreported, initially, because the uranium releases were all within control limits established in Westinghouse Hanford Company procedures, and DOE-RL and Hanford contractor personnel were unaware of the cancelled DOE standards until September 1989.

During routine start-up testing of the E-H4 concentrator at PUREX, in late May 1989, a steam tube bundle failed. The resulting high beta-gamma radiation readings caused the steam condensate discharge, normally directed to the steam condensate discharge crib, to automatically divert to the PUREX retention basin. A subsequent leak test of the tube bundle reactivated the alarm, confirming the existence of a leak. The resultant accumulation of 29 kg (63.2 lb) of uranium in the cribs and retention basin [21.5 kg (47.4 lb) from the initial leak and 7.53 kg (16.4 lb) from the test] was within documented Westinghouse Hanford Company guidelines and transferred to B Pond in early July 1989. The total amount of uranium released over a 22-day period exceeded the CERCLA limit of 0.45 kg (1.0 lb) per day.

HYDRAZINE RELEASE (WHC-UO-89-026-100N-01)

On May 10, 1989, in an attempt to maintain water quality standards, extra hydrazine was added to the N Reactor coolant. This caused an excess of unreacted hydrazine in the effluent

discharged to the 1325-N Liquid Waste Disposal Facility. Calculations, based on effluent flow rates and sample analyses, indicated the CERCLA reportable quantity for hydrazine [0.45 kg (1.0 lb) per day] had been exceeded. The hydrazine released was estimated to range between 0.9 and 5.4 kg (2.0 and 11.9 lb). As a result, the discharge of effluent and injection of hydrazine were reduced. Monitoring of hydrazine in the discharge continued.

HYDRAZINE RELEASE AT 100-N (WHC-UO-90-042-100N-03)

Approximately 0.59 kg (1.3 lb) of hydrazine were discharged to the 1325-N Liquid Waste Disposal Facility on August 8, 1989. This exceeded the CERCLA reportable quantity of 0.45 kg (1.0 lb) per day. This release occurred when the concentration of hydrazine in the graphite shield cooling system was found to be inadequate for impeding corrosion and the amount of hydrazine injected into the system was increased. The injection pump was allowed to operate for a longer time and at a higher pumping rate than normal. Effluent samples taken while the pump was still running showed elevated hydrazine levels. When the pump was shut down, hydrazine discharge levels returned to normal.

RELEASE OF CONTAMINATED WATER AT THE UO_3 PLANT (WHC-UO-89-048-PUREX-10)

During early September 1989, an estimated 16,730 L (4420 gal) of uranium-contaminated water leaked from a concrete sump (C Cell) at the UO_3 Plant into the surrounding soil. Based on the volume released and a water concentration of 0.7 g of uranium per liter (0.01 lb/gal), the total uranium loss approximated 12.1 kg (26.7 lb). Because the uranium concentration was low and the pH of the water was near 3.5, no state, federal, or Westinghouse Hanford Company operating contractor regulations were violated. Planned action includes testing the sump for leakage, repairing the water-level alarm system, and resealing the sump walls and floor, if necessary.

AMMONIA DISCHARGES AT THE 241-AW TANK FARM AND 242-A EVAPORATOR (WHC-UO-89-043-TF-06)

Under CERCLA section 103(f), notification of the National Response Center is not required for routine releases of hazardous substances in above-reportable quantities if the release is continuous, stable in quantity and rate, and initial and annual summary notifications of the continuous releases are made. Such notifications have been made for some Hanford Site chemical processing and waste management facilities. Additional notifications are required if there is any statistically significant increase in the quantity of hazardous substance being released.

During 1989, the discharge from the 242-A Evaporator was reassessed and found to contain ammonia, not ammonium hydroxide as the EPA had been notified. As a result, in August 1989, notifications were made that above-reportable quantities of ammonia had been released from the 242-A Evaporator approximately 161 times between January 1, 1988, through August 24, 1989. Twenty of these releases exceeded the Washington State dangerous waste criteria. In August 1989, notification was also made about four statistically significant releases of ammonia from the 241-AW Tank Farm Exhaust during

1988. There were no statistically significant releases of ammonia from tank farms during 1989.

Plans for limiting such releases in the future include developing procedures for identifying ammonia species in discharges and prompt analysis of ammonia releases. Additionally, at the 242-A Evaporator, treatment processes and operating procedures will be changed to maintain ammonia discharges below Washington Administrative Code 173-303 limits.

3.0 Environmental Program Information

3.0 ENVIRONMENTAL PROGRAM INFORMATION

It is DOE policy to conduct its operations in an environmentally safe manner and to comply with the letter and spirit of applicable environmental standards. At Hanford, a variety of environmental activities are performed to comply with laws and regulations, to enhance environmental quality, and to monitor the impact of environmental pollutants from Site operations.

The environmental management activities described here are discussed in the *Environmental Restoration and Waste Management Five-Year Plan* (DOE 1989c). The environmental surveillance activities include a description of the scope, design, and activities of the programs covering Hanford surface- and ground-water surveillance. The environmental studies and programs include those relating to wildlife resources, cultural resources, meteorology and climatology, and Hanford dose reconstruction.

3.1 ENVIRONMENTAL RESTORATION AND WASTE MANAGEMENT

The cornerstone and framework for DOE's long-term strategy in environmental restoration and waste management at Hanford is the DOE-Headquarters (HQ) *Environmental Restoration and Waste Management Five-Year Plan* (DOE 1989c). This annually updated document consists of a DOE-HQ plan and a Hanford Site specific plan. Originally released in August 1989 for a 90-day public comment period, the document is now being revised and will be reissued in May 1990.

ENVIRONMENTAL RESTORATION

The environmental restoration program has been established, as mandated by Congress in 1988, to remediate inactive waste sites, to decontaminate and decommission surplus facilities, and to provide for technology development and demonstration. The Hanford Site has established three major programs for implementing these actions, which are fully defined in *Environmental Restoration and Waste Management Five-Year Plan* (DOE 1989c).

Environmental Restoration Remedial Action

The environmental restoration remedial action program was established to comply with regulations for characterization and cleanup of inactive waste sites. The program specifically includes identification and characterization of inactive sites, remedial design and cleanup action, and postclosure activities of inactive radioactive, chemically hazardous, and mixed waste sites.

The Hanford Site has identified over 1100 inactive waste management units. These have been grouped into 78 operable units, based on common characteristics of individual sites, similarity of waste disposal practices, and amenability to remediation. The 78 operable units have been further grouped into four aggregate areas using identifiable geographic boundaries on the Hanford Site (100, 200, 300, and 1100 Areas). The four aggregate areas have been listed on EPA's National Priorities List. In addition to the 78 operable units, four special operable units have been created to characterize and remediate the ground water under the Hanford Site.

Operable units form the basis for planning, scheduling, budgeting, and establishing the working order for some of the environmental restoration milestones for the Tri-Party Agreement. The DOE is actively pursuing the remedial investigation/feasibility study process at selected operable units on the Site. These include units in all four aggregate areas. The units in the 1100 Area have been given high priority because of their proximity to drinking water sources for the city of Richland.

The environmental restoration remedial action program will support development of optimal waste retrieval and in-place disposal technologies for the several types of single-shell tank wastes. These efforts will include the removal and analysis of at least 177 core samples from the wastes, a very complex and expensive process.

Environmental Restoration Decontamination and Decommissioning

Many DOE-owned facilities at the Hanford Site that were used for nuclear materials production have been retired from service and declared surplus. The Hanford surplus facilities program provides for managing these facilities for the DOE. The program provides for surveillance and maintenance, as well as eventual decontamination and decommissioning (D&D), of these facilities.

There are currently 115 separate facilities managed through the program, consisting of large concrete and cement block structures used to house chemical separations processes, nuclear production reactors, underground effluent water systems and storage tanks, and ancillary buildings. Included are the eight graphite-moderated plutonium production reactors constructed between 1943 and 1955. The reactors have now been shut down for approximately 20 years.

The activities currently under way include the 183-H Solar Evaporation Basins cleanup in accordance with the interim closure plan; D&D of the 201-C Strontium Semiworks; D&D of several 100 Areas ancillary facilities; and preparation of the final environmental impact statement (EIS) based on the draft EIS, *Decommissioning the Eight Shutdown Production Reactors Located at the Hanford Site, Richland, Washington* (DOE 1989e). The draft EIS, which has been released for public review, discusses various methods for their decommissioning.

Decommissioning of the current inventory of surplus facilities is scheduled to be completed in approximately 30 years at an estimated total cost of $600 million.

Environmental Restoration Technology Development and Demonstration

Much of the funding for developing and demonstrating environmental restoration technology is provided by the Hazardous Waste Remedial Action Program (HAZWRAP), which is managed by the DOE-Oak Ridge Operations Office. Other funding sources provide for the remainder of the effort.

Environmental restoration technology development and demonstration programs are divided into two main categories: 1) HAZWRAP and 2) technology development and demonstration. The HAZWRAP for the Hanford Site consists of three categories of projects. The projects that will be active during FY 1989-1995 include 1) demonstration projects, 2) research and development projects, and 3) a hexone tank waste treatment project.

The HAZWRAP demonstration projects include a waste acid pilot plant demonstration, an in situ vitrification demonstration for contaminated soil sites and underground storage tanks, a biological treatment demonstration on one ground-water stream, a study on the movement of and what happens to polychlorinated biphenyls during in situ vitrification, and a demonstration of in situ heating.

The HAZWRAP research and development projects include organic waste destruction by in situ heating, waste acid detoxification and reclamation, in situ electrochemical oxidation of hazardous waste, catalytic destruction of hazardous organics in aqueous wastes, biodegradation of hazardous waste using white rot fungi, development of biological treatments, biodehalogenation of contaminated aquifers, and in situ biological treatment of ground water.

The HAZWRAP hexone tank waste treatment project will demonstrate technology to treat mixed waste (primarily hexone, paraffin hydrocarbons, tributyl phosphate) stored in two underground waste tanks and to dispose of any residues.

WASTE MANAGEMENT

Waste management consists of the safe and effective management of active and standby facilities and the treatment, storage, and disposal of radioactive, hazardous, and mixed waste. These activities require implementing plans that provide for all active treatment, storage, and disposal facilities to attain and maintain compliance with regulations that will allow the facilities to be permitted as required by the Resource Conservation and Recovery Act (RCRA); some of the actions to fulfill this requirement are described below as corrective activities. An important effort is to minimize the generation of waste and to provide safe storage for any newly generated wastes.

The four Site contractors have integrated waste minimization and pollution prevention awareness programs into a single, coordinated initiative. This initiative is being implemented through awareness, training, and procurement programs appropriate to each contractor's mission and needs. These programs are being given top management support and are being coordinated by special task forces by the two largest contractors.

A plan and schedule have been prepared and implemented to discontinue the disposal of contaminated liquids into the soil at the Hanford Site. Best available technology is being developed to treat the effluent streams.

The major effort for cleanup of the Hanford Site will be the disposal of the stored wastes resulting from past production operations. The strategies for handling and disposing of these wastes, as well as newly generated wastes, were established through the National Environmental Policy Act process. The resulting Record of Decision recommends implementing preferred alternatives, described by the *Final Environmental Impact Statement, Disposal of Hanford Defense High-Level, Transuranic and Tank Wastes* (DOE 1987a).

The preferred alternatives recommend disposal of double-shell tank waste, retrievably stored and newly generated transuranic waste, and encapsulated cesium and strontium waste:

- Double-shell tank waste will be separated into three fractions: high-level waste, transuranic waste, and low-level waste. The 28 double-shell tanks store 64.35 million L of radioactive liquid and slurry, much of which has been transferred and concentrated from single-shell tanks. The high-level waste and transuranic waste will be processed into a solid, vitrified material similar to glass and disposed of in a repository. The low-level waste will be mixed with a cement-like material and allowed to harden in near-surface concrete vaults.

- Solid transuranic waste that has been stored since 1970 will be sorted and packaged in the proposed Waste Receiving and Processing Facility for shipment to the Waste Isolation Pilot Plant (WIPP) in New Mexico.

- Cesium and strontium capsules will continue to be stored for eventual disposal in a repository. There are 1576 cesium capsules and 640 strontium capsules. The cesium and

strontium were removed from single-shell tank wastes to reduce heat generation.

For single-shell tank waste, transuranic-contaminated soil sites, and pre-1970 buried, suspect transuranic-contaminated solid waste, the recommended strategy is to continue disposal technology development and evaluation before making a disposal decision. Wastes will continue to be stored in a manner that protects the environment and human health. Storage will continue until treatment and disposal facilities are constructed and treatment processes are implemented. The required new facilities that have been or are being constructed are described below.

Grout Treatment Facility

The Grout Treatment Facility consists of a dry materials facility, a grout mixing and pumping facility, and underground grout disposal facilities. For disposal, liquid waste is combined with dry materials, such as cement, fly ash, and blast furnace slag, to produce a grout slurry that is pumped into large underground disposal vaults where the slurry solidifies.

On July 11, 1989, the Grout Treatment Facility completed processing and disposal of an initial 3.785 million L of nonhazardous radioactive waste from Hanford's double-shell tanks. For the first time in the Hanford Site's 46-year history, tank wastes have been moved out of liquid storage and converted into a solid for environmentally safe disposal. In addition to the 3.785 million L of nonhazardous, low-level waste processed between August 30, 1988, and July 11, 1989, approximately 162.76 million L of mixed waste will be processed for disposal between 1991 and 2013.

Waste Receiving and Processing Facility

The Waste Receiving and Processing Facility is planned for inspecting, assaying, and treating radioactive solid waste to produce both a transuranic waste component for shipment to the WIPP and a low-level waste component for disposal on the Site. Construction of the Waste Receiving and Processing Facility will occur in two phases, with the advanced conceptual design of Module I scheduled for completion in 1990. The conceptual design of Module II is also in progress and is scheduled to be completed in 1990.

Hanford Waste Vitrification Plant

The Hanford Waste Vitrification Plant will be constructed to treat much of the waste currently stored in double-shell tanks. The Hanford Waste Vitrification Plant may also be required to eventually treat the wastes that are retrieved from the single-shell tanks.

The preliminary design of the Hanford Waste Vitrification Plant is over half complete, and detailed design will start in 1990. Construction is scheduled to commence in July 1991 and to be completed in 1998. The high-level waste fraction resulting from the pretreatment of the stored wastes would be immobilized into borosilicate glass and stored at the Hanford Waste Vitrification Plant until a repository is ready to receive this waste. The low-level waste fractions would be solidified as a cement-based grout and disposed of in near-surface, preconstructed, lined concrete vaults.

CORRECTIVE ACTIVITIES

Corrective activities consist of specific activities either required by statutory/regulatory environmental requirements or required to fulfill compliance agreements with federal, state, or local regulatory bodies, or both. These activities are required to ensure regulatory compliance for active facilities at the Hanford Site. Environmental corrective activities can be divided into three major categories: air, water, and solid waste.

Corrective activities for the air category include assessment and upgrade of building exhaust air sampling systems to ensure compliance with the DOE requirements for gaseous effluent management. Air emission permits are in place for all existing facilities; however, new permits may be required for several new projects and facility modifications and for the additional 87 stack effluents expected to be included in the state regulations not yet in place.

Currently, there are no known Clean Water Act violations; therefore, there are no corrective activities in the water category.

Solid waste management activities are more extensive than those for air and water. Obtaining RCRA operating permits for treatment, storage, and disposal facilities is a major activity. The Hanford Site has been assigned one RCRA permit number; however, the permit will have approximately 60 parts (one per treatment, storage, or disposal facility). Currently, the Hanford Site treatment, storage, and disposal facilities are under interim status, and the final permit is not expected to be granted until 1995. Corrective activities include construction of mixed-waste storage and disposal facilities, removal of polychlorinated biphenyls, installation of liquid effluent monitors, and development of methods for disposing of purge water from ground-water monitoring wells.

3.2 ENVIRONMENTAL SURVEILLANCE AT HANFORD

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

SCOPE

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

OBJECTIVES

Objectives of the program for 1989 were to:

- assess impacts from Hanford Site operations to the offsite public during 1989 and identify noteworthy changes in the radiological and chemical status of the environment

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

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

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

CRITERIA

The criteria for environmental surveillance are derived from requirements set forth in applicable federal, state, and local regulations; DOE orders; and recommendations given in the monitoring guide published for use at DOE sites (Corley et al. 1981). These criteria have been applied through investigating the radionuclides contributing the most dose, greatest number of exposure pathways, and highest exposure rates. Experience gained from environmental surveillance activities conducted at Hanford for over 45 years has also provided significant support for program planning and data evaluation.

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

Hanford Site operations to the public are the atmosphere, surface water, and ground water. Figure 3.1 illustrates these potential routes and the possible exposure pathways to humans. The significance of each pathway is determined from data and models that estimate the amount of radioactive material potentially available to be transported along each pathway and the significance of this material in comparison to standards. To ensure that radiological analyses of samples are sufficiently sensitive, minimum detectable concentrations of critical radionuclides in air, water, and food were established and appear in Table D.1, Appendix D. Minimum detectable concentrations for other types of samples are also listed.

SURVEILLANCE DESIGN

Environmental surveillance at Hanford is designed in response to specific characteristics of the Site and its operating facilities.

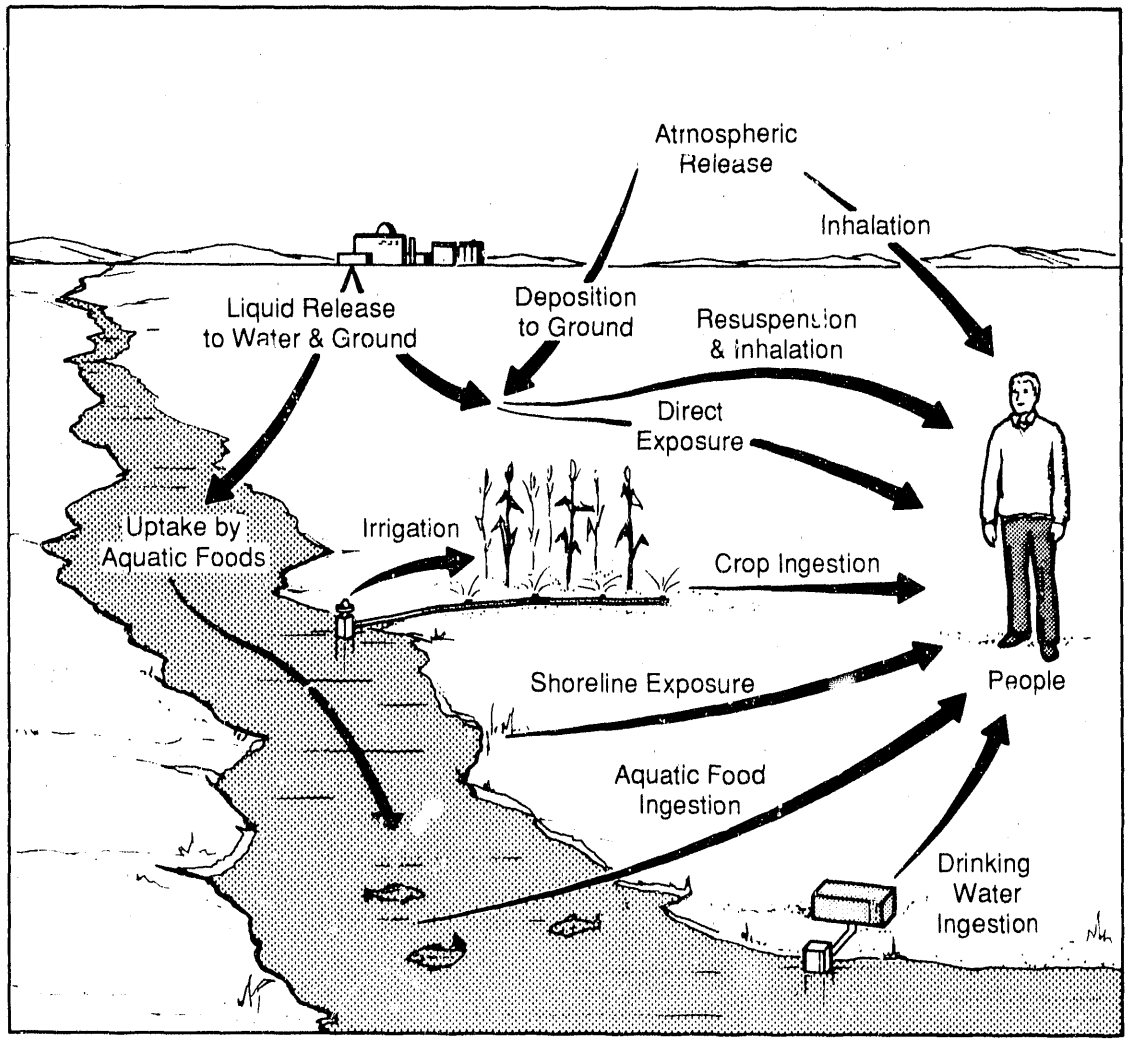

FIGURE 3.1. Primary Radiation Exposure Pathways

Operating facilities have effluent control systems to reduce the amounts of materials released to the environment and systems to measure the quantities of effluents that are released. The history of effluent releases from each facility and the known biological effects of exposure are used to determine what should be monitored. Environmental surveillance consists of collecting and analyzing samples and measuring penetrating radiation. Selected ground-water and surface-water samples are also analyzed for hazardous chemical constituents. Surveillance at Hanford is designed to meet the objectives of determining the environmental and public health impacts of Hanford operations and is not intended to provide a detailed radiological and chemical characterization of the Site or the surrounding area. The surveillance design takes into account the fact that releases from Hanford are low and are constantly monitored. Calculations based on effluent data show the expected concentrations off the Hanford Site to be low and, for most radionuclides, to be below the level that can be detected by monitoring. Past monitoring data show that the concentrations of radionuclides in environmental samples are detectable on Site near operating facilities and decrease with distance. At the Site perimeter and beyond, concentrations decrease to levels at which only a few radionuclides are detectable (see "Environmental Monitoring Information," Section 4.0).

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

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

The second surveillance zone consists of a series of sampling stations positioned around the Site perimeter. Data from these stations document the levels of radioactivity near the Site boundary. Ground-water monitoring wells are located on Site and near the Site boundary. Both hazardous chemical and radiological concentrations are measured in ground-water samples. Agriculture is an important industry near the Site; therefore, milk, crops, soil, and native vegetation are monitored to detect any influence from Hanford on locally produced food and farm products. The Columbia River is included in the second zone. River water is monitored upstream of the Site and at Richland, Washington, where it is used for public drinking water. Water pumped from the Columbia River for irrigation is also monitored. Water quality surveillance is performed by the U.S. Geological Survey (USGS) at Priest Rapids Dam and Richland.

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

Concentrations of radionuclides in environmental media are measured at background locations as a basis of comparison with onsite, perimeter, and community locations. Background locations are selected that are considered unaffected by Hanford effluents. The background station for the Columbia River is at Priest Rapids Dam, which is approximately 8 km upstream of the Hanford Site boundary. For other surface media, the background station is at Yakima, Washington, which is approximately 50 km upwind of the Hanford Site boundary.

The potential radiation doses received by the public are calculated from environmental surveillance data when Hanford-related radionuclide concentrations are measurable. However, data from the offsite environs and communities near the Site at most locations do not indicate a measurable effect from Hanford operations. The sources of radionuclides are Hanford operations, worldwide fallout from past nuclear tests, fuel reprocessing at other locations, and natural sources.

For dose estimates when the concentrations were too low to be detected by surveillance, potential radiation doses to the public were calculated using data from effluent measurements and computer models. The computer models are specific to the Hanford Site and vicinity and include the local population's dietary habits and recreational use of the Columbia River. These models simulate the movement of radioactive materials through the environment and food pathways and estimate the resulting radiation dose (see "Potential Radiation Doses from 1989 Hanford Operations," Section 4.8). In addition, the dose from the air pathway was also calculated for regulatory compliance purposes with the AIRDOS-EPA and RADRISK models as specified in 40 CFR 61.

PROGRAM DESCRIPTION

Environmental surveillance provides for the measurement and interpretation of the impact of Hanford operations on the public and the onsite and offsite environment. Numerous samples were collected and analyzed according to a predefined plan. Measured concentrations of radioactive materials were compared to applicable standards, concentration guides, natural levels of radiation, and results obtained by other monitoring organizations. The program was designed to examine significant exposure pathways, including direct radiation exposure from operating facilities. Radiological impacts, based on environmental surveillance or effluent monitoring and modeling, are expressed in terms of radiation dose.

Table 3.1 summarizes the geographic distribution of sample types and measurement locations. Schedules, records, and data are maintained in a computer system. In addition, unscheduled surveillances were conducted in response to specific needs.

Laboratory analyses of samples for radioactivity and chemicals were conducted by United States Testing Company, Inc. (UST), Richland, Washington. Analyses of environmental

TABLE 3.1. Routine Environmental Sample Types and Measurement Locations

	Total Number	Sample Locations			
		On Site	Perimeter	Nearby Communities	Distant Communities
Air	53	24	14	9	6
Ground Water	567	567			
Columbia River	4		2	2	
Irrigation Water	1		1		
Drinking Water	14	9	5[a]		
Columbia River Sediments	5		3	1	1
Ponds	3	3			
Foodstuffs	8		5	1	2
Wildlife	17	14	3		
Soil & Vegetation	38	15	14	3	6
Dose Rate	88	34	39[b]	9	6
Waste Site Surveys	73	73			
Railroad/Roadway Surveys	17	17			
Shoreline Surveys	27		27		
Aerial Survey	1		1		

(a) Includes four offsite water supplies.
(b) Includes locations in and along the Columbia River.

dosimeters for penetrating radiation were performed by PNL. Ground-water sample analyses were performed by PNL's analytical laboratories, Hanford Environmental Health Foundation, and UST. Water quality, temperature, and flow rates for the Columbia River were determined by the USGS. Quality assurance was an integral part of the program.

3.3 ENVIRONMENTAL STUDIES AND PROGRAMS

WILDLIFE RESOURCES

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

The Columbia River as Fish and Wildlife Habitat

One fish and two species of birds are regularly monitored in the Hanford Reach. These are the Chinook salmon (*Onchorhnchus tschawytscha*), the bald eagle (*Haliaeetus leucocephalus*), and the Canada goose (*Branta canadensis*). The same survey methodologies have been practiced by the same observers for the past 20 years. Trends in population counts are likely not due to changes in methodology or changing personnel. The number of individual, active spawning sites (redds) has been counted by aerial flight surveys each autumn since the 1940s. In recent years, the number of salmon redds (shallow basins in river gravels scraped by adult salmon) has dramatically increased (Figure 3.2). The increase is attributable to the coordinated efforts of various federal and state agencies, Indian tribes, and others dedicated to maintaining Columbia River salmon runs.

The bald eagle is listed as a threatened species in the State of Washington by the U.S. Fish and Wildlife Service and the Washington State Department of Wildlife. Bald eagles have historically spent winter months along the Hanford Reach and have been counted by aerial flight surveys since 1961. The counts of bald eagles were lower than the previous four years (Figure 3.3). Salmon redd counts were as high as the previous years, indicating that an important food resource was available to eagles. There were no apparent increases in human activities along the shoreline of the Hanford Reach that could diminish the use of shoreline trees as eagle perches. This suggests to us that the observed diminishment of eagles is due to offsite rather than onsite factors.

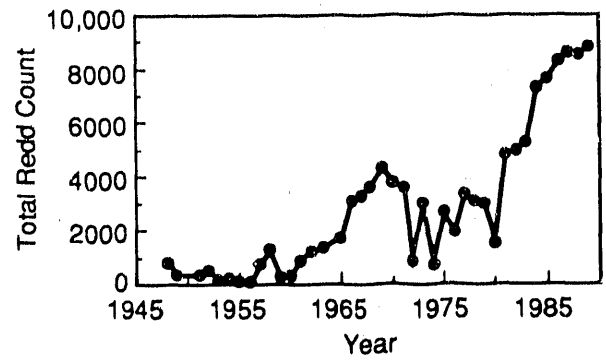

FIGURE 3.2. Counts of Chinook Salmon Spawning Redds in the Hanford Reach of the Columbia River, 1947 Through 1989

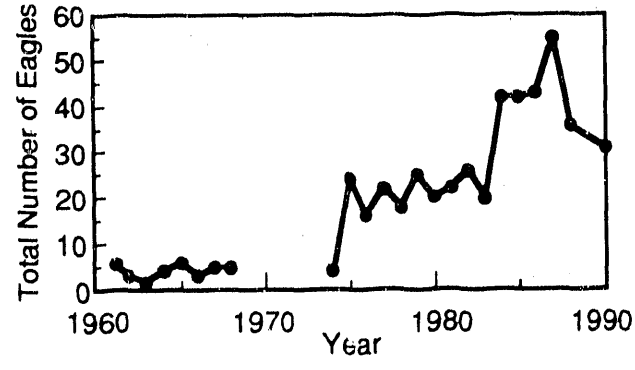

FIGURE 3.3. Maximum Numbers of Bald Eagles Seen Along the Hanford Reach of the Columbia River During Aerial Flights in Fall and Winter Months, 1961 Through 1989

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

Strontium-90 in Canada Goose Eggshells

Because eggshells are rich in calcium, they can be useful biological indicators of radioactive strontium since strontium is chemically similar to calcium. Fragments of newly hatched eggshells were collected in 1986-1989 from the nests of Canada geese on several islands in the Columbia River both upstream and downstream of the Hanford reactor areas. The purpose of the collection was to determine if enhanced levels of ^{90}Sr could be detected in eggshells. Low levels of ^{90}Sr were measured in all samples collected from islands in the Columbia River and from background stations. The measured concentrations were in the range of 1 pCi/g of dry eggshell. Samples from Plow Island near Ringold Springs have had the highest concentrations with an average of 1.3 pCi/g from 1986 to 1989 (see Table C.1). The potential sources of ^{90}Sr in the eggshells are worldwide fallout, wild plants growing along the shoreline where ground water seeps into the Columbia River, and plants irrigated with Columbia River water. All concentrations are too low to expect deleterious effects to the health or reproductive success of wild geese.

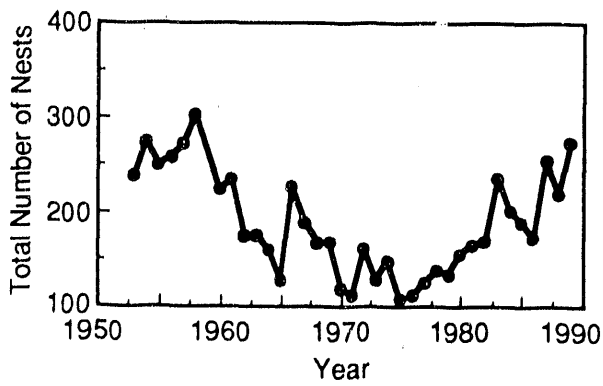

FIGURE 3.4. Number of Canada Goose Nests Established on Islands in the Hanford Reach of the Columbia River, 1953 Through 1989

Sagebrush/Grass Vegetation on the Hanford Site as Wildlife Habitat

The elk (*Cervus elaphus*) and three species of hawks, ferruginous hawk (*Buteo regalis*), Swainson's hawk (*B. swainsoni*), and red-tailed hawk (*B. jamaicensis*), are surveyed on the Hanford Site. Elk first appeared in 1972, probably as transients from Cascade Mountain herds. By 1977, the elk had established a breeding population on the Arid Lands Ecology (ALE) Reserve, a protected portion of the Hanford Site used for ecological research. In the absence of hunting and predators and competition for the grasses and other forage plants by domestic livestock, the herd rapidly increased. Elk from the ALE Reserve easily crossed the fences built to exclude livestock and damaged crops on private property adjacent to the reserve. To reduce crop damage, an autumn hunting season was established by the

Washington State Department of Wildlife on the private lands bordering the reserve. Elk are counted by direct viewing from low-flying fixed-wing aircraft before and after the annual hunting season (Figure 3.5). Elk fitted with radiotransmitters are used as an aid to locate elk herds for counting. Hunting appears to have slowed the growth of the herd.

Hawk populations have diminished in eastern Washington due to the loss of suitable nest sites and foraging habitats attributed to agricultural land uses. Hawks are counted by locating active nests on trees, artificial structures, or cliffs using either aerial or ground surveys.

In recent years, the number of nesting ferruginous hawks, a species with a very low population in Washington State and listed as threatened by the Washington State Department of Wildlife, has increased (Figure 3.6). The increase is attributed to the hawks' acceptance of Hanford Site electrical transmission line towers as nesting sites.

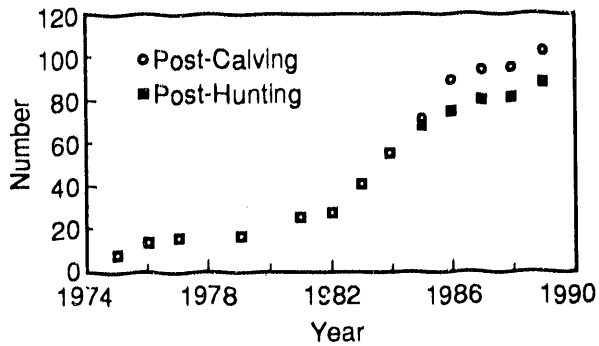

FIGURE 3.5. Number of Elk Counted on the Hanford Site by Aerial Surveillance During the Post-Calving Period, August Through September, and the Post-Hunting Period, December Through January

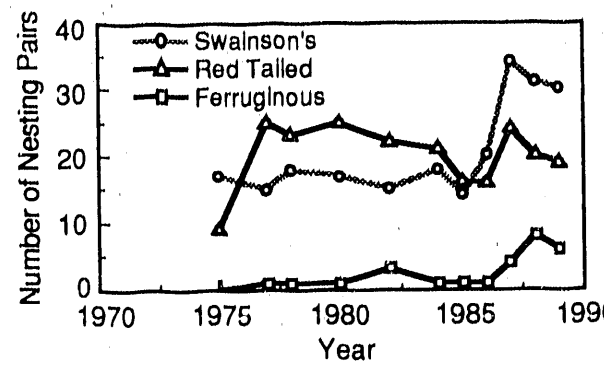

FIGURE 3.6. Counts of Nesting Pairs of Red-Tailed, Swainson's, and Ferruginous Hawks on the Hanford Site

Federally Listed Candidate Species

Two aquatic invertebrate species that inhabit the Hanford Reach of the Columbia River are federally listed as candidate species for listing as threatened or endangered. These are the Great Columbia River Spire Snail (*Fluminicola columbiana*) and the Giant Columbia River Limpet (*Fisherola nuttalli*). As candidate species, they are not protected by law; however, the U.S. Fish and Wildlife Service monitors construction activities in the Columbia River Basin where candidate species are known or expected to occur. Searches for snails and limpets were performed in 1989 and revealed that these species occur in the Hanford Reach of the Columbia River as well as several of the river's tributaries. Activities conducted on the Hanford Site at the present time are probably not detrimental to the continued existence of the snail or limpet.

CULTURAL RESOURCES

Since 1987, the Cultural Resources Project has been providing support for managing the archaeological, historical, and cultural resources of the Hanford Site in a manner

consistent with the National Historic Preservation Act of 1966, the Archaeological Resources Protection Act of 1979, and the American Indian Religious Freedom Act of 1978.

A major task of the Cultural Resources Project in 1989 was completion and publication of the *Hanford Cultural Resources Management Plan* (Chatters 1989). This plan outlines the statutory basis for cultural resources management, presents in detail the policies and procedures to be followed by DOE-RL to comply with these statutes, and sets priorities for cultural resource management activities.

The highest priority task is to conduct cultural resource reviews, pursuant to Section 106 of the National Historic Preservation Act, for each proposed ground-disturbing or building alteration/demolition project on the Hanford Site. During the year, Hanford contractors requested 108 Section 106 reviews. Twenty-four of these requests required archaeological surveys. The surveys covered over 150 ha and resulted in the discovery of 10 prehistoric archaeological sites and 3 historic archaeological sites. Projects were relocated to avoid any potential impact to two sites in the vicinity of the Hanford Solid Waste Landfill and the 300 Area. The remaining sites, located on the Saddle Mountains and between the Hanford Townsite and 200-West Area, have not yet been evaluated. The most interesting discoveries are the remains of a *Bison* kill and butchering site in an ancient dune, and a series of hunting blinds high on the Saddle Mountains.

The second priority task is a monitoring program, designed to determine the condition of cultural resources and the adequacy of DOE-RL's cultural resource management and protection policies. Monitoring results are used in planning for cultural resource site management and protection. Following procedures established in the *Hanford Cultural Resources Management Plan*, staff monitored the condition of 40 sites, including 6 cemeteries, 15 properties listed on the National Register of Historic Places (National Register), and 19 sites that have not been listed. Five conclusions were drawn from observations made during the first year's monitoring: 1) Cemetery sites are subject only to natural erosive processes, with the exception of Site 45BN157b, which was still being looted to a small degree by surface collectors and people digging for relics. 2) With the exception of a fire lane cut across National Register Site 45BN149, DOE-RL is having little direct impact on sites within the Hanford Site security fence. 3) The absence of surface artifacts typically of interest to collectors indicates that there has been collection of artifacts from the surface. 4) Areas outside the security fence, particularly those areas near roads and boat launches, are being impacted by relic hunters, who have been doing minor digging into intact portions of some sites. 5) Livestock are damaging archaeological sites in Franklin County by causing increased erosion.

The third priority set by the *Hanford Cultural Resources Management Plan*, following guidelines for compliance with the Archaeological Resources Protection Act, is to establish a curation system for artifacts and associated records. The first step is to ascertain the location of collections, which was the task set for FY 1989. Collections were found to be curated by the University of Idaho and the Mid-Columbia Archaeological Society. Current curators of these collections have agreed to cooperate with PNL in assessing curation needs for these materials.

The fourth priority task is evaluation of cultural resources for possible nomination to the National Register. Evaluation procedures were conducted for three properties during 1989. Two of these, the Hanford B Reactor and the Gable Mountain/Gable Butte Cultural District, are believed to be eligible. Nomination documents have been prepared and submitted to the Washington State Historic Preservation Officer for review. Evaluation is under way for the Wahluke Archaeological District, a group of sites previously nominated to the National Register but rejected for lack of information. Sites in the proposed district were inspected, and five were found to be potentially eligible for the National Register. Test excavations, which are required for archaeological evaluations, were conducted at the Wahluke Site with assistance from Central Washington University. The Wahluke Site was found to contain a pithouse village dating back to at least 700 A.D. and a campsite that may date between 2000 and 4000 B.C. Data analysis is not yet complete, but preliminary findings show strong indications of scientific significance for this site.

The fifth task is public education. The education program, which was planned in late 1988, consists of targeting elementary and middle school students, secondary school students, and the general public. During 1989, the program included lectures to schools and public organizations.

The lowest priority task is the archaeological survey of areas of the Hanford Site that are not targeted for development, a requirement of Section 110 of the National Historic Preservation Act. In 1989, 16 survey plots of a 1/6-square-mile area were located in stabilized dunes and in a variety of environments near a mountainous area. Plots in stabilized dunes contained no cultural resources, whereas plots on and near mountain slopes contained a variety of prehistoric and historic archaeological sites and isolated artifacts. Results of tasks conducted in 1989 have been used to refine procedures and develop plans for cultural resource management activities in 1990.

METEOROLOGY AND CLIMATOLOGY OF THE HANFORD AREA

The Meteorological and Climatological Services Project provides meteorological and climatological data and operational forecasts in support of the following Site activities: 1) emergency response, 2) atmospheric dispersion modeling and dose calculations, and 3) routine Site operations.

Like the three previous years, 1989 was warmer than normal. The average temperature of 12.2°C was 0.4° above normal (11.8°C). The warmest years on record were 1934 and 1958, which averaged 13.4°C; the coldest was 1985, which averaged only 9.8°C. Six months during 1989 were at least 0.3°C above normal, 4 months were at least 0.3°C below normal, and 2 months departed from normal by less than 0.3°C. January had the greatest positive departure (+3.9°C), and February had the greatest negative (-5.8°C).

Precipitation for 1989 totaled 17.5 cm, 111% of normal (15.8 cm). Calendar year snowfall totaled 55.2 cm, compared to a normal of 34.8 cm. Most snowfall (43.2 cm) was recorded during February.

The 1988-89 winter season (December 1988, January and February 1989) was colder than normal, averaging 0.1°C (0.9°C below normal). The coldest temperature was -20.6°C on February 5. Winter season snowfall totaled

60.4 cm (normal is 34.8 cm). The first measurable snow fell on December 18, 1988, and the last fell on March 5.

The spring months (March, April, and May) averaged 12.2°C, 0.7°C above normal (11.5°C), representing the fifth consecutive above-normal spring. The spring months were much wetter than normal, with 7.6 cm of precipitation recorded, 227% of normal for those months (3.4 cm). Spring snowfall totaled 7.9 cm, which was above the spring normal of 2.3 cm.

The average temperature of 23.1°C for summer 1989 (June, July, and August) was normal (23.1°C). Summertime precipitation totaled 0.7 cm, only 31% of normal (2.3 cm).

Fall 1989 (September, October, and November) was warmer than normal, averaging 12.9°C, 1.3°C above normal (11.6°C), and the seventh warmest on record. Fall precipitation totaled 3.8 cm, 95% of normal (3.9 cm). No snow was recorded during the period (normal is 3.6 cm in November).

The maximum wind gust during 1989 was 93 km/h on January 16. The average annual wind speed of 10.0 km/h was below the annual normal of 12.4 km/h.

Table 3.2 presents additional statistics for 1989. Table C.2, Appendix C, provides monthly climatological data from the Hanford Meteorology Station for 1989. Table C.3, Appendix C, provides a temperature summary of monthly and annual temperatures from the Hanford Telemetry Network, and Figure 3.7 shows wind roses.

HANFORD ENVIRONMENTAL DOSE RECONSTRUCTION PROJECT

The objective of the Hanford Environmental Dose Reconstruction Project is to develop estimates of the radiation doses that people could have received from Hanford operations. The study, which began in 1988, was prompted by concern about potential health effects to the public from more than 45 years of nuclear operations at Hanford. An independent Technical Steering Panel directs the dose reconstruction effort, which is conducted by Battelle staff at PNL.

In 1989, researchers implemented Phase I of the dose reconstruction work. Phase I is devoted to developing a feasible technical approach and compiling historical information that can be used to estimate past radiation doses.

Phase I focuses on a limited geographical area and time period. Airborne radionuclides released from 1944 through 1947 and waterborne releases from 1964 through 1966 are being investigated to determine the resulting doses to people who lived in a 10-county area surrounding the Hanford Site. The stretch of the Columbia River being studied in Phase I runs from Priest Rapids Dam south to McNary Dam.

An integrated computer model, made of individual submodels that simulate radionuclide transport through various environmental pathways, was developed to calculate doses. Uncertainties in the input data are propagated

TABLE 3.2. Meteorology Statistics for 1989

Category	1989	Normal
Days with maximum temperatures ≥ 32.2°C	45	52
Days with maximum temperatures ≥ 37.8°C	4	13
Days with minimum temperatures ≤ 0°C	98	112
Days with minimum temperatures ≤ -17.8°C	4	3
Days with thunderstorms	10	11
Days with fog (visibility ≤9.6 km)	62	42
Days with dense fog (visibility ≤ 400 m)	27	24
Days with peak wind gusts ≥64 km/h	23	26

throughout the model, resulting in distributions of doses rather than point estimates.

To develop data for the submodels, researchers compiled and reconstructed several types of historical information: amounts and types of radionuclides emitted from Hanford facilities; pathways of radionuclides transported through the environment; radionuclide concentrations in air, water, vegetation, and foods; and demographic, agricultural, and food consumption patterns that may have affected people's exposures to radionuclides.

After completion and testing of the dose estimation model, preliminary doses for the Phase I area and time periods will be available, with complete results reported in 1993.

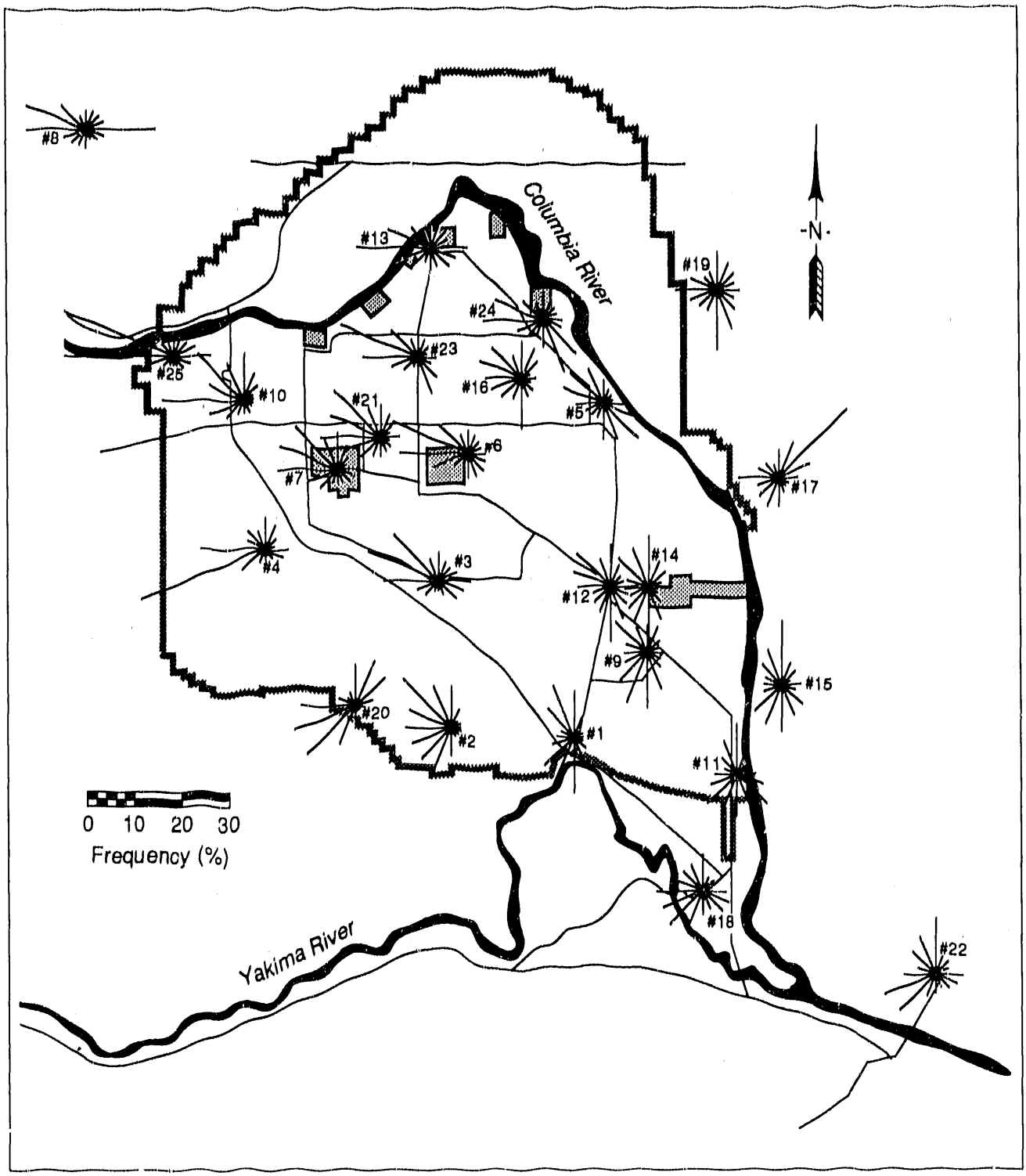

FIGURE 3.7. Hanford Telemetry Network Wind Roses for 1989[a]

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

4.0 Environmental Monitoring Information

4.0 ENVIRONMENTAL MONITORING INFORMATION

4.1 AIR SURVEILLANCE

Transport of atmospheric releases of radioactive and nonradioactive materials from Hanford to the surrounding region represents a direct pathway for human exposure. Radioactive materials in air were sampled continuously on the Site, at the Site perimeter, and in nearby and distant communities at 53 locations. Particulates filtered from the air at all locations were analyzed for radionuclides. Air was sampled and analyzed for selected gaseous radionuclides at key locations. Nitrogen dioxide (NO_2) was sampled at three locations on Site.[a]

Several radionuclides released at Hanford are also found worldwide from two other sources: those that are naturally occurring and those resulting from nuclear weapons testing fallout. The influence of Hanford emissions on local radionuclide levels is indicated by the difference between concentrations measured at a distant upwind location within the region and concentrations measured close to the Site.

In 1989, the annual average Hanford Site downwind perimeter concentration of ^{90}Sr was numerically greater than the concentration measured at a distant upwind location, but the difference was not statistically significant (at the 5% significance level). Tritium, ^{129}I, uranium, gross alpha, and gross beta concentrations were greater at the downwind perimeter than at a distant upwind location, and the differences were statistically significant (beyond 5% significance level). The differences in the tritium and ^{129}I are likely due to site operations. The differences in gross alpha, gross beta, and uranium are predominately due to the effects of natural geographic variations. However, even the maximum single perimeter sample for any radionuclide was only 0.1% of the applicable DOE Derived Concentration Guide (DCG) (Table B.6, Appendix B). The total dose from air emissions is compared to Clear Air Act and DOE dose standards in Section 4.8, "Potential Radiation Doses from 1989 Hanford Operations." Annual average NO_2 concentrations at all sampling locations were less than 14% of federal and Washington State ambient air standards.

SAMPLE COLLECTION AND ANALYSIS

Radioactivity in air was sampled by a network of continuously operating samplers at 24 locations on the Hanford Site, 14 near the Site perimeter, 9 in nearby communities, and 6 in relatively distant communities (see Figure 4.1 and Table C.4, Appendix C). Air samplers on the Hanford Site were located primarily around major operating areas to measure maximum concentrations from Site operations. Site perimeter samplers were located on all sides, with emphasis in the prevailing downwind directions to the south and east of the Site to measure concentrations at the boundaries. Continuous samplers located in Benton City,

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

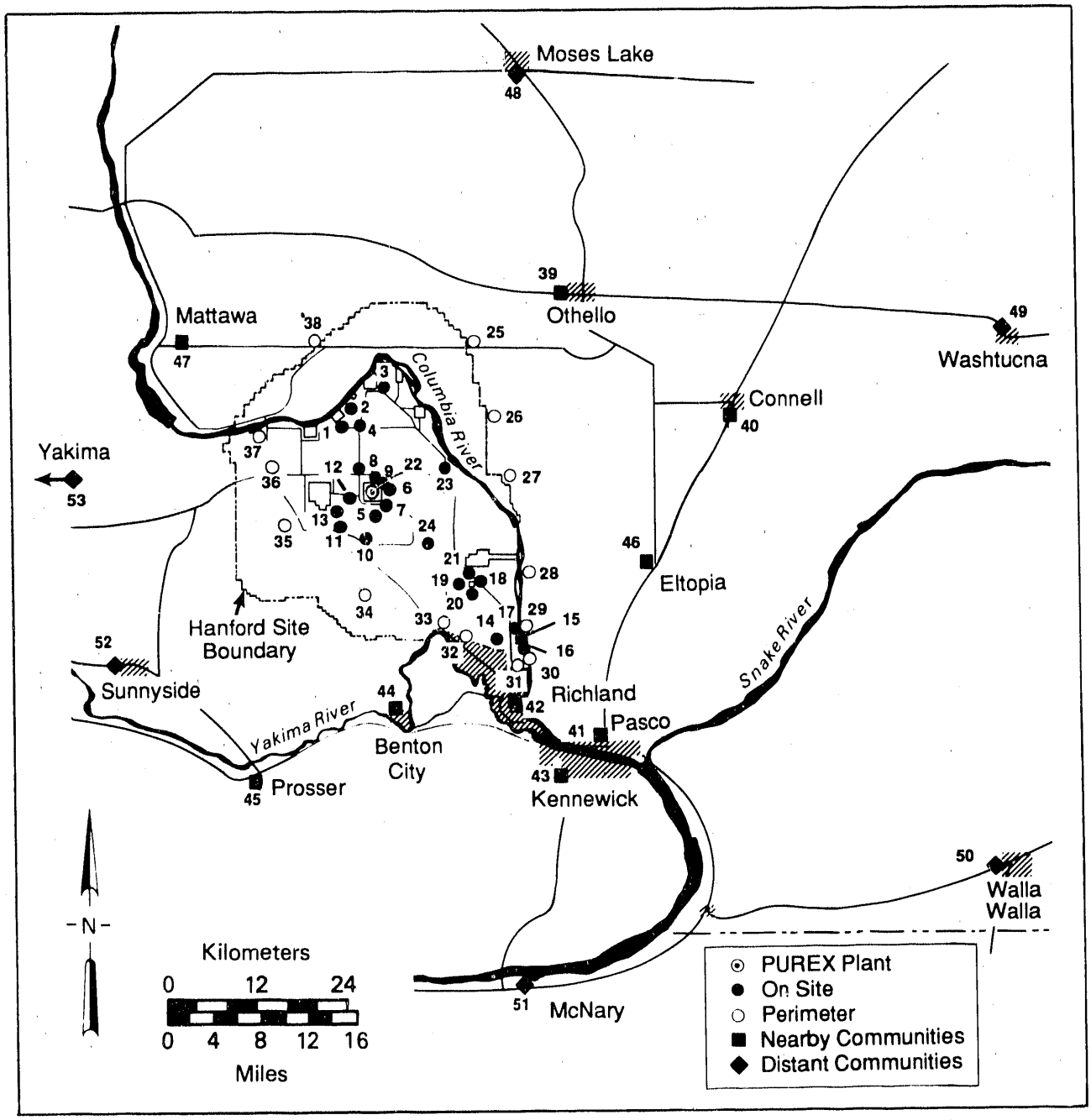

FIGURE 4.1. Air Sampling Locations (see Table C.4, Appendix C, for location key)

Connell, Eltopia, Kennewick, Mattawa, Othello, Pasco, Prosser, and Richland provided air concentrations in the nearest population centers. Samplers at McNary Dam and in the distant communities of Moses Lake, Sunnyside, Walla Walla, Washtucna, and Yakima provided data from essentially unaffected distant communities. Yakima is a distant upwind location and provides reference regional background concentrations.

Samples were collected according to a schedule established before each monitoring year (Bisping 1989). The distribution of air samples by types

is summarized in Table 4.1. Airborne dust was sampled at each of these locations for 2 weeks by continuously drawing air at a flow rate of 2.6 m^3/h through a 5-cm-diameter high-efficiency, glass fiber filter. The filters were collected every 2 weeks, field surveyed for gross radioactivity to detect any unusual occurrences, held for 7 days, and then analyzed for gross beta radioactivity in a laboratory. The holding period was necessary to allow for the decay of short-lived, naturally occurring radionuclides that would otherwise obscure detection of the lower levels of longer-lived radionuclides potentially present from Hanford emissions. Gross radioactivity measurements provide a current indication of changes in environmental trends that could warrant special attention. In addition, filters from selected locations were analyzed for gross alpha radioactivity in a similar manner for the same purpose.

For most radionuclides, the amount present in the atmosphere that could have been collected on a particle filter by continuously sampling for 2 weeks was too small to be measured with the accuracy desired. Because the accuracy of sample analysis is increased when the sample contains more material, two biweekly samples were combined into monthly composite samples for each location. The monthly composites for a few nearby locations were then combined to form a geographical composite. (The 27 geographical composites used in 1989 are listed in Table C.4, Appendix C.) Each monthly geographical composite was analyzed for 53 gamma-emitting radionuclides (listed on page D.1, Appendix D), then combined into quarterly composites and analyzed for strontium and plutonium. Selected quarterly composites were analyzed for uranium isotopes.

TABLE 4.1. Air Sampling Locations (see Table C.4, Appendix C, for location key)

			Particulates[a]			Gases					
Locations	Gross Beta	Gross Alpha	^{89}Sr,^{90}Sr ^{238}Pu,$^{239,240}Pu$	Gamma Scan	Uranium	^{131}I[b]	^{129}I	^{3}H	^{14}C	^{85}Kr	NO_2
				Numbers of Locations Sampled							
On Site	24	20	10/23	10/23	8/17	7/21	1	6	3	2	3
Perimeter	14	10	6/13	6/13	2/4	5/14	2	8	---[c]	4	---
Nearby Communities	9	2	5/9	5/9	---	2/9	---	1	---	3	---
Distant Communities	6	2	4/6	4/6	2/2	2/6	1	2	2	2	---

(a) Number of location-composited samples/total number of individual locations contained in the composites. For example, 10/23 indicates 10 composite groups that are made up of 23 individual locations, or between 2 and 3 individual locations per composite on the average. The individual locations making up composite groups are listed in Table C.4, Appendix C, and shown in Figure 4.1.

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

(c) None.

Gaseous ^{131}I was sampled by drawing a 2.6-m^3/h air flow (5.2 m^3/h at a few locations) through a 6.3-cm-diameter by 2.5-cm-deep cartridge containing activated charcoal. These cartridges were downstream of the particle filter at each air sampling station. Charcoal cartridges were exchanged biweekly and analyzed for ^{131}I. Sampling was performed near operating facilities to maximize the potential for detecting a chronic loss of control, and at distributed distant locations to determine concentrations at points of potential public exposure. Cartridges from additional locations were exchanged monthly to maintain fresh adsorption media, but were analyzed only if ^{131}I was identified in one of the routinely analyzed samples or if there was any other indication of an effluent release that could result in a detectable concentration.

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

Atmospheric water vapor was collected for ^{3}H analysis by continuously passing air through cartridges of silica gel at a flow rate of 0.014 m^3/h for 4 weeks. The moisture was removed from the silica gel and analyzed. The silica gel cartridges were exchanged every 4 weeks. Atmospheric carbon dioxide was collected by continuously passing air through a soda-lime collection medium for 8 weeks at a flow rate of 0.028 m^3/h. The trapped carbon dioxide was then analyzed for ^{14}C content and the atmospheric concentration calculated.

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

Three locations were sampled by the Hanford Environmental Health Foundation to assess nitrogen oxide concentrations. Nitrogen oxides are primarily released by the PUREX Plant. Sample locations are depicted in Figure 4.2 and identified in Table C.5, Appendix C. The sampling was performed in accordance with EPA "Designated Equivalent Method EQN-1277-028" (EPA 1977). The sampling unit consisted of a bubbler assembly operated to collect 24-hour integrated samples.

RESULTS

Onsite, major operating areas, perimeter, and nearby and distant community maximum, minimum, and average annual concentrations

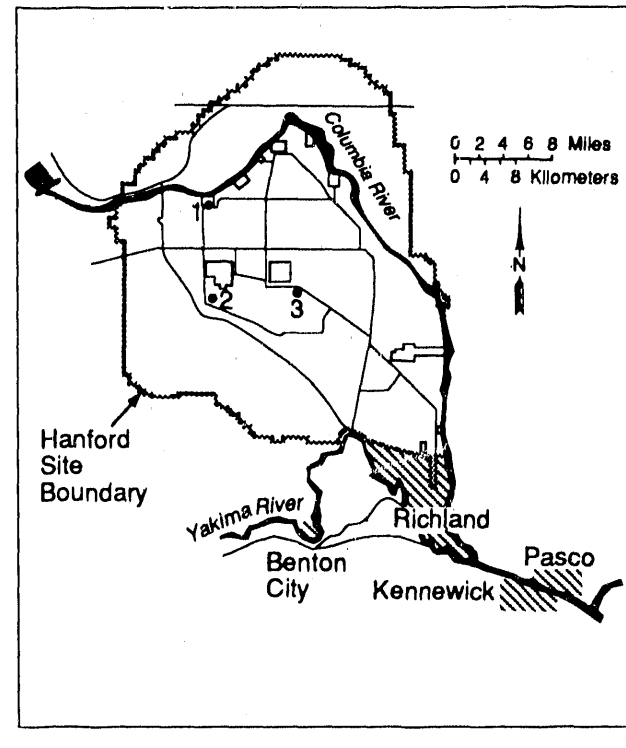

FIGURE 4.2. 1989 Nitrogen Dioxide Sampling Locations

for gross beta, gross alpha, and specific detectable radionuclides are summarized in Table C.6, Appendix C. Fifty-three radionuclides were analyzed in the monthly composite gamma energy analyses (see page D.1, Appendix D), but none of Hanford origin were consistently detectable.

Gross beta levels for 1989, as shown in Figure 4.3, peaked during winter, repeating a pattern of natural annual radioactivity fluctuations. As shown in Table C.6, Appendix C, gross beta and gross alpha levels were about the same on the Site, at the Site perimeter, and in nearby and distant communities, indicating that the observed levels were predominantly a result of natural sources and worldwide fallout. An exception is an indication that elevated uranium levels in the 300 Area are being reflected in the gross alpha measurements.

Measurements of ^{85}Kr have historically been an indicator of PUREX Plant plume behavior. With the resumption of PUREX Plant operations in late 1983, ambient air concentrations of ^{85}Kr at most sampling locations increased above preoperational levels of about 19 pCi/m^3 (Sula and Price 1983). Because of nuclear operations worldwide, global background has been increasing annually but appears to be leveling off and has been reported to be between 25 and 26 pCi/m^3 during the last 3 years at the EPA network in Nevada (EPA 1989a). The local background in 1989 was 20 pCi/m^3 for the distant communities in Table C.6, Appendix C. This value represents a decrease from recent years and may represent a shift from decreased PUREX Plant operations, an analytical shift, or a combination of the two. Concentrations on Site and at the Site perimeter have fluctuated annually primarily in

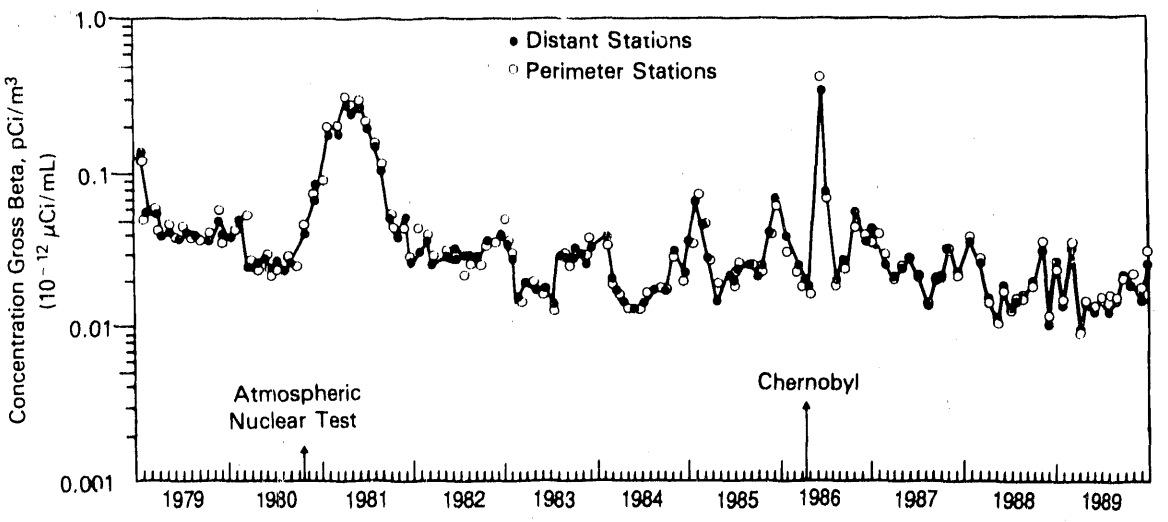

FIGURE 4.3. Monthly Average Gross Beta Radioactivity in Airborne Particulate Samples, 1979 Through 1989

response to changing operating levels (Figure 4.4). Concentrations in 1989 were low on the Site and at the perimeter because the PUREX Plant was operated for only a few weeks during the year. The perimeter annual average ^{85}Kr concentration was 18 [±1[a]] pCi/m^3 compared to the DCG of 60,000 pCi/m^3.

Strontium-90 in air (Table C.6, Appendix C, and Figure 4.5) on the Site, at the perimeter, and in nearby and distant communities was very low and generally not detectable. Figure 4.5 shows the variation from 1984 to 1989 for the 200-East Area sample composite, for a sample composite made up of samples from stations along the southeast perimeter of the Site and the Tri-Cities, and for a sample composite from distant communities. Also shown

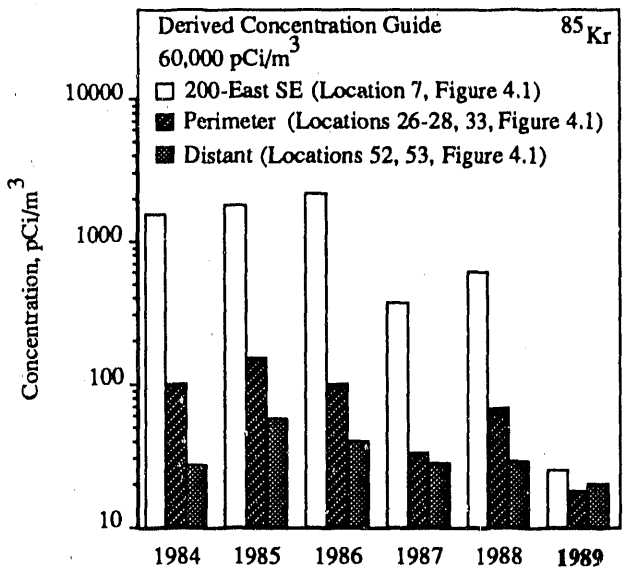

FIGURE 4.4. Annual Average Krypton-85 (^{85}Kr) Air Concentrations at Selected Locations, 1984 Through 1989

(a) Annual average values are expressed as the average ± two standard errors of the mean (2 SEM). Statistically, there is a 95% probability that the true average is within ±2 SEM of the measured average.

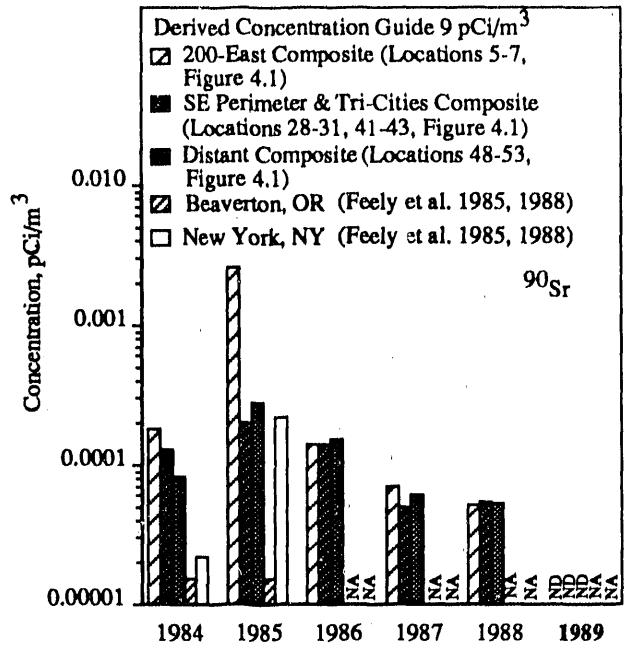

FIGURE 4.5. Annual Average Strontium-90 (^{90}Sr) Air Concentrations in the Hanford Environs Compared to Other U.S. Locations, 1984 Through 1989 (NA: New York and Beaverton data not available after 1985, ND: nondetectable)

are measurements for 1984 and 1985 at two other U.S. locations in northern latitudes (New York, New York, and Beaverton, Oregon) reported by the DOE Environmental Measurements Laboratory (EML) as part of its international fallout monitoring program (Feely et al. 1985, 1988). The EML discontinued ^{90}Sr analyses at the end of 1985. Most of the increase noted in Figure 4.5 for the 200-East Area composite sample in 1985 was the result of an inadvertent airborne release from a liquid-waste diversion box in the C Tank Farm that occurred in January (Price 1986). The annual average Site perimeter concentration in 1989 was 0.000005 (±0.000014) pCi/m^3. The applicable DCG is 9 pCi/m^3.

Quarterly air sampling for ^{129}I began in July 1984. Iodine-129 was sampled on Site

immediately downwind of the PUREX Plant (200-East SE location), at two downwind perimeter locations, and at a distant background location (Yakima) in 1989. (Because of the low levels of ^{129}I, concentrations are reported in aCi/m^3 rather than pCi/m^3. One aCi/m^3 = 0.000001 pCi/m^3.) Concentrations at the perimeter were larger than those observed at Yakima (Figure 4.6). The average onsite and perimeter concentrations decreased significantly from 1988 to 1989 in response to decreased operations. The annual average ^{129}I concentration at the perimeter was 2.5 (±0.7) aCi/m^3 compared to the DCG of 70,000,000 aCi/m^3 (70 pCi/m^3).

Average ^3H concentrations measured at the Site perimeter and at distant locations were similar (Table C.6, Appendix C). Figure 4.7 traces the annual trend of ^3H concentration for two onsite and two downwind perimeter locations, and the average for two distant community locations. The PUREX Plant was restarted in late 1983, with a measurable effect on air ^3H concentrations at the 200-East SE sampling

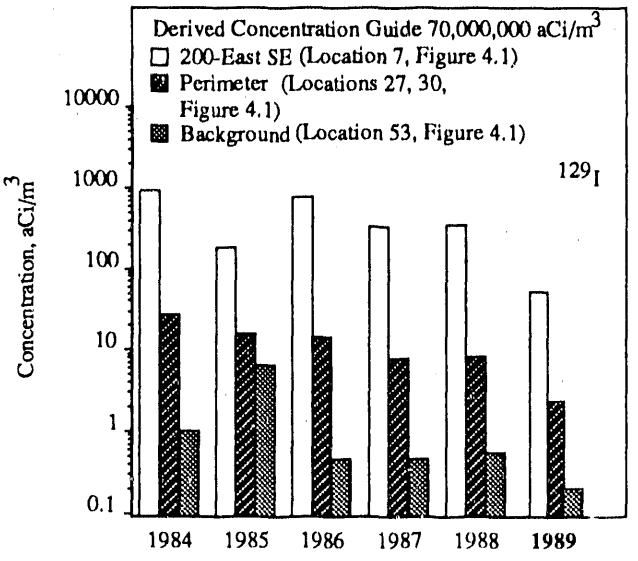

FIGURE 4.6. Annual Average Iodine-129 (^{129}I) Air Concentrations in the Hanford Environs, 1984 Through 1989

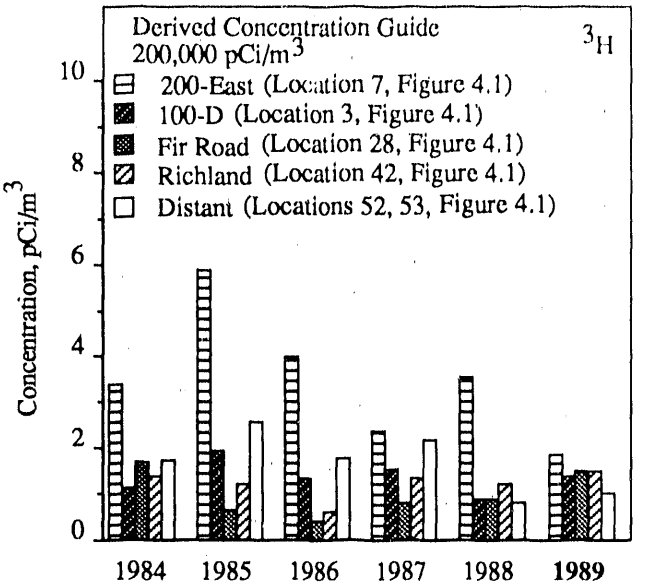

FIGURE 4.7. Annual Average Tritium (^3H) Air Concentrations in the Hanford Environs, 1984 Through 1989

location. However, there appears to be little or no effect by the time the plume reaches the downwind perimeter. The annual average perimeter concentration of ^3H in air in 1989 was 0.91 (±0.16) pCi/m^3 compared to the proposed DCG of 200,000 pCi/m^3.

Air concentrations of $^{239,240}Pu$ in 1989 were similar to those measured in 1988 and generally not detectable except near the 200-West Area. The annual averages of all onsite, major operating area, perimeter, and near and distant community samples are shown in Table C.6, Appendix C. The 1989 perimeter annual concentration was 0.2 (±0.2) aCi/m^3 compared to the DCG of 20,000 aCi/m^3.

The most recent regional data for $^{239,240}Pu$ reported by the EPA for Seattle, Spokane, and Portland for 1984 through 1989 (EPA 1984a through 1989) are compared in Figure 4.8 with measurements at the Hanford southeast perimeter and Tri-Cities composite locations. A

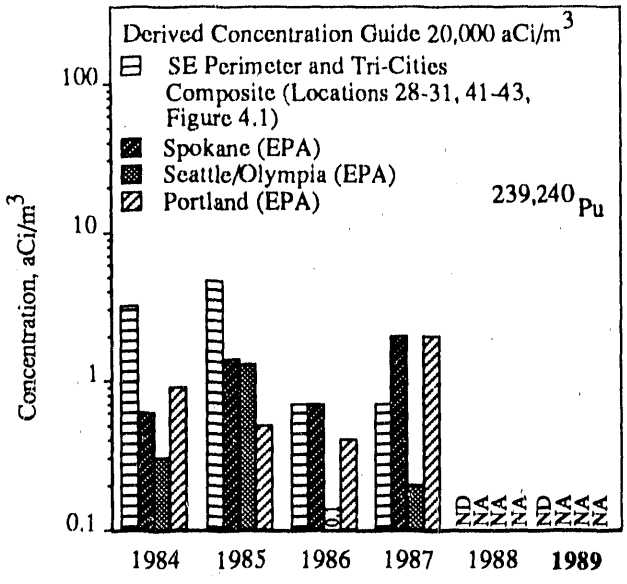

FIGURE 4.8. Annual Average Plutonium-239, 240 ($^{239,240}Pu$) Air Concentrations in the Northwest and Hanford Environs, 1984 Through 1989 (NA: EPA data for 1988 and 1989 were not available, ND: nondetectable)

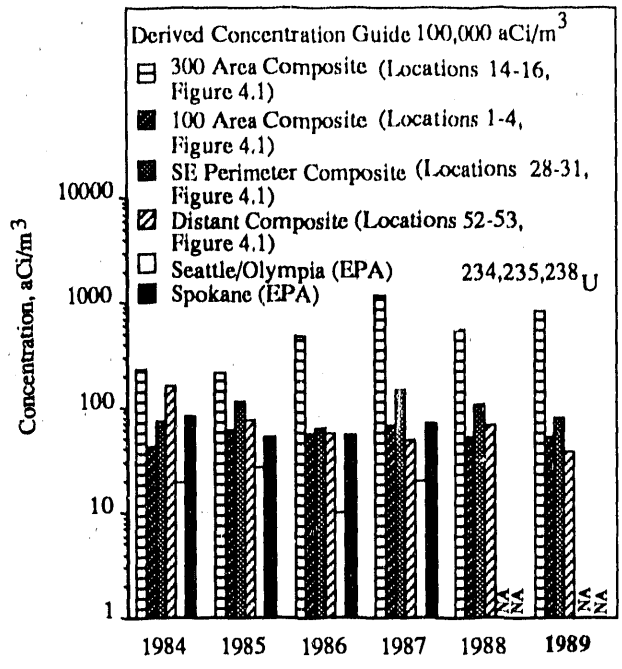

FIGURE 4.9. Annual Average Uranium (^{234}U, ^{235}U, and ^{238}U) Air Concentrations in the Northwest and Hanford Environs, 1984 Through 1989 (NA: EPA data for 1988 and 1989 were not yet available)

decrease in air concentrations in 1986 followed the installation of additional source controls at the PUREX Plant in late 1985.

Uranium concentrations (^{234}U, ^{235}U, and ^{238}U) in airborne particulate matter in 1989 were higher at the perimeter than at the distant communities (Table C.6, Appendix C) as well as being elevated relative to values typical of Seattle/Olympia and Spokane as reported by EPA. This increase is due to wind resuspension of soil in and around the 300 Area as reflected in the 300 Area air concentrations shown in Figure 4.9. The 1989 annual average concentration in the southeast perimeter composite (map locations 25-28, Figure 4.1) was 78 (±42) aCi/m^3 compared to the DCG of 100,000 aCi/m^3.

Ruthenium-106, ^{131}I, and ^{137}Cs were routinely monitored through gamma energy analyses of the monthly composite sample and were generally below detectable levels both on and off the Hanford Site. The results obtained for 1989 are included in Table C.6, Appendix C. Even the maximum individual measurements for these nuclides were a small fraction of their DCGs.

The comparisons of radionuclide concentrations discussed in the previous paragraphs are based on measured numerical results without taking into account the uncertainty in the data or their averages. However, a statistical analysis of variance (Snedecor and Cochran 1980) was conducted to take such uncertainty into account when evaluating the effect of Hanford operations on the environment. A comparison was made between regional background concentrations represented by measurements at Yakima, and the average at the downwind

perimeter of the Hanford Site. The 1989 average Hanford Site downwind perimeter concentration of ^{90}Sr was detectable and higher than background, but the difference was not statistically significant (5% significance level). Downwind concentrations of ^{3}H, ^{129}I, uranium, gross alpha, and gross beta were higher than background, and the differences were statistically significant (beyond the 5% significance level).

Nitrogen dioxide data collected in 1989 (Table C.5, Appendix C) indicate that the highest annual average (<0.007 ±0.0012 ppm) observed at three sampling locations (Figure 4.2) was below the applicable federal and Washington State annual average ambient air standard for NO_2, which is 0.05 ppm.

4.2 SURFACE-WATER SURVEILLANCE

The Columbia River was one of the primary environmental exposure pathways to the public during 1989 as a result of operations at Hanford. Radiological and nonradiological contaminants entered the river along the Hanford Reach as direct effluent discharges and through the seepage of contaminated ground water. Water samples were collected from the river at various locations (Figure 4.10) throughout the year to determine compliance with applicable standards.

Although radionuclides associated with Hanford operations continued to be routinely identified in Columbia River water during the year, concentrations remained extremely low at all locations and were well below applicable standards. Nonradiological water quality constituents measured in Columbia River water during 1989 were also in compliance with applicable standards.

Three onsite ponds were sampled to determine radionuclide concentrations. These ponds are accessible to migratory waterfowl and other animals. As a result, a potential biological pathway exists for the removal and dispersal of contaminants that may be in the ponds. Concentrations of radionuclides in water collected from these ponds during 1989 were similar to those observed during past years.

Radionuclide levels in Columbia River surface sediments were measured at five offsite locations during 1989. Samples were collected from behind McNary and Priest Rapids Dams and from three Columbia River shoreline sloughs along the Hanford Site. Previous sampling has shown that slightly elevated levels of some radionuclides exist in surface sediments behind McNary Dam as a result of Hanford operations.

Offsite water, used for irrigation and/or drinking water, was sampled to determine radionuclide concentrations in water used by the nearby public. Elevated gross alpha and gross beta concentrations, attributed to naturally occurring uranium, were observed at some locations. Average radionuclide concentrations in offsite water during 1989 were within applicable drinking water limits.

COLUMBIA RIVER

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

Pollutants, both radiological and nonradiological, are known to enter the river along the Hanford Site. In addition to direct discharges of liquid effluents from Hanford facilities,

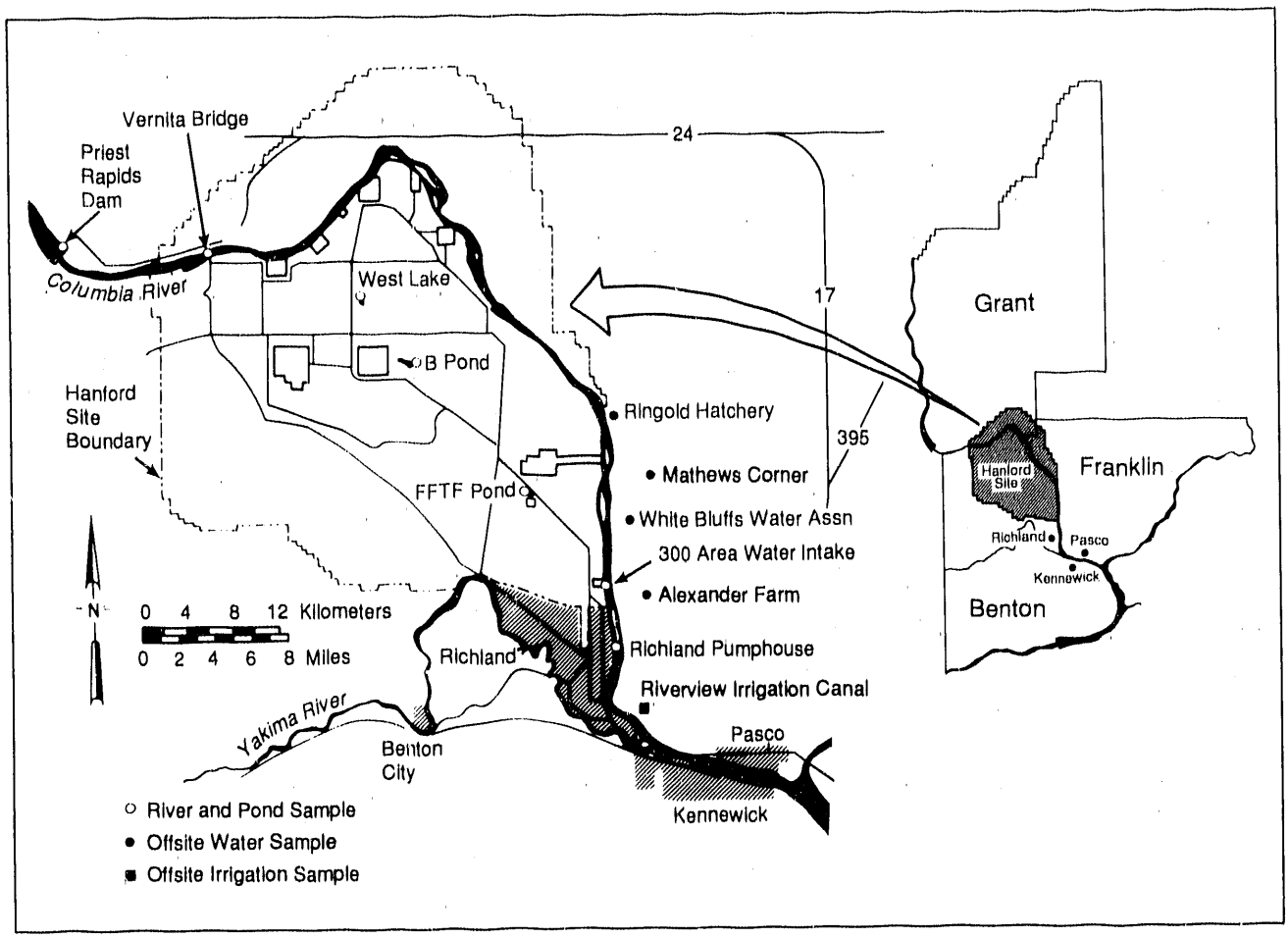

FIGURE 4.10. Onsite Pond, Columbia River, and Offsite Water Sampling Locations in 1989

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

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

Sample Collection and Analysis

Samples of Columbia River water were collected throughout 1989 at the locations shown in Figure 4.10. Samples were collected upstream of Hanford facilities at Priest Rapids Dam and near the Vernita Bridge to provide background data from locations unaffected by Site operations. Samples were collected from the 300 Area water intake and the Richland Pumphouse to identify any increase in contaminant concentrations at these locations from Hanford operations. The Richland Pumphouse is the first downstream point of river water withdrawal for a public drinking water supply.

Radiological analyses on water samples included gross alpha, gross beta, gamma scan, ^{3}H, ^{89}Sr, ^{90}Sr, ^{99}Tc, ^{129}I, $^{239,240}Pu$, and isotopic uranium. Gross alpha and gross beta measurements provided a general indication of the radioactive contamination. Gamma scans provided the ability to detect numerous specific radionuclides (listed on page D.1, Appendix D), most of which were not found in measurable quantities in the Columbia River. Specific radiochemical analyses and, in some cases, special sampling techniques were used to determine the concentrations of ^{3}H, ^{89}Sr, ^{90}Sr, ^{99}Tc, ^{129}I, ^{234}U, ^{235}U, ^{238}U, and $^{239,240}Pu$ in river water during the year. Radionuclides of interest were selected based on their importance in determining water quality, verifying effluent control and effluent monitoring systems, and determining compliance with applicable standards. The half-lives of specific radionuclides were considered in determining sampling and analysis frequencies.

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

The 300 Area water intake is near the southern boundary of the Site at the point of withdrawal for the 300 Area sanitary water supply. This is a source of onsite drinking water and provides a valuable historical database for certain constituents, as it has been in existence since the early days of Hanford. Concentrations observed here are influenced by seepage of local ground water, known to contain elevated levels of ^{3}H and uranium (see "Ground-Water Protection and Monitoring Program," Section 5.0).

The Richland Pumphouse is located approximately 3 km downstream of the Site boundary and about 5 km downstream of the most downstream effluent discharge. The water sampling intake is located with the city of Richland drinking water supply intake on the Benton County shoreline, approximately 9 m into the river. Historical environmental monitoring reports indicate this to be the drinking water supply having the maximum radionuclide concentrations downstream of Hanford (Corley 1970, 1973; Corley and Woolridge 1969; Fisher and Wilson 1970; Foster 1966; Foster and Wilson 1964, 1965; Honstead 1967). Past sampling transects near this location indicated the distribution of gross beta activity to be slightly elevated near the Benton County shoreline (Soldat 1962). A special task to evaluate the relationship between concentrations observed at the Richland Pumphouse and average river concentrations was initiated during 1987. Field sampling was completed during

1989, and results will be reported in FY 1990 in a separate topical report.

Two types of water sampling systems were used to collect radiological samples: 1) a composite system that collected a fixed volume of water at set intervals at each location during each sample period and 2) a specially designed system that continuously collected waterborne radionuclides from the river on a series of filters and ion-exchange resins.

Composite sampling systems were operated at Priest Rapids Dam, 300 Area water intake, and the Richland Pumphouse. The composite samplers at Priest Rapids Dam and the Richland Pumphouse consisted of timer-activated units that periodically collected water from a continuously flowing substream of Columbia River water into a 10-L container. The sample sequence included a pre- and post-sample purge of the sample lines to preclude cross contamination between consecutive aliquots. The cycle was repeated throughout the 1-week sample period at Priest Rapids Dam and the Richland Pumphouse, such that approximately 55 mL of water were collected every hour. The 10-L sample container was changed every week, and the sample was taken to the laboratory, where water from each location was composited over a 4-week period, resulting in a total sample size of approximately 40 L. The system at the 300 Area was similar, except that water samples were collected approximately every 4 hours, removed monthly, and composited for quarterly analysis. Gross alpha, gross beta, gamma scan, ^{3}H, ^{89}Sr, ^{90}Sr, ^{99}Tc, ^{234}U, ^{235}U, and ^{238}U analyses were performed on these samples. In addition, weekly alpha and beta analyses were performed on an aliquot of the composite sample from the Richland Pumphouse.

Continuous sampling systems were located at Priest Rapids Dam, 300 Area water intake, and the Richland Pumphouse. A special, continuously flowing system was used to separate radionuclides from the river water before analysis. A large volume of water was required to allow the extremely small concentrations of these radionuclides 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 diameter were removed on a series of filters, and soluble radionuclides, except ^{3}H, were collected on a mixed-bed, ion-exchange resin column. The filters and ion-exchange resin were changed every 2 weeks and analyzed for gamma-emitting radionuclides (see Appendix D). The filters and resin from each location were then composited on a quarterly basis for analyses of ^{129}I, ^{238}Pu, and $^{239,240}Pu$.

Monthly grab samples of Columbia River water were collected from shoreline sites near the Vernita Bridge and near the Richland Pumphouse for analyses of various nonradiological water quality parameters. Special care was taken to obtain water from a flowing portion of the river, avoiding stagnant backwater areas. Surface debris and bottom sediment were also avoided during the sampling process by collecting the samples from approximately mid-depth. Samples were delivered to the laboratory, where processing was initiated promptly to ensure sample integrity. Water quality analyses performed during 1989 included pH, NO_3^-, total coliform and fecal coliform bacteria, and biological oxygen demand. All of these parameters are indicators of the quality of Columbia River water.

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

Samples of Columbia River sediment were collected during 1989 at locations shown in Figure 4.11. Offsite samples were collected upstream of the Hanford Site behind Priest Rapids Dam and below the Site at Richland and behind McNary Dam. Samples were collected from sloughs at White Bluffs, 100-F Area, and Hanford Townsite. Samples were obtained from approximately 15 cm of the top sediment material using a dredge sampler. Analyses of the sediment samples included gamma scans, ^{90}Sr, ^{235}U, ^{238}U, ^{238}Pu, and $^{239,240}Pu$.

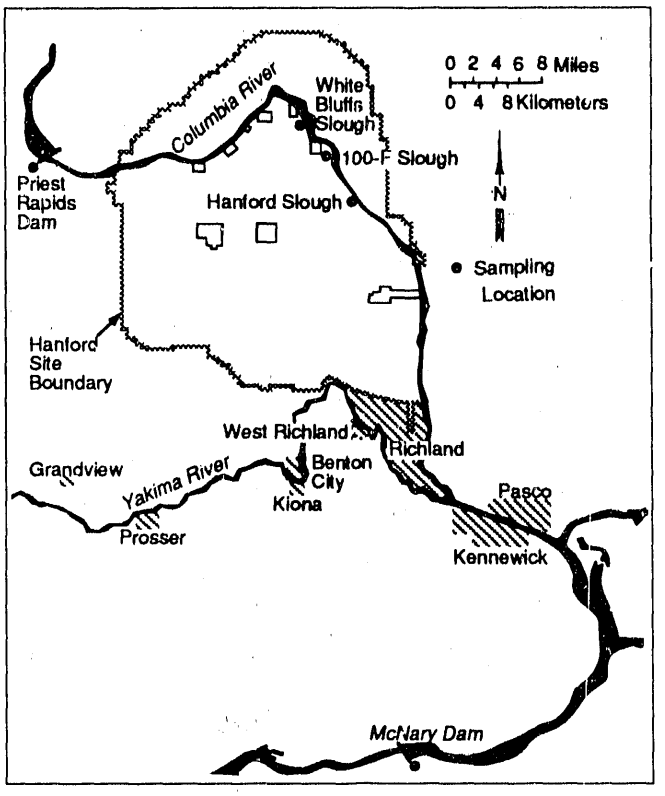

FIGURE 4.11. Columbia River Sediment Sampling Sites During 1989

Results

Results of the radiological analyses of Columbia River water samples collected at Priest Rapids Dam, 300 Area, and the Richland Pumphouse during 1989 are summarized in Tables C.7, C.8, and C.9, Appendix C, respectively. Tables C.7 through C.9 list radionuclides for which detectable concentrations were observed during the year. Levels throughout the year were extremely low, essentially undetectable without the use of special sampling techniques and analytical procedures. Concentrations of ^{95}Nb, ^{95}Zr, ^{106}Ru, ^{134}Cs, and ^{238}Pu, reported in previous annual reports, were generally below detection levels and thus were omitted from most of the tables. Radionuclides consistently measurable in river water during 1989 were ^{3}H, ^{90}Sr, ^{99}Tc, ^{129}I, ^{234}U, ^{235}U, ^{238}U, and $^{239,240}Pu$. Most of these radionuclides exist in worldwide fallout, as well as in effluents from Hanford facilities. In addition, ^{3}H and uranium occur naturally in the environment.

Significant results are discussed and illustrated in the following paragraphs, with comparisons to previous years provided. Statistical analyses of the differences between radionuclide concentrations at Priest Rapids Dam and the Richland Pumphouse provide an indication of the influence, if any, of Hanford operations on the city of Richland drinking water source. Annual average radionuclide concentrations are also compared to applicable State of Washington

and EPA DWS. All radionuclide concentrations during 1989 were below the state and EPA DWS (see Tables C.7 through C.9, Appendix C).

Gross alpha and gross beta measurements are useful indicators of the general radiological quality of the river and provide an early indication of changes in the levels of radioactive contamination. The 1989 average gross alpha and gross beta concentrations in Columbia River water at Priest Rapids Dam, 300 Area, and the Richland Pumphouse were below the applicable DWS of 15 and 50 pCi/L, respectively. Figures 4.12 and 4.13 illustrate the annual average gross alpha and gross beta concentrations, respectively, at Priest Rapids Dam and the Richland Pumphouse during the past 6 years. The 1989 gross beta concentrations were slightly higher than those of 1987 and 1988 but were consistent with levels seen between 1984 and 1986. Gross alpha concentrations at both locations increased slightly in 1989. The cause of the slight increase in gross alpha and gross beta concentrations during 1989 has not been determined. The

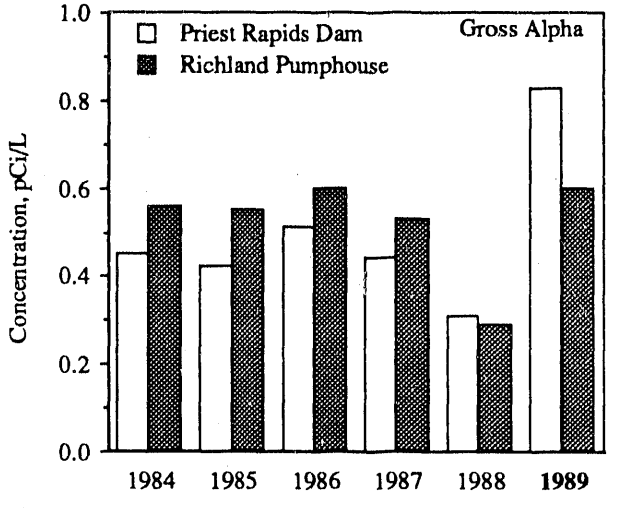

FIGURE 4.12. Annual Average Gross Alpha Concentrations in Columbia River Water, 1984 Through 1989

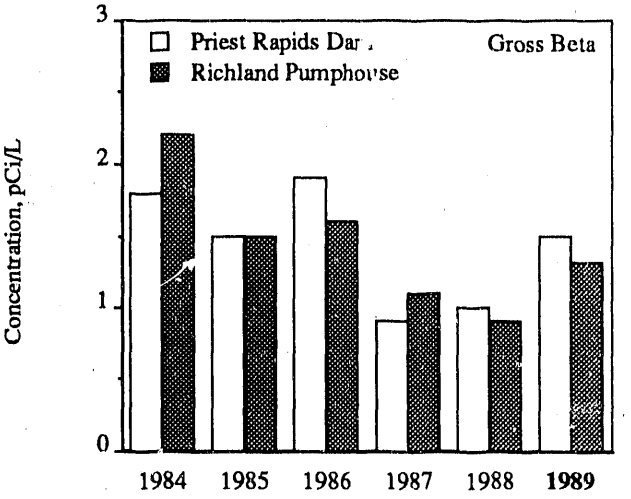

FIGURE 4.13. Annual Average Gross Beta Concentrations in Columbia River Water, 1984 Through 1989

increases were very small and generally within the range of uncertainties associated with the annual averages. As in 1988, gross alpha concentrations in 1989 were slightly higher at Priest Rapids Dam than at the Richland Pumphouse. Statistical analyses (i.e., paired sample comparison and t-test of differences) of gross alpha and gross beta concentrations at Priest Rapids Dam and the Richland Pumphouse indicated the differences were not significant (5% significance level) (Snedecor and Cochran 1980).

Annual average ^3H concentrations at Priest Rapids Dam and the Richland Pumphouse during 1989 were 63 and 129 pCi/L, respectively. Figure 4.14 compares the annual average ^3H concentrations at Priest Rapids Dam and the Richland Pumphouse from 1984 through 1989. Tritium concentrations in Columbia River water during 1989 were similar to those during recent years. Figure 4.15 provides a comparison of monthly ^3H concentrations in river water during 1989, showing that concentrations at the Richland Pumphouse were

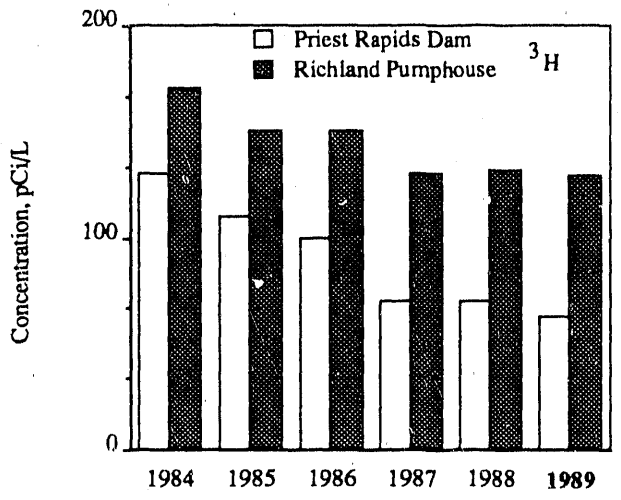

FIGURE 4.14. Annual Average Tritium (^3H) Concentrations in Columbia River Water, 1984 Through 1989

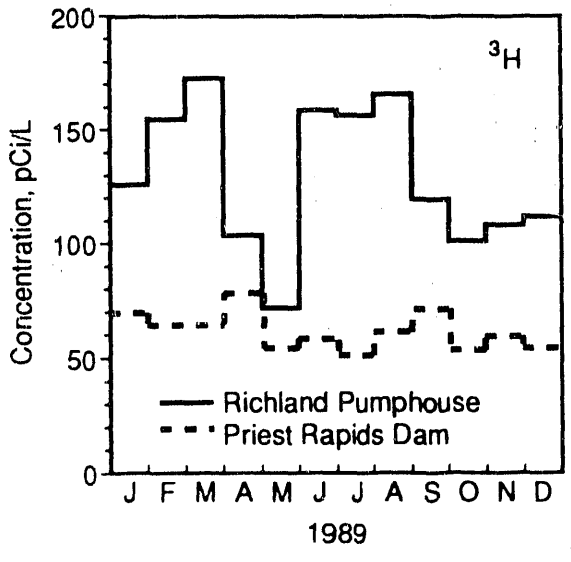

FIGURE 4.15. Monthly Tritium (^3H) Concentrations in Columbia River Water During 1989

continually higher during the year than those at Priest Rapids Dam. The difference between the ^3H concentrations at Priest Rapids Dam and the Richland Pumphouse was significant (paired sample comparison, t-test of differences, 5% significance level). Tritium sources entering the river were effluent releases from N Reactor and ground-water seepage into the river along the Site (see "Effluent Monitoring," Section 4.7, and "Ground-Water Protection and Monitoring Program," Section 5.0). All ^3H concentrations were at least a factor of 100 below the State of Washington and EPA DWS of 20,000 pCi/L.

Annual average ^{90}Sr concentrations at Priest Rapids Dam and the Richland Pumphouse during 1989 were 0.08 and 0.07 pCi/L, respectively. Figure 4.16 shows the annual average ^{90}Sr concentrations at these locations from 1984 through 1989. Although the Richland Pumphouse annual average concentrations were generally higher than those at Priest Rapids Dam, the differences since 1984 were slight, especially when the uncertainty associated with the averages was considered. Figure 4.17 shows monthly ^{90}Sr concentrations during the year at both locations. The difference between the ^{90}Sr concentrations throughout the year at these locations was not significant at the 5% significance level. The primary source of ^{90}Sr

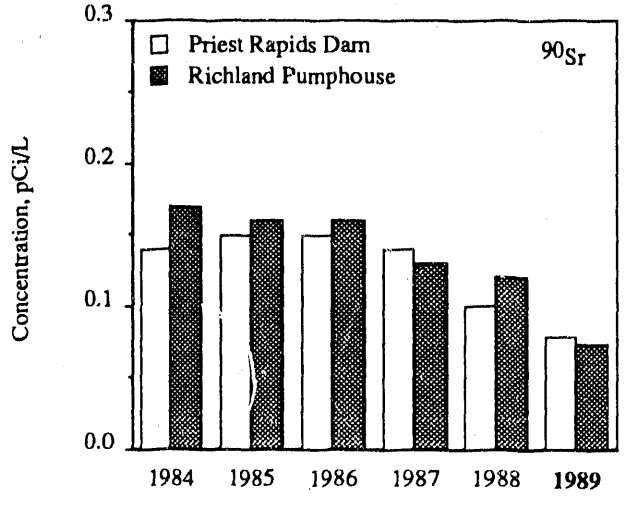

FIGURE 4.16. Annual Average Strontium-90 (^{90}Sr) Concentrations in Columbia River Water, 1984 Through 1989

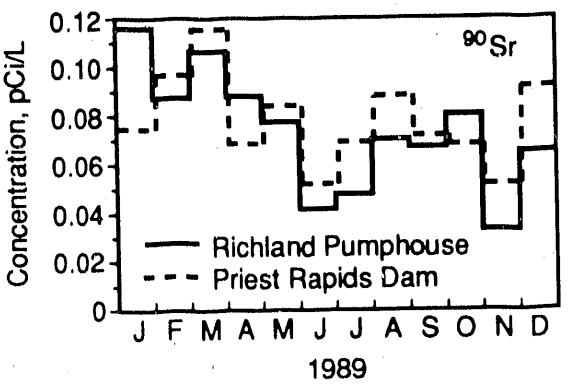

FIGURE 4.17. Monthly Strontium-90 (^{90}Sr) Concentrations in Columbia River Water During 1989

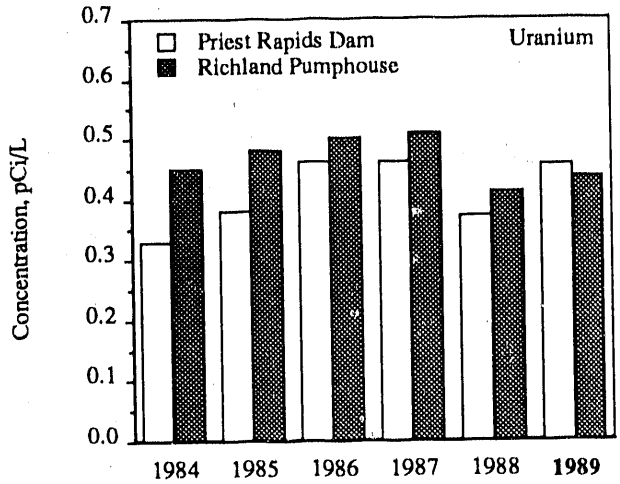

FIGURE 4.18. Annual Average Uranium Concentrations in Columbia River Water, 1984 Through 1989

entering the Columbia River has been the 100-N Area Liquid Waste Disposal Facilities, which are known to discharge to the river via ground-water seepage. Strontium-90 concentrations in Columbia River water during 1989 remained below the State of Washington and EPA DWS of 8 pCi/L.

Annual average uranium concentrations in 1989 were slightly higher in river water at Priest Rapids Dam than at the Richland Pumphouse (Figure 4.18). The difference in annual averages (0.02 pCi/L) is small and within the level of uncertainty associated with the means. Monthly values were higher at the Richland Pumphouse during the first half of 1989 and higher at Priest Rapids Dam during the last half of 1989 (Figure 4.19). There was no consistently measurable contribution to Columbia River water uranium concentrations at the Richland Pumphouse attributable to Hanford operations. Differences during the year were not statistically significant (5% significance level). Although there is no direct discharge of uranium to the river, uranium is present in the ground water beneath the 300 Area (see "Ground-Water Protection and Monitoring

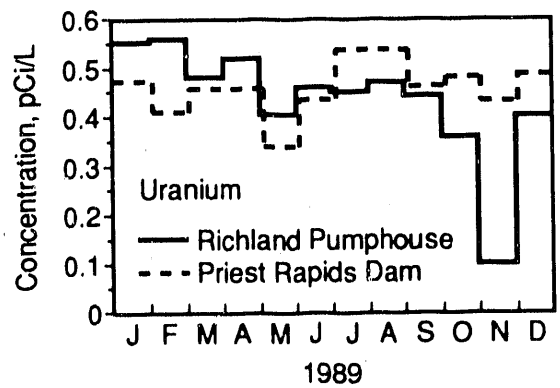

FIGURE 4.19. Monthly Uranium Concentrations in Columbia River Water During 1989

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

As in past years, ^{129}I concentrations, while extremely low, continue to be significantly higher (5% significance level) at the 300 Area

water intake and the Richland Pumphouse than at Priest Rapids Dam. Average ^{129}I concentrations in river water collected at Priest Rapids Dam, 300 Area, and the Richland Pumphouse during 1989 were 5.3, 166, and 118 aCi/L, respectively. Iodine-129 in the river downstream of Hanford is attributable to the flow of contaminated ground water from the unconfined aquifer into the river (McCormack and Carlile 1984). Ground water beneath the Hanford Site is contaminated as a result of past waste disposal practices. Figure 4.20 provides the annual average ^{129}I concentrations from 1984 through 1989. Differences during 1989 among the Priest Rapids Dam, 300 Area, and the Richland Pumphouse concentrations were similar to the differences in past years. Figure 4.21 illustrates quarterly ^{129}I concentrations at Priest Rapids Dam and the Richland Pumphouse. As for other radionuclides, ^{129}I concentrations in Columbia River water during 1989 were extremely low, at least a factor of 3800 below the State of Washington and EPA DWS of 1 pCi/L.

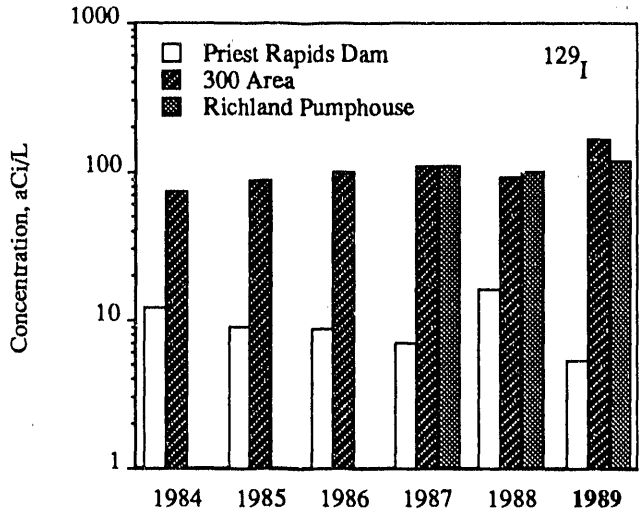

FIGURE 4.20. Annual Average Iodine-129 (^{129}I) Concentrations in Columbia River Water, 1984 Through 1989

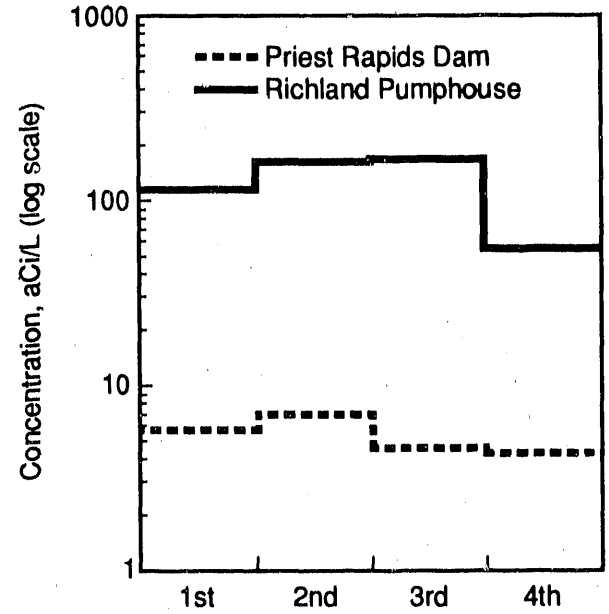

FIGURE 4.21. Quarterly Iodine-129 (^{129}I) Concentrations in Columbia River Water During 1989

During 1989, ^{60}Co, ^{89}Sr, ^{131}I, and ^{137}Cs were not consistently found in measurable quantities in the Columbia River at Priest Rapids Dam, the 300 Area water intake, or the Richland Pumphouse. Small quantities of ^{60}Co and ^{137}Cs were discharged to the Columbia River during 1989 (see Appendix G). No production sources of ^{89}Sr or ^{131}I exist following the shutdown of N Reactor. Highest concentrations of $^{239,240}Pu$ were found at the 300 Area water intake, but levels at all locations were extremely low. All ^{60}Co, ^{89}Sr, ^{131}I, ^{137}Cs, and $^{239,240}Pu$ concentrations during the year were below the State of Washington and EPA DWS (see Tables C.7, C.8, and C.9, Appendix C).

Analytical results for sediment samples collected from the Columbia River during 1989 are presented in Table C.10, Appendix C. Surface sediments behind McNary Dam are known

to contain low levels of radionuclides of Hanford origin (Robertson and Fix 1977; Beasley et al. 1981). In 1989, radionuclide levels in surface sediments behind McNary Dam were generally higher then levels found in samples collected behind Priest Rapids Dam and in Hanford Site sloughs. However, concentrations of ^{106}Ru were highest in sediments from White Bluffs and Hanford sloughs, and ^{238}U levels were highest in Priest Rapids Dam sediments. Most results for samples collected from behind Priest Rapids Dam and from Hanford slough locations were similar. However, ^{60}Co concentrations were consistently higher in the slough areas.

Nonradiological water quality data compiled by PNL and the USGS during 1989 are summarized in Table C.11, Appendix C. A number of parameters have no regulatory limits. These parameters are, however, useful as indicators of water quality. The PNL and USGS results, when duplicated, were in agreement and were comparable to levels in recent years. In general, applicable standards for Class A-designated water were met. There was no indication during 1989 of any significant deterioration of the water quality along this stretch of the Columbia River resulting from Hanford operations. Potential sources of pollutants not associated with Hanford include irrigation return water and seepage associated with extensive irrigation practices north and east of the Columbia River.

Figure 4.22 shows Vernita Bridge and Richland results for the period 1984 through 1989 for several water quality parameters with respect to the applicable standards. The pH measurements above and below the Site were in close agreement and were within the acceptable range for Class A waters, with the exception of one measurement at each location. Turbidity, median fecal coliform, and dissolved oxygen

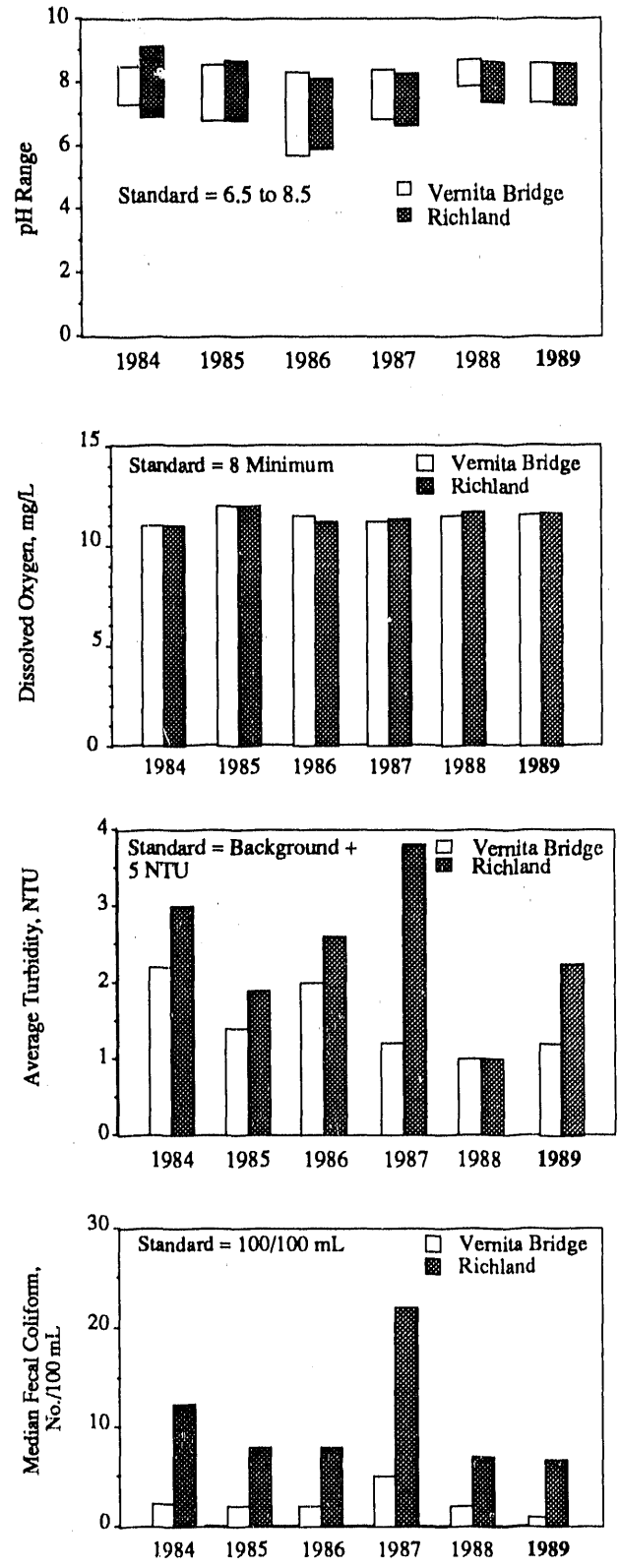

FIGURE 4.22. Columbia River Water Quality Measurements, 1984 Through 1989

concentrations during 1989 were in compliance with Class A requirements at both locations as well.

The annual average flow rate of the Columbia River was 2815 m^3/s during 1989, similar to 1988 and slightly lower than recent years. The monthly average flow rates at Priest Rapids Dam are shown in Figure 4.23. The peak monthly average flow occurred during May (4475 m^3/s), and the lowest average monthly flow occurred during August (1897 m^3/s). Daily average flow rates varied from 340 to 5466 m^3/s during 1989.

Average monthly Columbia River water temperatures at Priest Rapids Dam and the Richland Pumphouse are shown in Figure 4.24. The major source of heat to the Columbia River in the Hanford Reach is solar radiation (Dauble et al. 1987). River temperatures and the differences between Priest Rapids Dam and the Richland Pumphouse temperatures during 1989, in the absence of reactor operations, were similar to those in the past (Price 1986). Monthly average temperatures were higher at

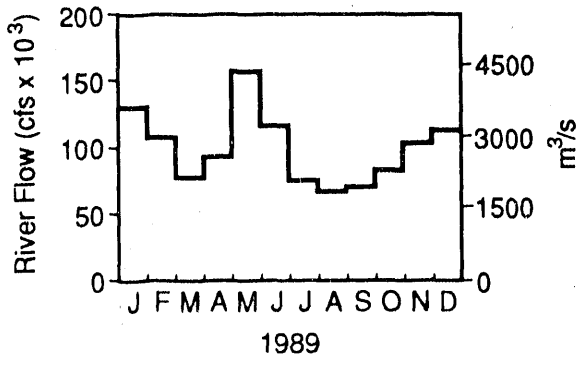

FIGURE 4.23. Monthly Average Flow Rates of the Columbia River During 1989 (measured at Priest Rapids Dam)

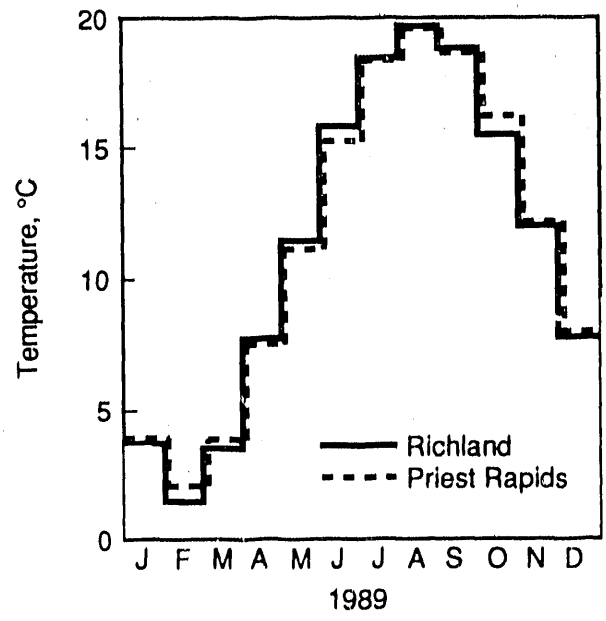

FIGURE 4.24. Monthly Average Temperatures in the Columbia River Water During 1989

the Richland Pumphouse than at Priest Rapids Dam from April through June 1989. Cooler monthly average temperatures were observed at the Richland Pumphouse from January through March and during October. Average temperatures were essentially the same at both locations in July, August, September, November, and December.

ONSITE PONDS

Three onsite ponds (see Figure 4.10) located near operating areas were sampled periodically during 1989. B Pond, located near the 200-East Area, was excavated in the mid-1950s for disposal of process cooling water and other liquid wastes occasionally containing low levels of radionuclides. West Lake, located north of the 200-East Area, is recharged from the ground water (Gephart et al. 1976). This pond has not received direct effluent discharges from Site facilities. The Fast Flux Test Facility (FFTF) Pond, located near the 400 Area, was

excavated in 1978 for the disposal of cooling water from various facilities in the 400 Area.

Westinghouse Hanford Company is responsible for monitoring effluents discharged to the ponds and for operational surveillance of the ponds (Cooney et al. 1988). Although the ponds were inaccessible to the public and did not constitute a direct offsite environmental impact during 1989, they were accessible to migratory waterfowl, creating a potential biological pathway for the dispersion of contaminants (see "Wildlife Surveillance," Section 4.4). Periodic sampling of the ponds also provided an independent check on effluent control and monitoring systems.

Sample Collection and Analysis

During 1989, 10-L grab samples were collected quarterly from each pond. Care was taken to avoid surface debris and resuspension and inadvertent collection of bottom sediments. Unfiltered aliquots of the samples were analyzed for gross alpha and gross beta activities, gamma-emitting radionuclides, ^{3}H, and ^{90}Sr. Sodium-22 analyses were performed on FFTF Pond samples to provide indications of process failure.

Results

Analytical results from pond samples collected during 1989 are summarized in Table C.12, Appendix C. Maximum, minimum, and average concentration values are provided for various radionuclides at each pond. Further discussion of individual constituents and comparisons with results obtained during previous years are provided below for each pond.

Annual average radionuclide concentrations in B Pond are shown in Figure 4.25. Radionuclide concentrations in B Pond water during

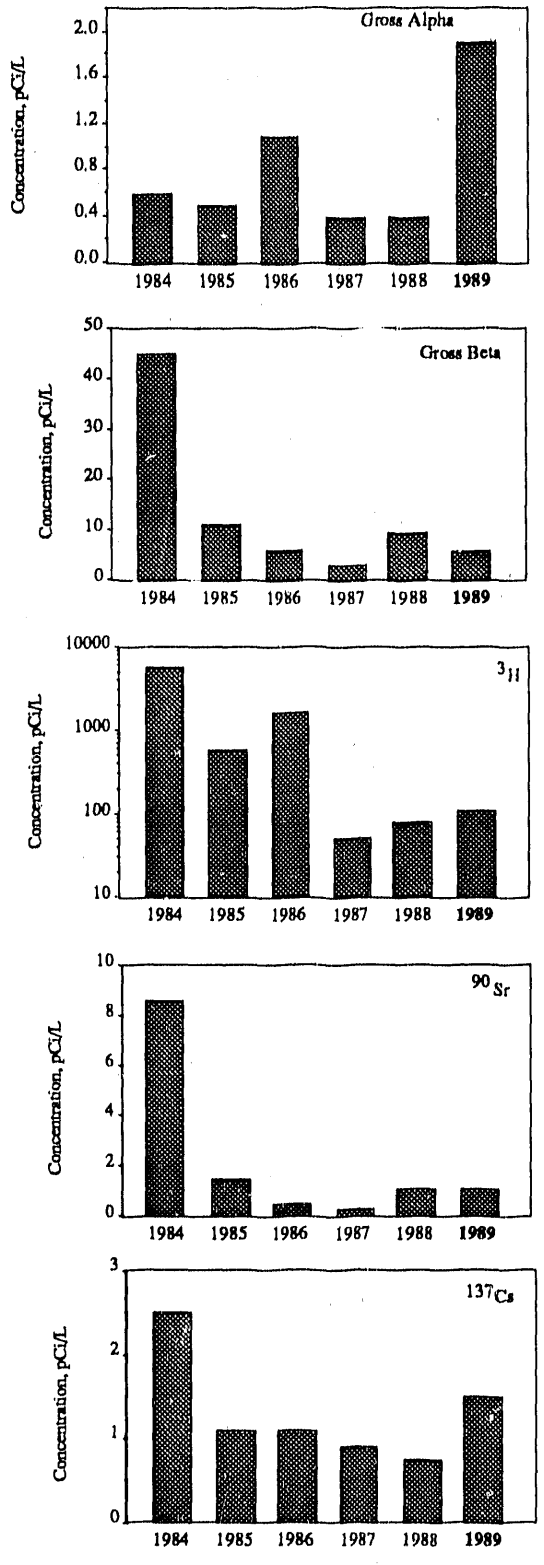

FIGURE 4.25. Annual Average Radionuclide Concentrations in B Pond, 1984 Through 1989

1989 were comparable to those observed during the previous 5 years. Gross alpha concentrations during the year were somewhat higher than those observed during the previous 5 years but remained near the analytical detection limit. Gross beta concentrations in 1989 were slightly lower than those observed in 1988 but were similar to those observed during 1986 and 1987. Concentrations of ^{90}Sr were comparable to those observed in 1988. Tritium concentrations in B Pond remained below the detection level, as has been the case in recent years. Cesium-137 concentrations were also generally below the detection level during 1989 and similar to concentrations observed in recent years.

Figure 4.26 shows the annual average gross beta and tritium concentrations in FFTF Pond during 1989. As in the past, gross alpha, ^{22}Na, and ^{90}Sr concentrations were below the detection level and were omitted from this figure. Gross beta concentrations in FFTF Pond water were similar to those reported during the previous 5 years. The concentrations of tritium were also comparable to those measured in FFTF Pond in the past.

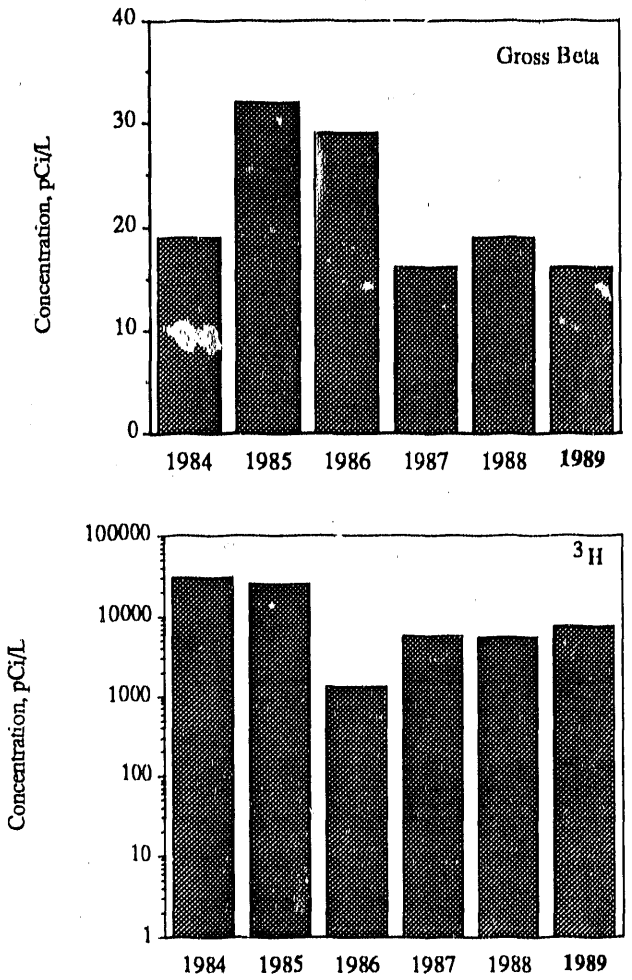

FIGURE 4.26. Annual Average Radionuclide Concentrations in FFTF Pond, 1984 Through 1989

The 1989 annual average radionuclide concentrations in West Lake were comparable to those observed during recent years (Figure 4.27). Average gross alpha concentrations were slightly lower than in 1988 but were similar to those observed in past years. Gross beta concentrations have remained relatively stable over the years. The 1989 concentration was within the range observed during the previous 5 years. Gross alpha and gross beta concentrations in West Lake, which is recharged from ground water (Gephart et al. 1976), continued to be higher than the gross alpha and gross beta levels found in the other onsite ponds. These elevated levels are believed to result from high concentrations of naturally occurring uranium (Speer et al. 1976). Annual average uranium concentrations were slightly elevated during 1989 and substantiate the elevated gross alpha and gross beta measurements. Strontium-90 concentrations during 1989 were higher than those observed during the previous 5 years. Tritium concentrations in West Lake during 1989 were the lowest observed in the past 6 years and remained similar to those observed in the local ground water.

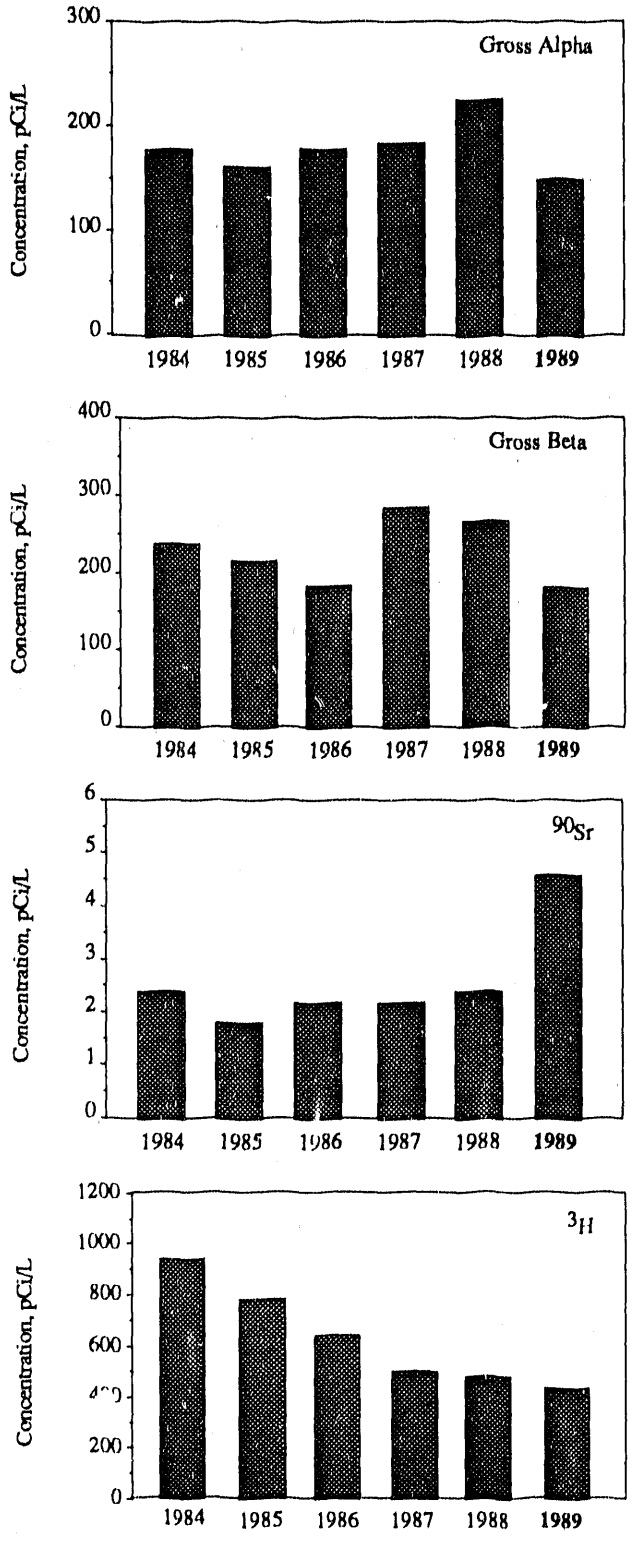

FIGURE 4.27. Annual Average Radionuclide Concentrations in West Lake, 1984 Through 1989

OFFSITE WATER

Water samples were collected from four water systems directly east of and across the Columbia River from the Hanford Site during 1989. Samples were also collected from an irrigation canal that obtains water from the Columbia River downstream of Hanford. Sampling was initiated to document the levels of radionuclides in the water used by the public and as a result of public concerns about the potential for Hanford-associated contaminants being present in offsite water. Consumption of food irrigated with Columbia River water from downstream of the Site has been identified as one of the primary pathways contributing to the dose to the hypothetical maximally exposed individual (Jaquish and Mitchell 1988).

Water was collected from four offsite domestic water supplies during 1989 (see Figure 4.10). Analyses of these samples included gross alpha, gross beta, gamma scan, ^{3}H, ^{129}I, ^{234}U, ^{235}U, and ^{238}U. Results are presented in Table C.13, Appendix C. Grab samples were collected quarterly. Elevated gross alpha and gross beta concentrations are attributable to elevated natural uranium concentrations in the ground water of this area. The general levels observed in the offsite water supplies were comparable to those reported by the State of Washington. Iodine-129 concentrations were within the range previously reported in offsite water (WDSHS 1987). Annual average radionuclide concentrations in offsite water during 1989 were within applicable DWS.

The Riverview irrigation canal was sampled three times during the irrigation season. These samples were analyzed for gross alpha, gross beta, gamma emitters, ^{90}Sr, ^{234}U, ^{235}U, and ^{238}U.

Results are presented in Table C.13, Appendix C. Strontium-90 was the primary radionuclide of concern because it has been identified as one of the primary contributors to the calculated hypothetical dose to the public via the water pathway (Jaquish and Mitchell 1988).

With the exception of one ^{137}Cs result, gamma emitters were below the detection level in all samples. The concentration of ^{90}Sr during 1989 was similar to that reported for the Columbia River at Priest Rapids Dam and the Richland Pumphouse.

4.3 FOOD AND FARM PRODUCT SURVEILLANCE

Alfalfa and a number of foodstuffs, including milk, vegetables, fruits, wine, wheat, beef, chickens, and eggs, were collected at several locations surrounding the Hanford Site during 1989 (Figure 4.28). Samples were collected primarily from locations in the prevailingly downwind directions (i.e., to the south and east of the Site) where airborne effluents from Hanford could be expected to be deposited. Samples were also collected in generally upwind directions somewhat distant from the Site to provide information on levels of radioactivity that could be attributed to worldwide fallout. Foodstuffs from the Riverview area were irrigated with water pumped from the Columbia River downstream of the Site. Alfalfa and foodstuff samples were analyzed for one or more of the following radionuclides: ^{3}H, ^{90}Sr, ^{129}I, ^{131}I, ^{137}Cs, and $^{239,240}Pu$.

Low levels of ^{3}H, ^{90}Sr, ^{129}I, and ^{137}Cs were found in a number of foodstuff samples collected during 1989; however, the concentrations in samples collected near the Hanford Site were similar to those in samples collected away from the Site. Thus, measured values in foodstuffs were not attributed to Hanford effluents. There are no radionuclide concentration limits for foodstuffs. The potential offsite radiation dose from consumption of foodstuffs grown in the Hanford vicinity was calculated based on reported radionuclide emissions and pathway modeling (as discussed in "Potential Radiation Doses from 1989 Hanford Operations," Section 4.8).

MILK

Selected samples of raw, whole milk were collected from several dairy farms near the Site perimeter and in the prevailingly downwind directions to evaluate possible Hanford impacts. Samples were also collected from dairy farms near Sunnyside and Moses Lake to provide indications of the general concentrations of radionuclides in milk attributable primarily to worldwide fallout. The general areas of sampling are shown in Figure 4.28, and results are listed in Table C.14, Appendix C. Samples were routinely collected every other week throughout the year from the Sagemoor and Sunnyside areas, and monthly from other areas. All samples were analyzed for ^{131}I and ^{137}Cs. Tritium analyses were conducted on one sample per month. Strontium-90 analyses were conducted on one sample per quarter, and ^{129}I analyses were conducted on one sample every 6 months.

A total of 92 milk samples were collected and analyzed for ^{131}I during 1989. Results for four of the samples were slightly above the detection level. These include one sample each from the Wahluke East, Sagemoor, Benton City, and Moses Lake areas. Statistically, four to five (5%) of the 92 samples analyzed would be expected to erroneously exceed the detection level when in fact no ^{131}I was present. A small amount (about 1 mCi) of ^{131}I was released from Hanford during 1989 (Table G.1, Appendix G), but this quantity would not be expected to be identified in milk samples. The assessment of

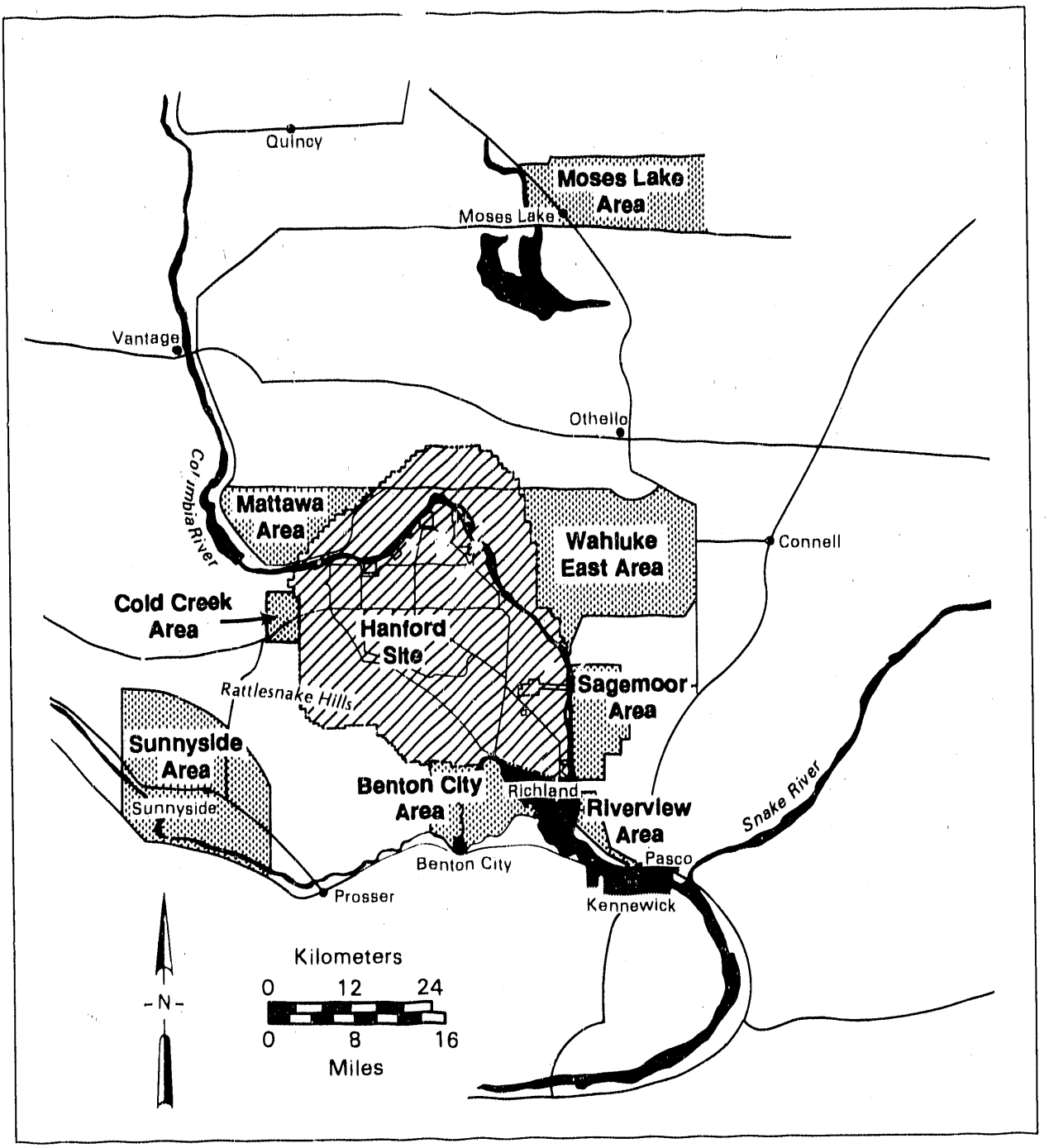

FIGURE 4.28. Foodstuff Sampling Areas in 1989 (stippling indicates areas sampled)

potential radiation dose from the release of ^{131}I was performed by pathway modeling (see "Potential Radiation Doses from 1989 Hanford Operations," Section 4.8).

Similar to the measurements for ^{131}I discussed above, about 5% of the 92 milk samples collected and analyzed for ^{137}Cs in 1989 contained detectable levels of ^{137}Cs. However, all samples

analyzed for ^{90}Sr contained ^{90}Sr. Neither ^{137}Cs nor ^{90}Sr is found naturally, but both are present to some degree in all milk samples because of the presence of these radionuclides in worldwide fallout and movement through the air-pasture-cow-milk food chain. Results (Table C.14, Appendix C) indicate an even geographical distribution and are similar to results published by the EPA for the first and second quarters of 1989 (EPA 1989b, 1989c). Figure 4.29 shows the 6-year record for ^{90}Sr and ^{137}Cs

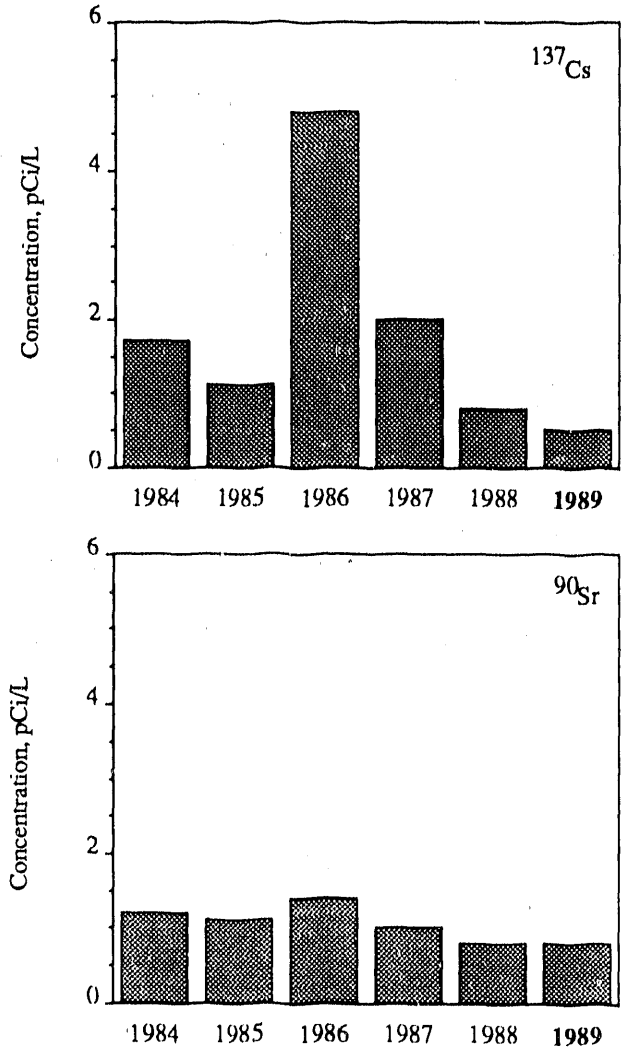

FIGURE 4.29. Annual Average Cesium-137 (^{137}Cs) and Strontium-90 (^{90}Sr) Concentrations in Milk for all Sampling Locations, 1984 Through 1989

in milk samples from all six sampling areas. The influence of the Chernobyl incident on ^{137}Cs in milk in 1986 is evident; otherwise, levels of both radionuclides have remained relatively constant. Results from sampling milk from the Hanford environs over the past 18 years were recently reviewed (Eberhardt et al. 1989). The overall trend has been downward, primarily from a decrease in the availability of fallout radionuclides.

Some milk samples were analyzed for ^{3}H and ^{129}I in 1989. Tritium was identified in about 40% of the 66 samples analyzed. Iodine-129 was identified in all 12 samples tested. Concentrations were very low and similar to those obtained in recent years. No differences were apparent between near-Site and distant sampling locations, except that, as in past years, samples from the Moses Lake area showed levels of ^{129}I lower than from other locations.

VEGETABLES

Samples of leafy vegetables (cabbage, broccoli leaves, or turnip greens) were obtained during the summer from gardens located within the sampling areas listed in Table C.15, Appendix C. The samples of leafy vegetables provided an indication of radionuclides present in locally grown produce. Three replicate samples of each leafy vegetable were analyzed for ^{90}Sr, ^{129}I, and ^{137}Cs. Results are shown in Table C.15, Appendix C. Strontium-90 and ^{137}Cs were identified in most samples but with no apparent difference between distant and nearby locations. Iodine-129 was not positively identified in any sample. Because there was no apparent difference, the observed concentrations of ^{90}Sr and ^{137}Cs at all locations were attributed to worldwide fallout. The concentrations are also comparable to those of recent years (Figure 4.30).

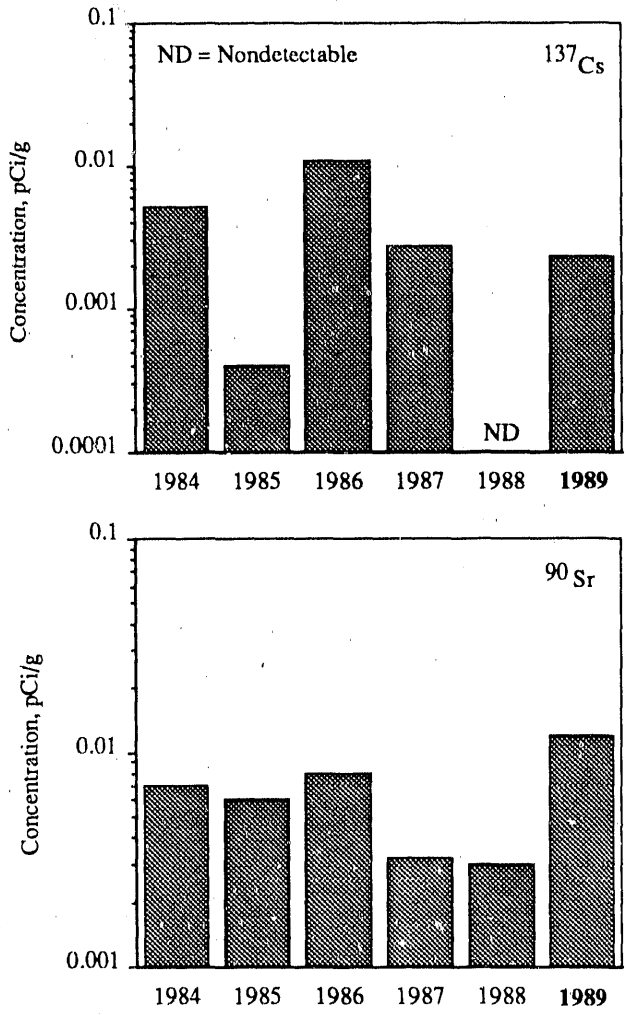

FIGURE 4.30. Annual Average Cesium-137 (^{137}Cs) and Strontium-90 (^{90}Sr) Concentrations in Leafy Vegetables for all Sampling Locations, 1984 Through 1989

An important contributor to potential radiation dose has been ^{90}Sr from Columbia River water used to irrigate crops. Commercially grown crops of vegetables from the Riverview area, which uses Columbia River irrigation water, and from other areas were analyzed for ^{90}Sr, gamma-emitting radionuclides (^{137}Cs), and $^{239,240}Pu$. Concentrations found in vegetables from the sampling areas were similar, and no effect from the current use of Columbia River water for irrigation was noted. Some vegetable samples contained small amounts of ^{90}Sr and ^{137}Cs attributed to worldwide fallout. The concentrations of ^{90}Sr and ^{137}Cs in vegetables over the past 18 years have been rather constant, with no detectable difference between samples from local or distant farms (Eberhardt et al. 1989). Plutonium-239,240 was not detected. Results are shown in Table C.16, Appendix C.

FRUIT

Samples of apples, cherries, grapes, and melons were collected during harvest from the areas listed in Table C.17, Appendix C. Three replicate samples were collected at each sampling location, and the edible portions were analyzed for ^{3}H, ^{90}Sr, ^{137}Cs, and $^{239,240}Pu$. Results are shown in Table C.17, Appendix C.

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

WINE

Locally produced wine (1989 vintage) was purchased and analyzed for ^{3}H and gamma-emitting radionuclides. Both red and white wines were analyzed. The wines were made from grapes grown in the Columbia Basin and, for comparison, the Yakima Valley. Results of the ^{3}H and ^{137}Cs analyses are shown in Table C.18, Appendix C. All samples contained trace amounts of ^{3}H; only one of the 12 samples analyzed contained a detectable level of ^{137}Cs. Concentrations detected in wine were about the

same as those commonly found in milk. The concentrations of radionuclides were similar for both sampling areas and attributed to worldwide fallout.

WHEAT AND ALFALFA

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

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

BEEF, CHICKENS, AND EGGS

A few samples of locally produced beef, chickens, and eggs were collected from the areas listed in Table C.20, Appendix C. Results of the analyses for ^{90}Sr and ^{137}Cs are shown in Table C.20, Appendix C. Concentrations were all low, generally near detection levels, and were attributed to worldwide fallout. Strontium-90 and ^{137}Cs concentrations in beef are shown in Figure 4.31 for the previous 5 years. The overall trend of ^{137}Cs in meat samples collected over the past 18 years has been downward, whereas ^{90}Sr concentrations have remained rather constant (Eberhardt et al. 1989).

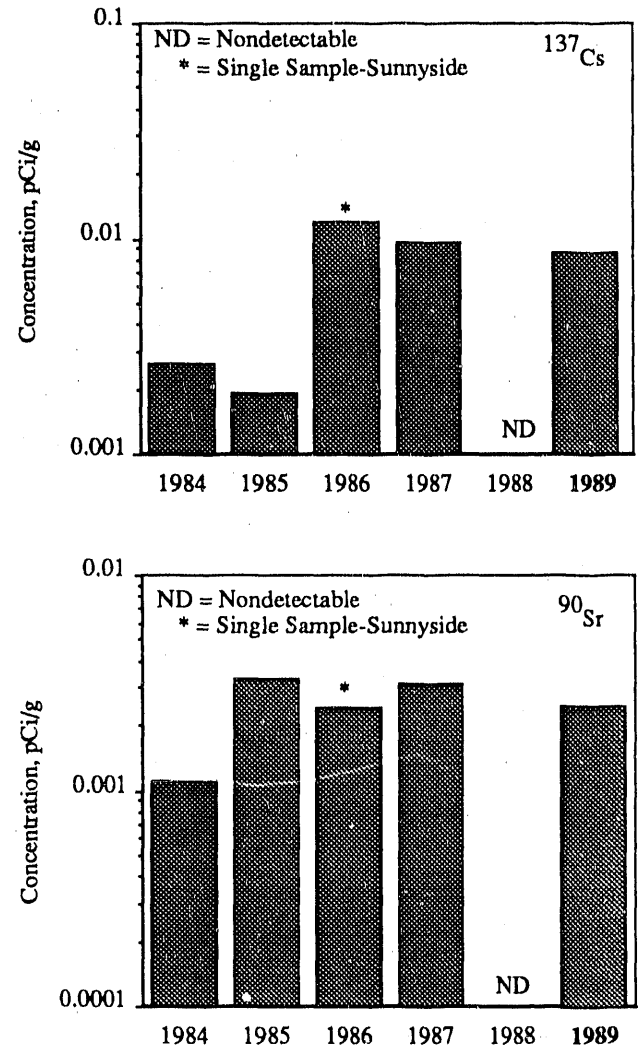

FIGURE 4.31. Annual Average Cesium-137 (^{137}Cs) and Strontium-90 (^{90}Sr) Concentrations in Beef for all Sampling Locations, 1984 Through 1989

4.4 WILDLIFE SURVEILLANCE

The Hanford Site serves as a refuge for waterfowl, upland game birds, and various terrestrial animals. Wildlife have access to several areas near facilities that contain low levels of radionuclides attributable to Site operations (e.g., waste-water ponds) and serve as biological indicators of environmental contamination. Sampling was performed in areas where the potential exists for wildlife to ingest radionuclides from sources of surface contamination (Figure 4.32). The number of animals that visited these areas was small compared to the total wildlife population in the region. Fish were collected from the Hanford Reach of the Columbia River. Analyses provided an indication of the radionuclide concentrations in local game fish and were used to evaluate the potential dose to humans from this pathway.

Analytical results for wildlife and fish samples collected during 1989 were similar to those observed in recent years. There are no radionuclide concentration limits for wildlife. The potential dose to a person who consumed any of the wildlife sampled, even at the maximum radionuclide concentrations measured in 1989, was well below applicable standards for radiation dose.

DEER

Samples taken from road kills (see Figure 4.32) provided an indication of the general levels of radionuclides in Hanford Site deer. Five deer were sampled and analyzed for ^{137}Cs in muscle and $^{239,240}Pu$ in liver. Muscle tissue (i.e., meat that could be used for human consumption) is most likely to contain ^{137}Cs when this radionuclide is present in the diet of deer. The liver could also be used for human consumption and is the organ most likely to retain $^{239,240}Pu$. Results showed very low or nondetectable levels of ^{137}Cs in muscle samples. Liver samples did not contain detectable levels of $^{239,240}Pu$. The ^{137}Cs concentrations were in the range generally attributed to worldwide fallout, and the median value[a] was consistent with those observed in previous years (Figure 4.33). A significant decline in the median concentrations of ^{137}Cs in deer muscle samples was noted when data for the past 18 years were reviewed (Eberhardt et al. 1989). Results for 1989, showing the maximum and average values, are given in Table C.21, Appendix C.

FISH

Whitefish, bass, and salmon were collected at various locations along the Columbia River (see Figure 4.32). Boneless fillets were analyzed for ^{60}Co, ^{90}Sr, and ^{137}Cs. The remaining carcasses were analyzed to estimate ^{90}Sr in bone. Whitefish were collected near the 100-D Area and upstream of the Hanford Site, just downstream of Priest Rapids Dam. Bass were collected near the 100-F Area. Maximum and average results for ^{60}Co, ^{90}Sr, and ^{137}Cs for 1989 are shown in Table C.22, Appendix C.

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

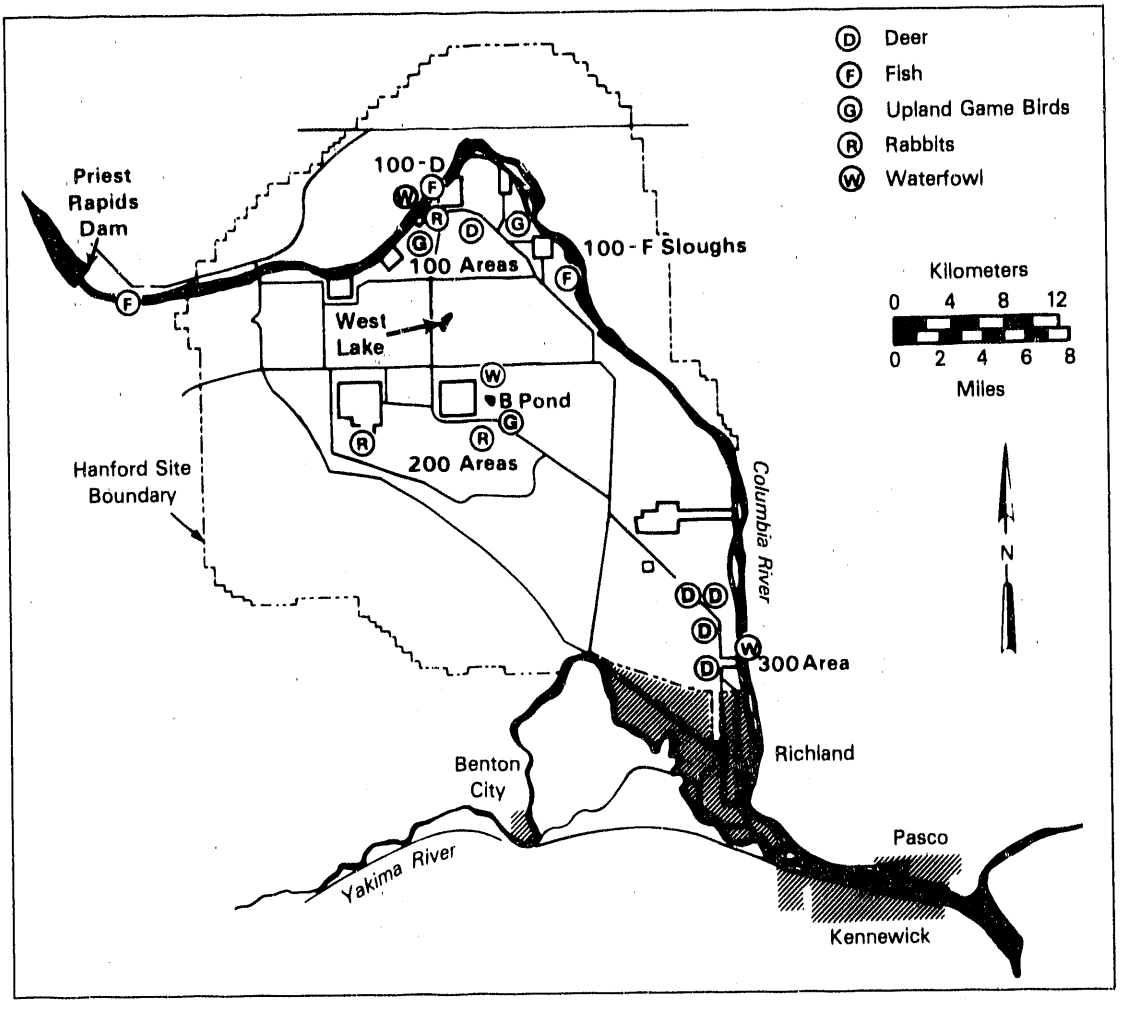

FIGURE 4.32. Wildlife Sampling Areas

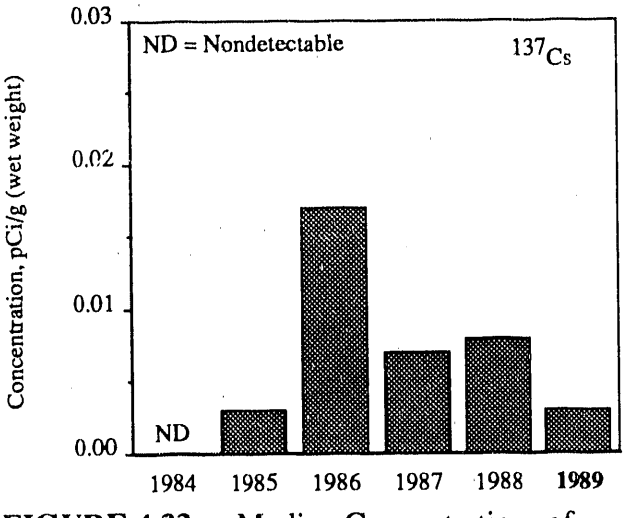

FIGURE 4.33. Median Concentrations of Cesium-137 (^{137}Cs) in Deer Muscle, 1984 Through 1989

Cobalt-60, ^{90}Sr, and ^{137}Cs were detected in a few whitefish muscle samples collected along the Hanford Reach near the 100-D Area, as well as upstream of the Site, just downstream of Priest Rapids Dam. However, there were no apparent differences between samples from the two locations. Median concentrations for ^{60}Co and ^{137}Cs in whitefish and bass in 1989 and recent years are shown in Figure 4.34. Strontium-90 levels in whitefish carcasses in samples collected near the 100-D Area were similar to those in samples collected upstream of the Site. Samples of bass muscle and carcass collected from the slough near the 100-F Area showed ^{137}Cs concentrations slightly higher than those

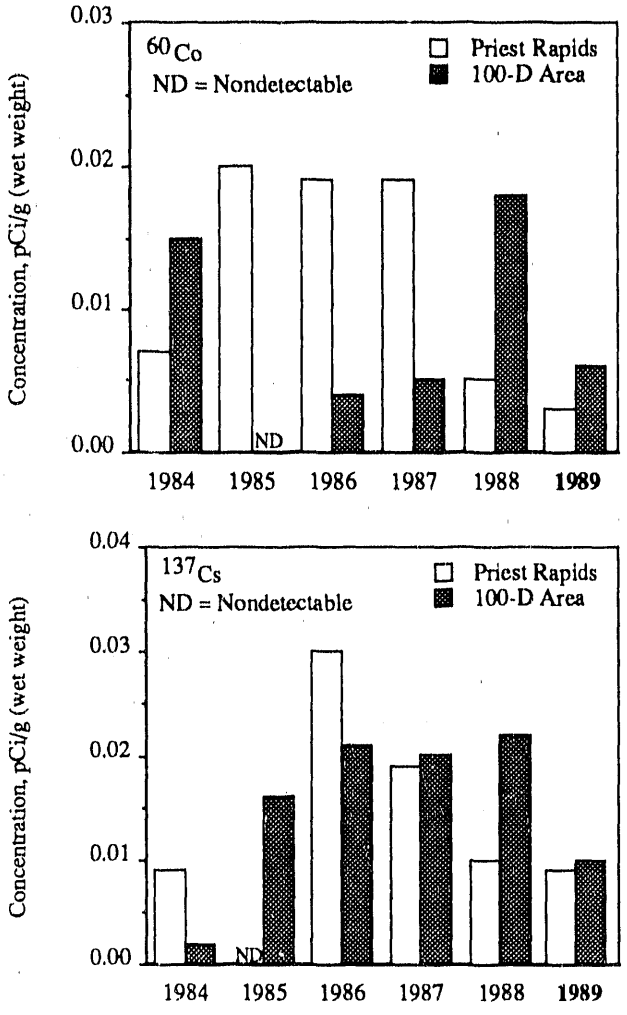

FIGURE 4.34. Median Concentrations of Cobalt-60 (^{60}Co) and Cesium-137 (^{137}Cs) in Whitefish and Bass Collected Near Priest Rapids Dam and Near the 100-D Area, 1984 Through 1989

for whitefish. These results indicate no measurable influence on fish from radionuclides released to the Columbia River during current or past operations at Hanford.

UPLAND GAME BIRDS

Pheasants were collected from the 100 and 200 Areas (see Figure 4.32). Samples of breast meat were analyzed for ^{60}Co and ^{137}Cs. Four of the birds showed detectable concentrations of ^{137}Cs. Cobalt-60 was not detected in any of the samples. Median concentrations for ^{137}Cs in birds were within the ranges observed during previous years (Figure 4.35) and were attributed to worldwide fallout. Maximum and average concentrations for 1989 for both radionuclides are shown in Table C.23, Appendix C.

WATERFOWL

Canada geese were collected from the Columbia River near the 100-D Area, and mallard ducks were collected from B Pond in the 200 Areas and from the 300 Area trench (see Figure 4.32). Approximately 0.5 kg of breast meat from each bird was analyzed for ^{137}Cs. Results (Figure 4.36) continue to show concentrations of ^{137}Cs decreasing in mallard ducks collected from B Pond. Average concentrations of ^{137}Cs in samples collected from the 300 Area trench in 1989 were less than the concentrations measured in ducks from B Pond and were near levels expected from worldwide

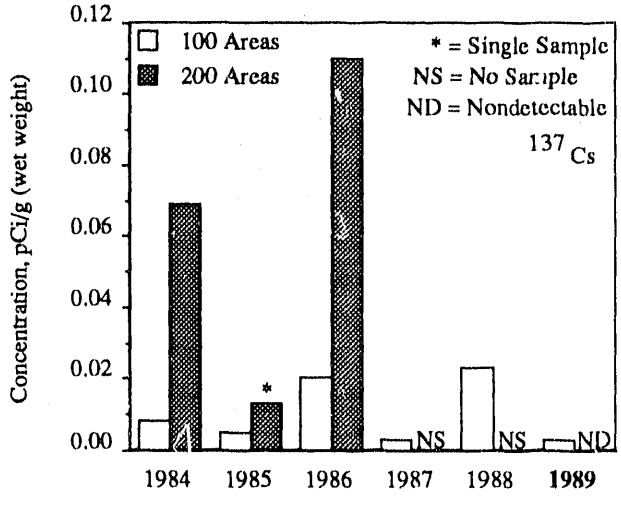

FIGURE 4.35. Median Concentrations of Cesium-137 (^{137}Cs) in Game Birds from the 100 Areas and 200 Areas, 1984 Through 1989

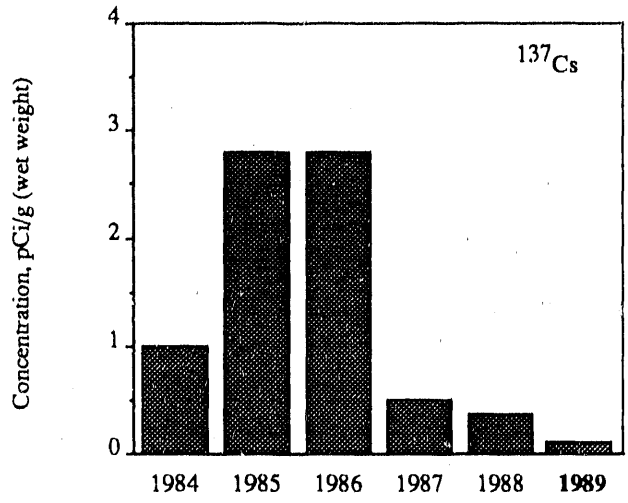

FIGURE 4.36. Median Concentrations of Cesium-137 (^{137}Cs) in Mallard Ducks from B Pond, 1984 Through 1989

fallout. The concentrations of ^{137}Cs in Canada geese samples were low and at levels expected from worldwide fallout (Table C.24, Appendix C).

RABBITS

Rabbits were collected (see Figure 4.32) and analyzed to evaluate the general levels of environmental contamination near operating facilities. Hanford waste materials usually contain equal quantities (activities) of ^{90}Sr and ^{137}Cs. Muscle tissue does not retain ^{137}Cs for a very long time, whereas ^{90}Sr remains incorporated in bone tissue for the lifetime of the animal. Liver tissue tends to accumulate and retain $^{239,240}Pu$ that may be present in food or water consumed by the animal.

Cottontail rabbits were collected near the 100-N Area, and black-tailed jack rabbits were collected near the 200 Areas during 1989. Muscle samples were analyzed for ^{137}Cs and other gamma-emitting radionuclides. Bone samples were analyzed for ^{90}Sr, and liver samples were analyzed for $^{239,240}Pu$. Median (middle) values of ^{90}Sr in bone and ^{137}Cs in muscle tissues measured in rabbits over the last several years are shown in Figures 4.37 and 4.38. Maximum and average concentrations for samples analyzed in 1989 are given in Table C.25, Appendix C.

The levels of ^{90}Sr in bone samples indicated that most of the rabbits at some time had consumed food or water contaminated with ^{90}Sr.

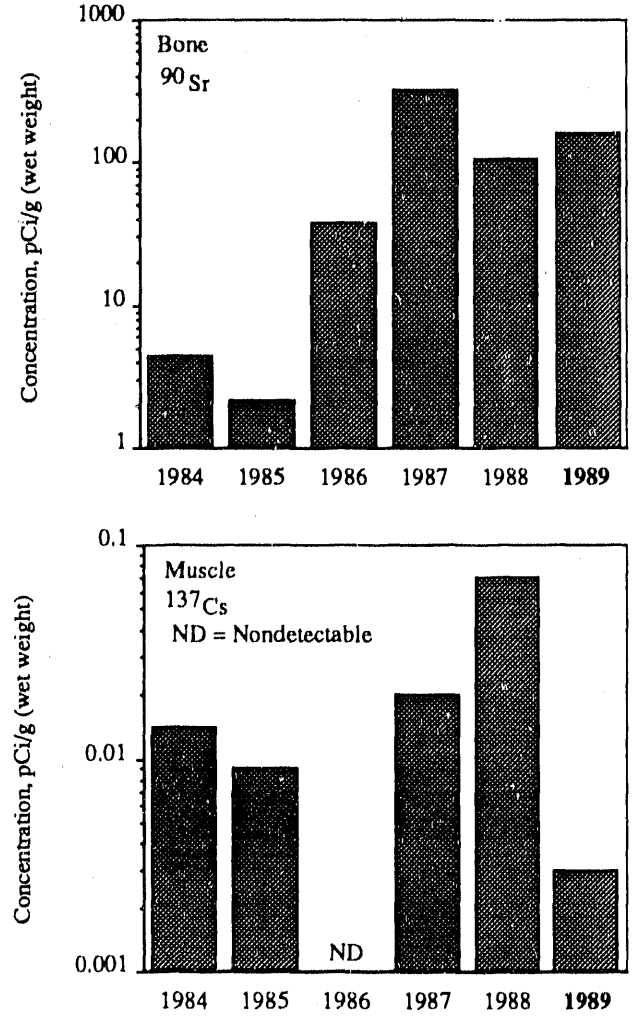

FIGURE 4.37. Median Concentrations of Strontium-90 (^{90}Sr) in Bone and Cesium-137 (^{137}Cs) in Muscle of Cottontail Rabbits in the 100 Areas, 1984 Through 1989

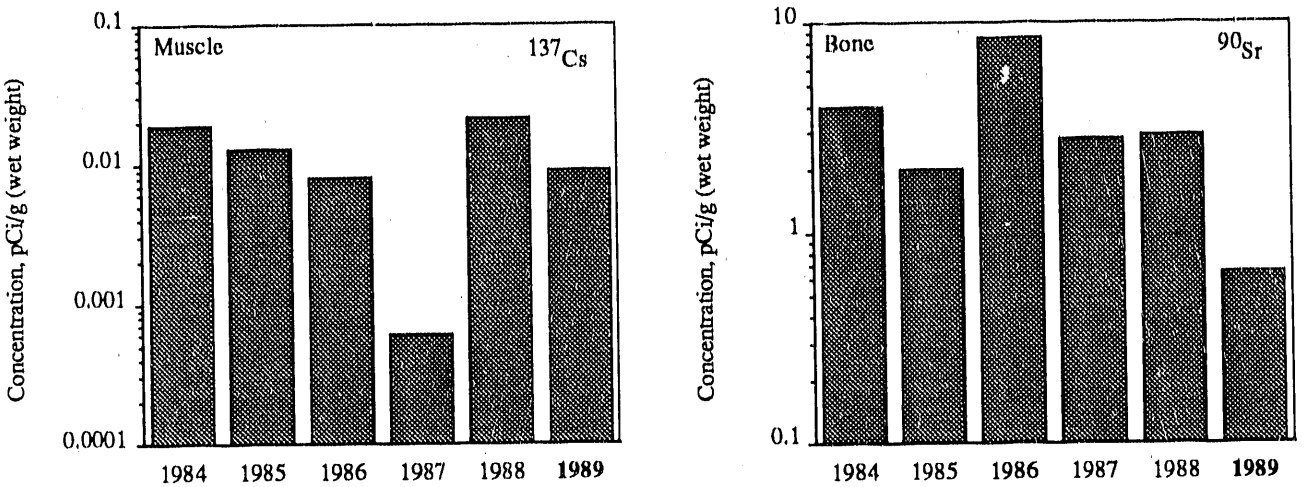

FIGURE 4.38. Median Concentrations of Cesium-137 (^{137}Cs) in Muscle and Strontium-90 (^{90}Sr) in Bone of Jack Rabbits in the 200 Areas, 1984 Through 1989

4.5 SOIL AND VEGETATION SURVEILLANCE

Surface soil and rangeland vegetation samples were collected at 28 locations during 1989, both on and off the Hanford Site. The purpose of sampling was to detect the possible build-up of radionuclides from the deposition of airborne effluents released from Hanford facilities. Samples were collected at nonagricultural, relatively undisturbed sites so that natural deposition and build-up processes would be represented. Because the radionuclides of interest were present in worldwide fallout or occurred both naturally and in Hanford effluents, these radionuclides were expected in all samples.

An assessment of radionuclide contributions from Hanford operations was made by comparing results from samples collected 1) on the Site with those collected off the Site, 2) around the Site perimeter with those collected at distant locations, and 3) downwind (primarily east and south of the Site) with those collected from generally upwind and distant locations. In addition, results obtained from each location in 1989 were compared to results obtained from the same location in previous years. The results provided no indication of trends or increases in the concentrations of radionuclides in the offsite environment that could be attributed to Hanford operations. [a]

SAMPLE COLLECTION AND ANALYSIS

Soil and vegetation samples were collected at 15 onsite and 23 Site perimeter and offsite locations (Figure 4.39). Most onsite sampling locations were adjacent to major operating areas, where the contribution of radionuclides from operations could be readily assessed. Most offsite samples were collected around the Site perimeter and in a generally downwind direction, where any Hanford contribution to radionuclides in soil and vegetation would be easily detected. Samples also were collected in a generally upwind direction and at distant locations for comparison.

Single composite samples of surface soil were collected at each location. Samples were made up of five soil "plugs," each approximately 2.5 cm deep and 10 cm in diameter, obtained within a 100-m^2 sampling area. Samples were oven dried (105°C), sieved through a 2-mm screen, and thoroughly mixed. Aliquots of this well-mixed, composite sample were analyzed for gamma-emitting radionuclides (^{137}Cs), ^{90}Sr, ^{238}U, and $^{239,240}Pu$.

When soil samples were collected, samples of perennial vegetation also were collected in the immediate vicinity. Vegetation samples

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

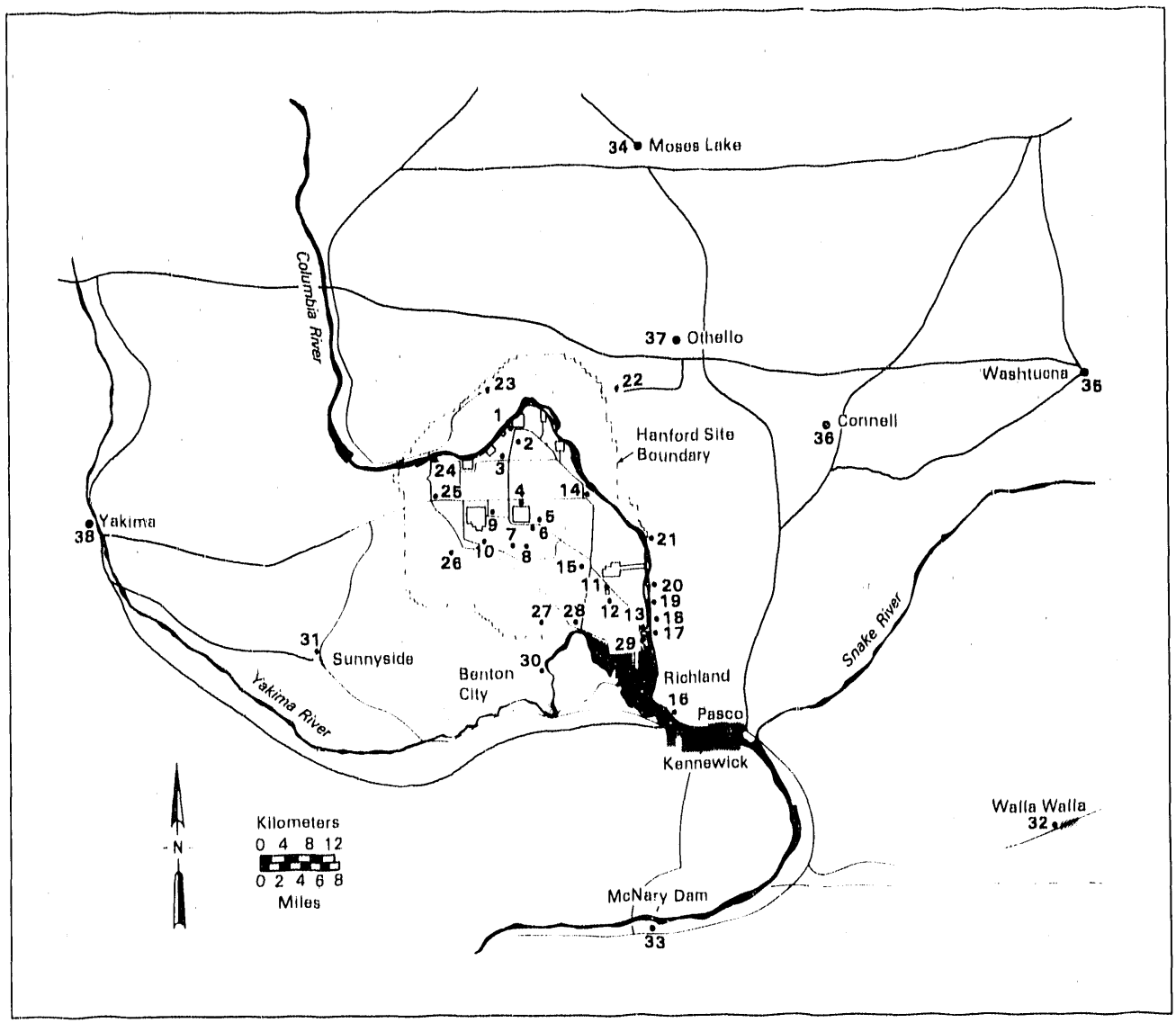


FIGURE 4.39. Onsite and Offsite Sampling Locations for Soil and Vegetation in 1989

included a mixture of rabbitbrush, sagebrush, and bitterbrush, in roughly the same proportions as occurred naturally at the sample site. A small amount of recent growth was cut from enough plants in the area to make up a sample weighing approximately 1 kg. The sample was dried and ground, and aliquots were analyzed. Vegetation samples were analyzed for gamma-emitting radionuclides (^{137}Cs), ^{90}Sr, $^{239,240}Pu$, and total uranium.

SOIL RESULTS

Analytical results for soil samples collected on and off the Site during 1989 are reported in Tables C.26 through C.29, Appendix C. Included in the tables are results for the previous 5 years from each location. For comparative purposes, averages of the results from all onsite and offsite locations are provided. No new sample locations were added in 1989.

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

Radionuclide concentrations in onsite soil samples during 1989 were similar to those observed in previous years, although some variability was evident between sampli. g locations. Locations near operating areas, the 200 Areas in particular, continued to show slightly elevated concentrations for a few radionuclides. Specifically, the 200-East Area north-central (see Figure 4.39, number 4) sample had elevated levels of ^{90}Sr and ^{137}Cs. The sample taken east of the 200-West Area (see Figure 4.39, number 9) had elevated levels of ^{90}Sr, ^{137}Cs, and $^{239,240}Pu$, as in previous years. The offsite soil sample results were similar to those obtained during the past several years. Histograms in Figure 4.40 show median (middle) values for ^{90}Sr, ^{137}Cs, $^{239,240}Pu$, and ^{238}U for all samples collected on and off the Site during 1989. Radionuclide concentrations, except uranium, were higher at onsite locations than at offsite locations.

Radionuclide concentrations in soil collected at locations near the Hanford Site were similar to those collected at distant locations. Results from offsite locations generally downwind were similar to those from locations generally upwind. As in past years, radionuclide concentrations in soil were low, although they appeared to be highly variable over time at a single location.

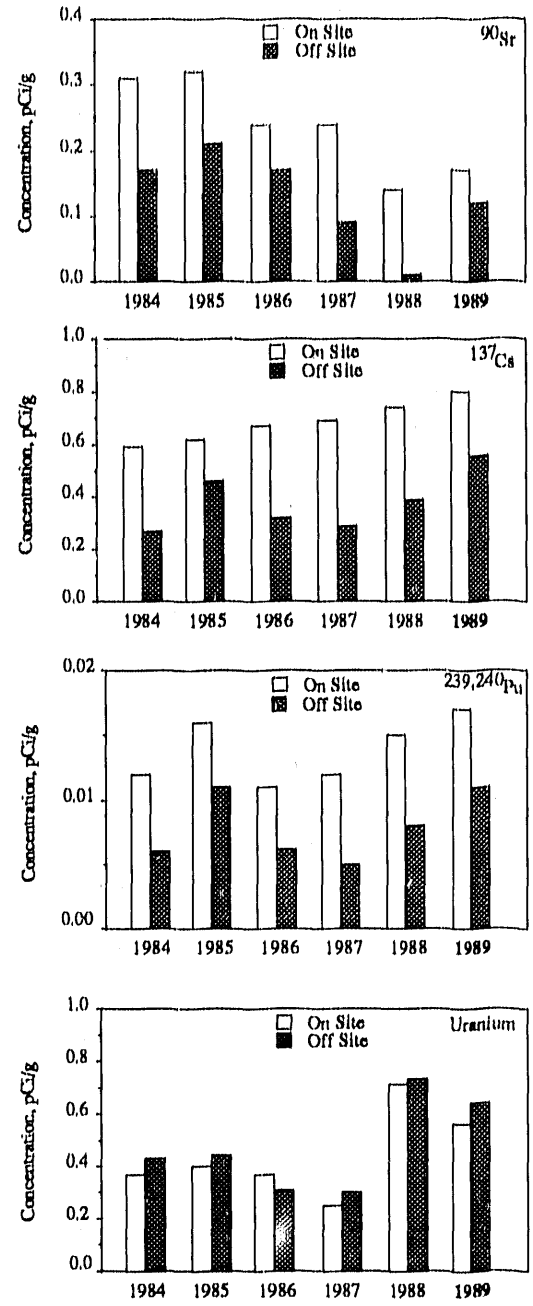


FIGURE 4.40. Median Strontium-90 (^{90}Sr), Cesium-137 (^{137}Cs), Plutonium-239,240 ($^{239,240}Pu$), and Uranium[a] Concentrations Measured in Soil at Onsite and Offsite Locations, 1984 Through 1989

(a) Uranium-238 beginning in 1988.

VEGETATION RESULTS

Analytical results for samples of mature, perennial vegetation collected during 1989 are shown in Tables C.30 through C.33, Appendix C. Individual results for the previous 5 years at each location are given in the tables, along with the average of onsite and offsite results for the same time period. No new sample locations were added in 1989.

Radionuclide concentrations in vegetation samples collected on and off the Site in 1989 were similar to those observed at the same locations during previous years. Figure 4.41 shows histograms illustrating median (middle) values of ^{90}Sr, ^{137}Cs, $^{239,240}Pu$, and uranium. The high ^{137}Cs value recorded in 1986 was attributed to the Chernobyl incident. The effect of Chernobyl was not noted in subsequent years. As with soil data, concentrations of ^{90}Sr and $^{239,240}Pu$ in onsite vegetation were slightly elevated compared with offsite concentrations. Uranium concentrations in vegetation, however, were slightly higher at offsite locations than at onsite locations.

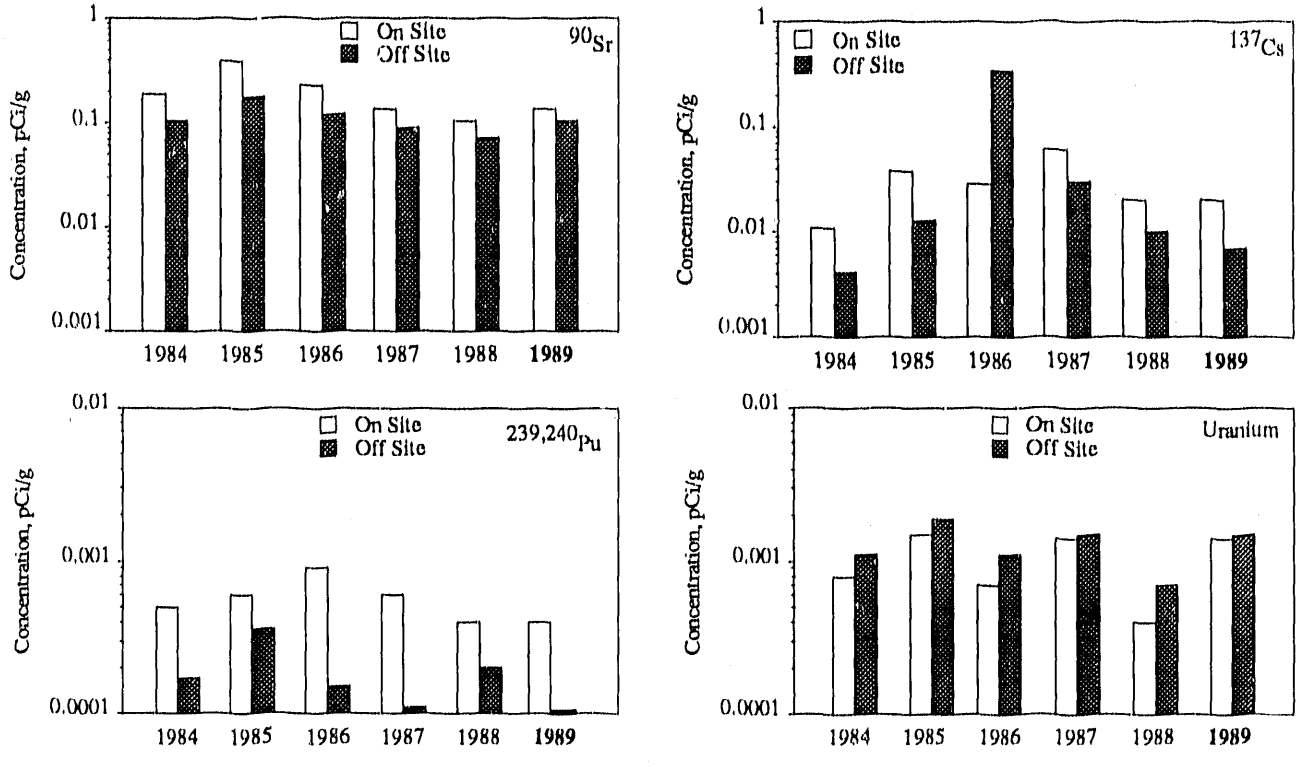


FIGURE 4.41. Median Strontium-90 (^{90}Sr), Cesium-137 (^{137}Cs), Plutonium-239,240 ($^{239,240}Pu$), and Uranium Concentrations in Vegetation at Onsite and Offsite Locations, 1984 Through 1989

4.6 PENETRATING-RADIATION SURVEILLANCE

Dose rates from penetrating radiation (gamma rays) were measured at numerous locations in 1989 using thermoluminescent dosimeters (TLDs). Penetrating radiation from naturally occurring sources, including cosmic radiation and natural radioactive materials in the air and ground, as well as from worldwide fallout, was recorded by all dosimeters. Dosimeters also measured dose rates from exposure to radioactive materials associated with Hanford activities. Results obtained both on and off the Site were within statistical variability of those of the previous 5 years. The observed variability is attributed to variability in naturally occurring dose rates from year to year and statistical uncertainty in conducting low-level environmental dose measurements. Dose rates near waste storage and handling facilities were somewhat higher than natural background rates.

Radiation surveys were conducted at numerous locations on the Hanford Site. Onsite roads, railroads, and inactive waste disposal sites located outside of operating areas were surveyed routinely. Survey results for 1989 were comparable to those of past years. No increases in radiation levels were observed on Site highways or railroads.

PENETRATING-RADIATION MEASUREMENTS

The TLDs were placed at numerous locations on the Site, around the Site perimeter, in nearby and distant communities, and along the shoreline of the Columbia River. Except for shoreline locations, TLD placements coincided with air monitoring stations. This placement scheme was based on convenience and security considerations. Environmental radiation dosimeters consisted of five CaF_2:Mn thermoluminescent chips encased in a plastic capsule. The capsule contained a lead/tantalum filter to provide uniform dose response characteristics for penetrating radiation above 70 kiloelectron volts (keV) (Fix and Miller 1978). Dosimeters were mounted 1 m above ground level. Most dosimeters were exchanged every 4 weeks during the first half of 1989 and quarterly thereafter. Shoreline TLDs were exchanged on a quarterly basis in 1989. Although they were measured in milliroentgens (mR), doses are reported in dose equivalent units (mrem) to allow comparison with dose standards and dose equivalents reported elsewhere in this document. Because the dosimeter is used in a multienergy beta/gamma radiation field (the environment near Hanford) that differs considerably from calibration conditions (^{137}Cs photons in air), the conversion factor relating mrem to mR may not be exactly 1.0. (It is actually a few percent less than 1.) Nonetheless, it is assumed to be 1.0 throughout this report. This bias, being consistent, does not affect the ability to distinguish differences in direct radiation levels between various locations.

Dosimeters were placed at numerous locations in the vicinity of Hanford and at several locations more distant from the Site (Figure 4.42). Dose rates measured at each location during 1989 are given in Table C.34, Appendix C. Offsite dosimeter locations were chosen to represent areas that could have been inhabited continuously. Dose measurements at all locations are reported in mrem/yr.

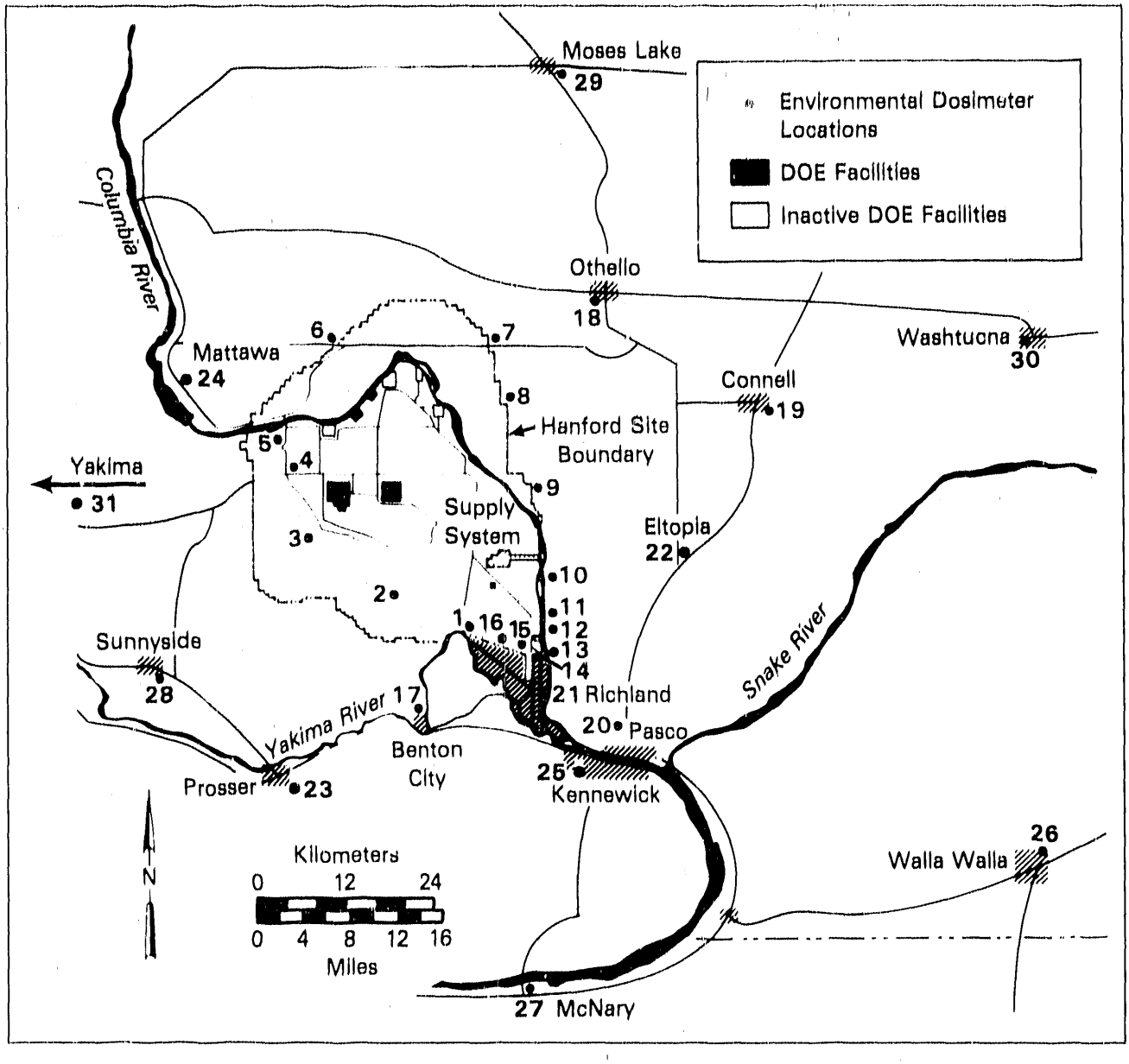


FIGURE 4.42. Environmental Dosimeter Locations at the Site Perimeter and at Nearby and Distant Communities (see location number key in Table C.34, Appendix C)

The 1989 dose measurements were similar to those observed in 1988 for the same locations. The background dose rate, calculated from the annual average dose rates at distant locations, was 80 mrem/yr (0.009 mrem/h), compared to 78 mrem/yr last year. Distant locations are those community locations under the "distant" heading in Table C.34, Appendix C. Dose rates measured at Seattle and Spokane in 1985 by the Washington State Department of Social and Health Services were 56 and 88 mrem/yr, respectively (WDSHS 1987).

Figure 4.43 shows average annual dose rates at perimeter and distant locations during 1989 and the previous 5 years. Dose rates for 1984

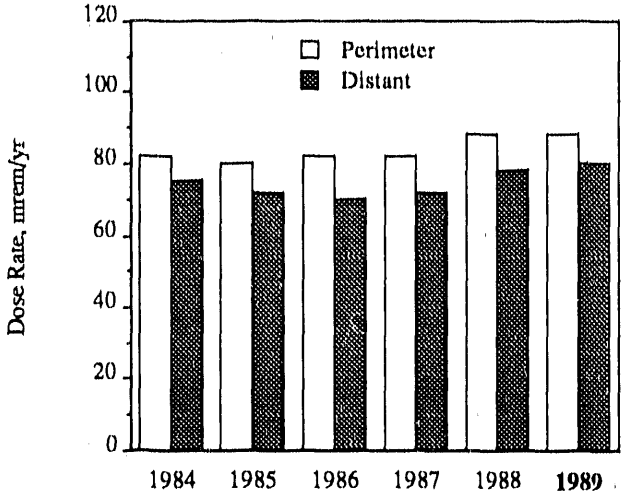


FIGURE 4.43. Annual Average External Dose Rates at Perimeter and Distant Locations, 1984 Through 1989. (Dose rates for the years 1984 through 1986 have been corrected to eliminate previous biases. Perimeter and distant locations are identified in Table C.34, Appendix C.)

through 1986 have been corrected to remove previous biases. These biases consisted of an unnecessary self-dosing correction (8.8 mrem/yr), the difference between a 4-week versus a 1-month monitoring period (2.5 mrem/yr), and background dose subtractions that were too large (4.5 mrem/yr). The net effect was the reporting of annual doses that were low by 16 mrem/yr. Some year-to-year natural variability was apparent. Natural variability is due to several weather and climatic factors and to solar flare activity. Although difficult to quantify, year-to-year variations of 10% are not unlikely (NCRP 1987). The below-normal precipitation in 1988 and 1989 may account for more dose from the soil reaching the TLDs.

Figure 4.43 shows that dose rates at perimeter stations generally averaged 8 mrem/yr higher than at distant locations. The difference between perimeter and distant location doses is due to 1) the addition of a low-dose distant location, 2) natural geographic variations in terrestrial radiation, and 3) variations resulting from human activities. Yakima, a low-dose location, was added to the list of distant locations in 1986. Many of the perimeter sites are richer in naturally occurring deposits of radioactive potassium and thorium (Rathbun 1989). Distant locations are near public buildings. The land near public buildings has been substantially altered by paving, gravel, etc. These alterations tend to lower the penetrating-radiation doses relative to natural conditions. Although not ideal for comparison with radiation fields from unaltered sites, the choice of the distant site locations was considered necessary for reasons of security and accessibility. Because of a 10% natural variability and a manmade reduction of 8 mrem/yr, the difference between perimeter and distant location doses would have to increase to approximately 15 mrem/yr before a Hanford impact could be observed.

Dosimeters were submerged in the Columbia River at Coyote Rapids and Richland Pumphouse (Figure 4.44) to provide an estimate of penetrating dose rates that could be received by a person immersed in the river. Measurements, shown in Table C.35, Appendix C, indicate a dose rate less than the background dose rate of 0.010 mrem/h measured on land. Average dose rates at Coyote Rapids and Richland Pumphouse were 0.007 and 0.006 mrem/h, respectively, during 1989. These dose rates have remained low, with a range of 0.003 to 0.007 mrem/h over the years.

Dosimeters were placed at several publicly accessible locations near the perimeter of operating areas on the Hanford Site (Figure 4.45). Locations included the Columbia River shoreline near the 100-N Area, a parking

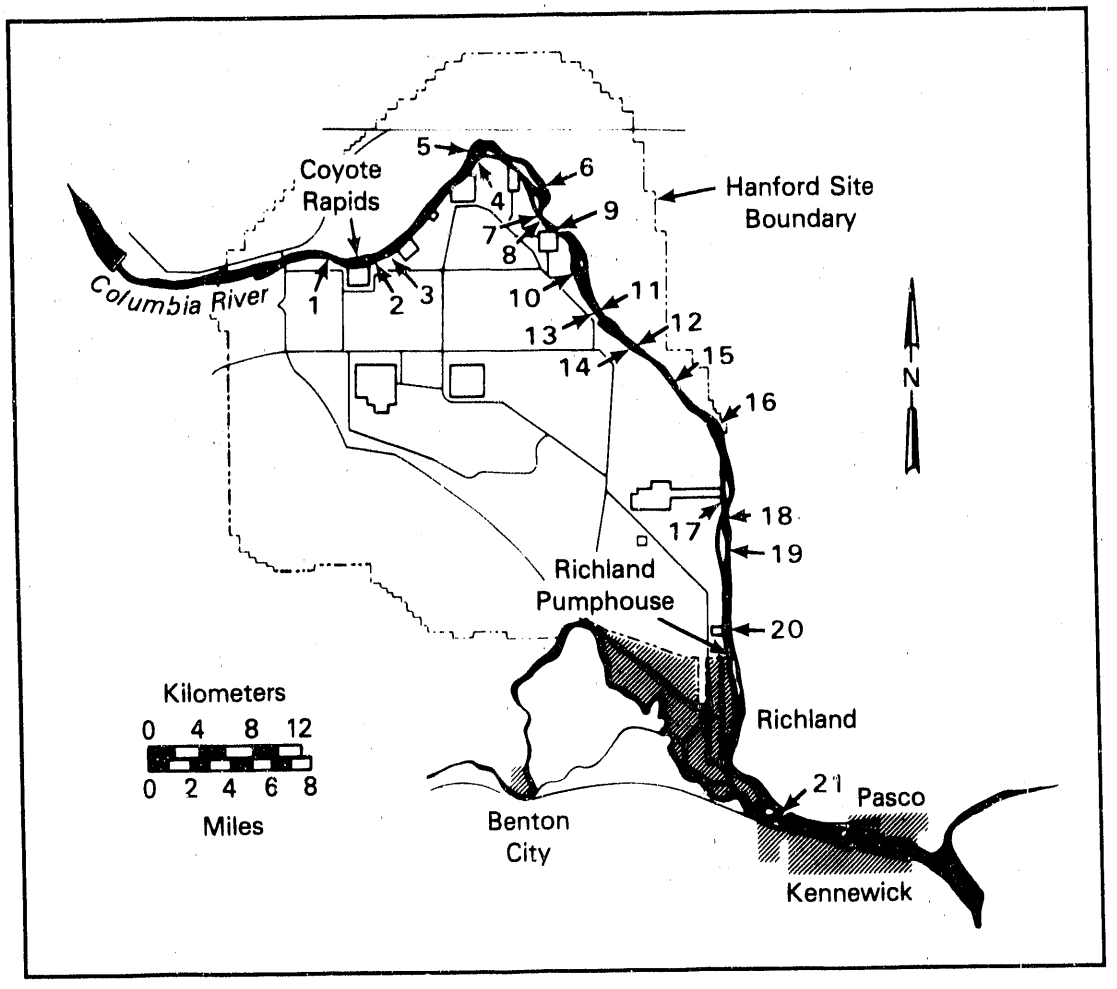


FIGURE 4.44. Environmental Dosimeter Locations Along the Hanford Reach of the Columbia River (see location number key in Table C.37, Appendix C)

lot near the west perimeter of the 300 Area, and the parking lot near the Visitors Center at the 400 Area. Results for 1989 are shown in Table C.36, Appendix C. Results are reported as mrem/h (instead of mrem/yr) because the locations are not continuously occupied by the same person.

Dose rates near the 100-N Area on the river shoreline were slightly above background but were similar to those observed in previous years. The maximum dose rate recorded near the 100-N Area was 0.037 mrem/h; the average varied between 0.018 and 0.030 mrem/h. Dose rates in this vicinity were attributed to waste management activities within the 100-N Area.

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

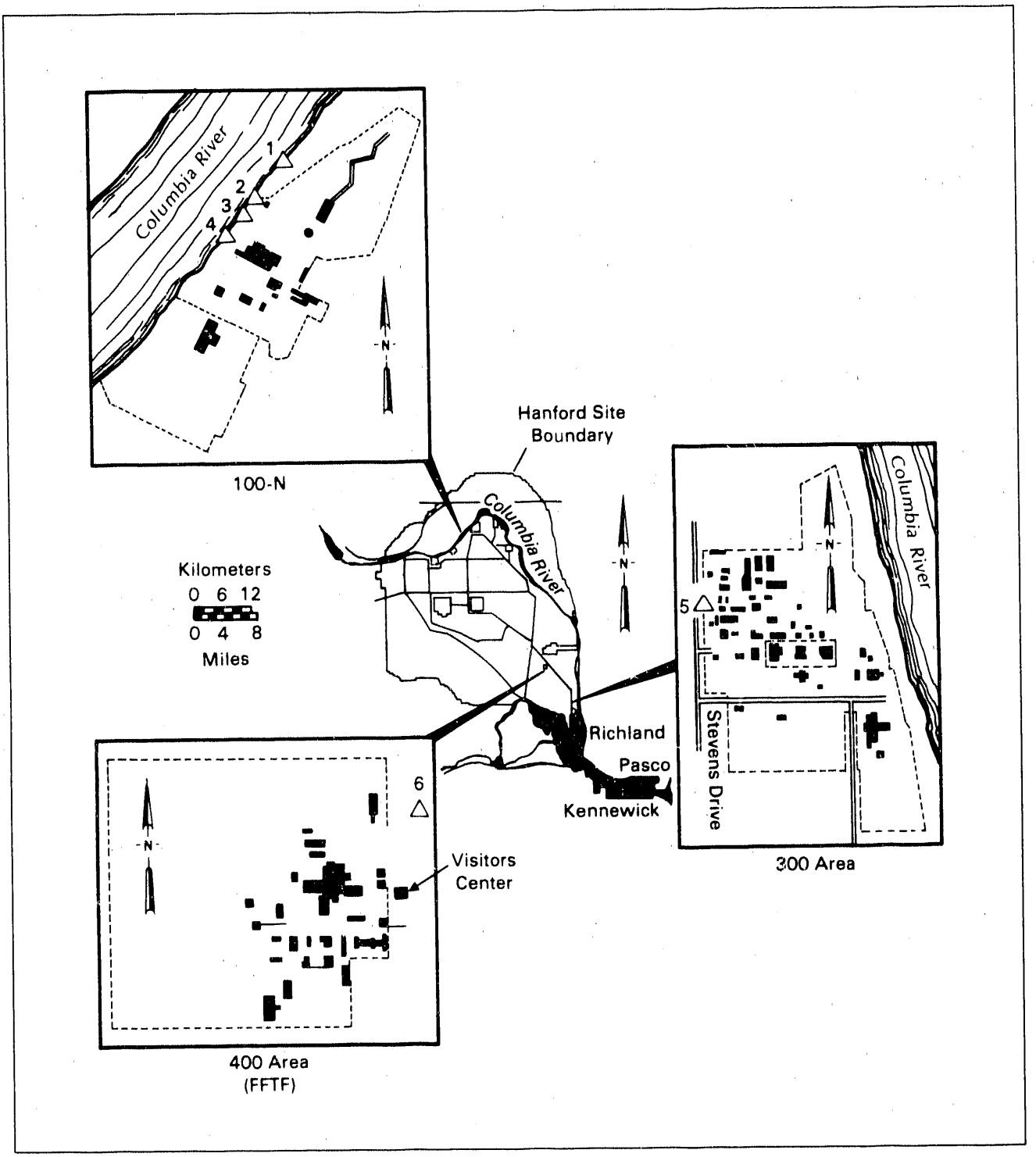


FIGURE 4.45. Environmental Dosimeter Locations at Publicly Accessible Onsite Locations (see location number key in Table C.36, Appendix C)

Low levels of radioactivity (primarily ^{60}Co and ^{154}Eu) from past reactor operations in the 100 Areas were measured at several locations along the shorelines and on islands in the Hanford Reach of the Columbia River. Radiation dose rates from these radionuclides were surveyed extensively in 1979 (Sula 1980). In 1980, based on findings of the survey, dosimeters were placed in areas along the river (see Figure 4.44) where dose rates were slightly elevated with respect to background levels. Table C.37, Appendix C, shows results of measurements taken at these locations during 1989. Dose rates measured during 1989 were similar to those observed in recent years. Differences are thought to be due to natural variability and statistical uncertainty in conducting low-level environmental dose measurements. Two standard errors of the calculated mean value in Table C.37, Appendix C, is typically 15% of mean.

Onsite external penetrating radiation was measured at the locations shown in Figure 4.46. Results are given in Table C.38, Appendix C. Dose rates slightly above background levels were observed at five onsite locations during 1989. Rates in excess of background observed near the 100-N, 200-East, and 300 Areas were attributed to direct radiation from waste handling and storage facilities. Dose rates around the 400 Area were within expected background levels.

RADIATION SURVEYS

Onsite roads, railroads, and inactive radioactive waste disposal sites outside of operating areas were surveyed routinely during 1989. The frequency of surveys on specific routes for roads and railroads was based on their use and the potential for contamination. Most waste sites were surveyed twice during 1989. Specific routes and frequencies for surveys in 1989 were defined in a master schedule developed by PNL (Bisping 1989).

Roads shown in Figure 4.47 were surveyed routinely at 10 mph using 4 scintillation detectors positioned approximately 0.5 m above the ground, evenly spaced across the width of a vehicle. No increased radiation was observed on Site roadways during 1989. Railroad routes (see Figure 4.47) were surveyed at 10 mph using a small railroad car with 2 scintillation detectors mounted approximately 0.3 m directly above the tracks. Surveys in 1989 did not reveal any increased readings on Site railways. The background readings on Site railways were similar to those of rails beyond the Site perimeter.

Inactive waste disposal sites outside operating area perimeter fences were surveyed during 1989 with portable instruments. The general physical condition of the sites was also visually inspected. Radiation surveys conducted during 1989 showed levels comparable to those observed in past years.

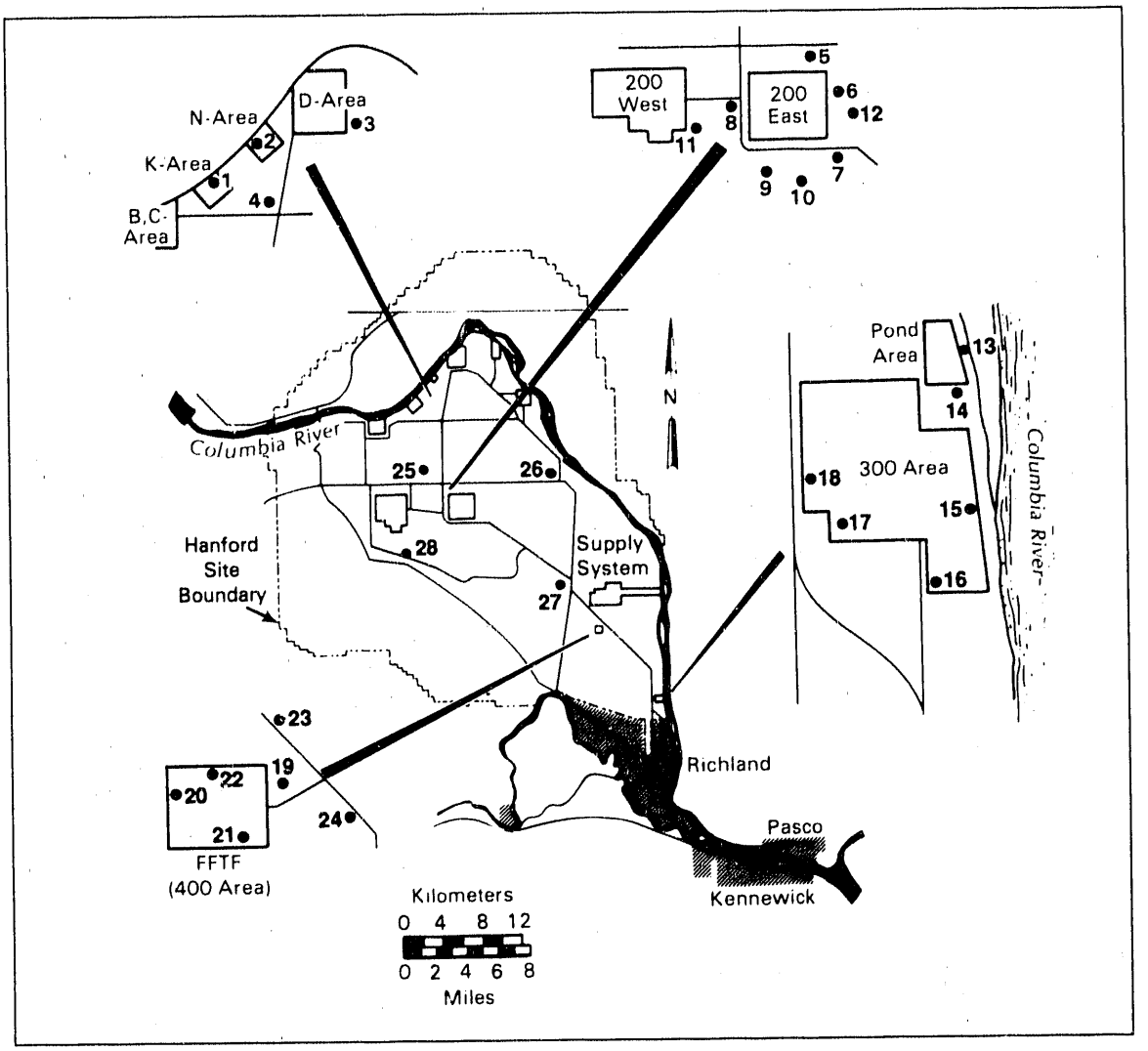


FIGURE 4.46. Environmental Dosimeter Locations on the Hanford Site (see location number key in Table C.38, Appendix C)

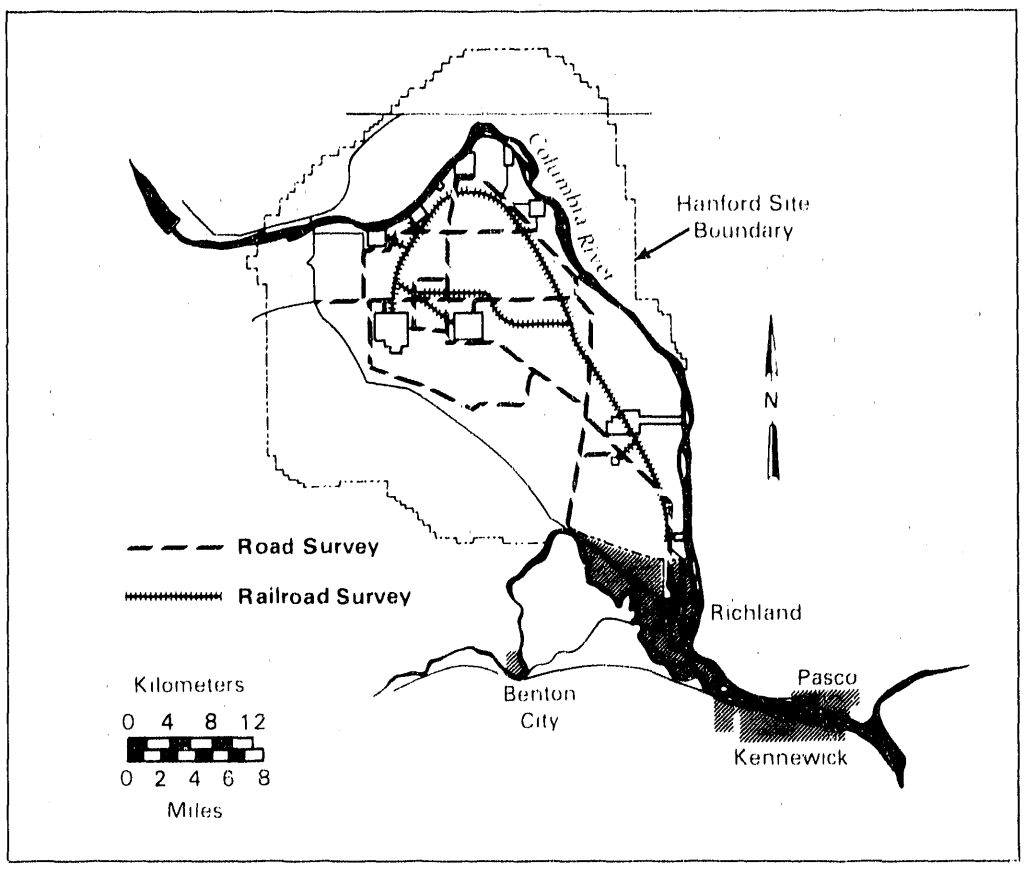


FIGURE 4.47. Road and Railroad Survey Routes

4.7 EFFLUENT MONITORING

Westinghouse Hanford Company, the prime operations and engineering contractor at Hanford, and PNL quantify and document the amounts of radioactive and nonradioactive liquids, gases, and solids released to, or disposed of in, the environment from their operations. These efforts are performed to determine the degree of compliance with applicable federal, state, and local regulations and permits. Monitoring data are also used in pollution abatement programs that assess the effectiveness of effluent treatment and control. Effluent monitoring serves a different but related function to surveillance monitoring. Surveillance monitoring measures the effect on the environment from regulated effluents, whereas effluent monitoring measures the amounts of regulated constituents released into the environment.

AIR EMISSIONS

Major air emission points are located in the 100, 200-East, 200-West, 300, 400, 600, and 1100 Areas. Brief descriptions of the gaseous emission sources in these areas are given below:

- Located in the 100 Areas are the N Reactor, eight inactive production reactors, and associated support facilities. Even though in cold standby, N Reactor is the main contributor of radioactive emissions in the 100 Areas, with lesser contributions through several ventilation systems of support facilities. Nonradioactive pollutants are emitted from the 184-N powerhouse. There are 16 airborne emission sources in the 100 Areas.

- The 200 Areas contain the chemical separations and processing facilities and the waste handling and disposal facilities. Radioactive emission sources include the Plutonium Uranium Extraction (PUREX) Plant, the Uranium Oxide (UO_3) Plant, the Plutonium Finishing Plant, B Plant, the Reduction Oxidation Plant, T Plant, the 222-S Laboratory, the Critical Mass Laboratory, the Laundry Facility, underground storage tanks, waste evaporators, and tank farms. The PUREX Plant, UO_3 Plant, and powerhouses also emit nonradioactive pollutants. There are 73 airborne emission sources in the 200 Areas.

- The 300 Area consists primarily of laboratories and research facilities, the N Reactor Fuel Fabrication Facility, and the steam plant. Radioactive emissions arise from the operation of the Fuel Fabrication Facility (currently inactive) and various laboratory hoods. Nonradioactive emissions originate from the steam plant, an incinerator, and a thermal treatment facility. There are 49 airborne emission sources in the 300 Area.

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

- The 600 Area encompasses all areas of the Site not assigned to the 100, 200, 300, and 400 Areas. Two facilities in the 600 Area currently discharge radioactive gaseous effluents.

- The 1100 Area is located outside the Hanford Site. It contains warehouses, vehicle maintenance shops, excess equipment and materials storage, and office buildings. The 1100 Area emissions are generated from heating plants. Three oil-fired boilers emit only nonradioactive effluents.

Radioactive airborne effluents from facilities at the Hanford Site include volatile forms of radionuclides, noble gases, and radioactive particles. Radioactive effluent streams that have a potential of exceeding 10% of discharge limits are monitored. Nonradioactive effluent streams are monitored that have a potential of exceeding 50% of applicable standards for nonradioactive constituents.

Annual effluent discharge release reports are produced for each of the major operating areas and submitted to DOE-Richland Operations Office. Radioactive effluent and onsite discharge data are reported to the Idaho National Engineering Laboratory via the Effluent Information System-Onsite Discharge Information System (EIS-ODIS) in April of each year (DOE 1987c). A summary of air emissions from the Hanford Site for 1989 is given in Table G.1, Appendix G.

LIQUID EFFLUENTS

Liquid effluents are discharged from facilities in all areas of the Hanford Site. Liquid effluent sources result in over 350 radioactive and nonradioactive liquid waste streams that discharge to the Columbia River, soil column, or sewer disposal systems. Total effluent discharge volume has averaged about 570 billion L annually. Approximately 98% of the total volume consists of cooling water and National Pollutant Discharge Elimination System (NPDES) discharges.

The purpose of liquid effluent monitoring is to ensure that limits for the release of liquid effluents to the environment are not exceeded. Discharges are monitored for both radioactive and nonradioactive constituents. Radioactive effluent monitoring is performed in the 100, 200-East and 200-West, and 300 Areas. Radioactive liquid effluents produced at the 400 Area are shipped to the 200 Areas for disposal. The 600 and 1100 Areas do not produce radioactive liquid effluents. Monitoring of regulated nonradioactive liquid effluents is also conducted in the 100, 200, 300, and 400 Areas.

Liquid effluent monitoring results are reported via the EIS-ODIS. Monitoring results for waste streams covered by the NPDES permit are reported monthly to EPA. A summary of liquid effluents for 1989 is given in Table G.3, Appendix G.

SOLID WASTE

Solid wastes produced at Hanford are classified as radioactive, nonradioactive, and mixed waste. Radioactive waste consists of transuranic, high-level, and low-level wastes. Radioactive mixed waste consists of wastes that have both radioactive and hazardous nonradioactive components. Nonradioactive wastes are composed of hazardous or nondangerous wastes or both. Hazardous waste consists of dangerous wastes or extremely hazardous wastes or both, as defined in Washington State Department of Ecology Dangerous Waste Regulations.

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

wastes are stored in vaults or underground storage pads, from which they can be retrieved.

Approximately 120 facilities on the Hanford Site generate dangerous waste. An annual report lists the dangerous wastes and extremely hazardous wastes generated, treated, stored, and disposed of on Site and off Site (DOE 1990). Dangerous wastes are treated, stored, and prepared for disposal at several Hanford Site facilities. Dangerous wastes generated at the Hanford Site are shipped off Site for disposal, destruction, or recycling. In 1989, 249,000 kg of dangerous wastes and 154,000 kg of extremely hazardous wastes were shipped off Site for disposal or recycling.

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

A summary of solid waste disposed of at Hanford is shown in Table G.6, Appendix G. Solid waste program activities are related to Resource Conservation and Recovery Act and Toxic Substances Control Act regulations and are further discussed in Section 2.0.

4.8 POTENTIAL RADIATION DOSES FROM 1989 HANFORD OPERATIONS

The potential radiation doses to the public from Hanford operations during 1989 were calculated as the committed dose equivalents to individual body organs and the effective dose equivalent to a hypothetical maximally exposed individual. In addition, the committed dose equivalents and the effective dose equivalent were calculated for the general public residing within 80 km of the Hanford Site. These doses were calculated from effluent releases reported by the operating contractors using Version 1.436 of the GENII code (Napier et al. 1988a, 1988b, 1988c) and Hanford Site-specific parameters.

The potential effective dose equivalent to the hypothetical maximally exposed individual from 1989 operations was 0.05 mrem (0.0005 mSv), compared to 0.08 mrem (0.0008 mSv) reported for 1988. The potential effective dose equivalent to the local population of 340,000 persons from 1989 operations was 1 person-rem (0.01 person-Sv), compared to 5 person-rem reported for 1988. The 1989 average population dose was 0.004 mrem (0.00004 mSv) per person. The current DOE radiation standards for an individual member of the public are 100 mrem/yr (1 mSv/yr) for prolonged exposures and 500 mrem/yr (5 mSv/yr) for occasional annual exposures.[a]

Radioactive materials were released to the environment in gaseous and liquid effluents from Hanford operations during 1989. Potential radiation doses to the public that resulted from these releases were evaluated in detail, as required by DOE Order 5484.1, to determine compliance with pertinent regulations and standards.

The potential radiological impacts of 1989 Hanford operations were assessed in terms of the following:

- maximum dose rate from external radiation at a publicly accessible location on or within the Site boundary (this quantity is also termed the "fence-post" dose rate)
- committed (50-yr) dose equivalents and effective dose equivalent to a hypothetical maximally exposed individual at an offsite location
- committed (50-yr) dose equivalents and effective dose equivalent to the population residing within 80 km of the onsite operating areas.

To the extent possible, radiation dose assessments should be based on direct measurements of radiation exposure rates and radionuclide concentrations in the surrounding environment. The amounts of most radioactive materials released during 1989 were too small to be measured directly once they were dispersed in

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

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

The radionuclides ^{3}H, ^{99}Tc, and ^{129}I were measurable in water samples from the Columbia River, and their measured concentrations were used for dose calculations. Tritium and ^{129}I in the Fast Flux Test Facility (FFTF) drinking water well and ^{129}I in offsite milk samples were also used for supplemental dose calculations were made on the basis of these measured concentrations.

Estimated potential radiation doses to the public were small. Although the uncertainty associated with the radiation dose calculations has not been quantified, whenever Hanford-specific data were not available for parameter values (i.e., plant uptake and consumption factors) conservative values were selected for use in models. Thus, doses calculated using these models should be viewed as maximum estimates (using maximizing assumptions) of potential doses resulting from Hanford operations.

MAXIMUM "FENCE-POST" DOSE RATE

The "fence-post" dose rate is a measure of the maximum potential external radiation dose rate at publicly accessible locations on or near the Site. The "fence-post" dose rate was determined from radiation exposure measurements using fixed radiation dosimeters at locations of expected maximum dose rates on Site and at representative locations off Site. Reporting of maximum "fence-post" dose rates is required by DOE Order 5484.1. These "fence-post" dose rates should not be used to calculate annual doses to the general public because no one can actually reside at any of these "fence-post" locations.

"Fence-post" dose rates were measured in the vicinity of the 100-N, 300, and 400 (FFTF) operating areas, as described in "Penetrating-Radiation Surveillance," Section 4.6. The 200 Areas were not included because they are not accessible to the general public.

The Columbia River provides public access to an area within a few hundred meters of the N Reactor and supporting facilities. Radiation measurements made at the 100-N Area shoreline were consistently above background levels. The highest average dose rate observed along the shoreline during 1989 was 0.03 mrem/h (0.0003 mSv/h), or about three times the background dose rate normally observed at offsite shoreline locations [0.01 mrem/h (0.0001 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 1989 at this location showed essentially normal background radiation levels [0.01 mrem/h (0.0001 mSv/h)].

MAXIMALLY EXPOSED INDIVIDUAL DOSE

The maximally exposed individual is a hypothetical person, living at a single location, who has a postulated lifestyle that results in him/her

receiving the maximum calculated radiation dose. This individual's characteristics were chosen to maximize the potential combined doses from all realistic, available environmental pathways for exposure to Hanford releases. The particular characteristics of the maximally exposed individual were based on factors such as the total amount, composition, and dispersion of effluents released to the air and the Columbia River. Such a combination of maximized parameters is unlikely to occur.

The location selected for the hypothetical maximally exposed individual can vary with time depending on the relative importance of the several sources of radioactive effluents released to the air and to the Columbia River from Hanford facilities. For several years, the maximally exposed individual had been assumed to reside at the Riverview irrigation district across the river from Richland. At that location, the individual could be exposed not only to airborne pathways but also to drinking water and to irrigated crops, both of which rely on the Columbia River for their water source.

In 1988, a new location, Ringold, was selected for the maximally exposed individual that is closer to the sources of airborne effluents and that still includes exposure to most of the river-water pathways. Ringold is one of the few farming areas using Columbia River water drawn downstream of the N Reactor for irrigation. Drinking water at Ringold is obtained from deep wells that do not contain radionuclides from the Columbia River. Ringold contains several farms along the Columbia River across from the Hanford Site. At Ringold, the maximally exposed individual is 26 km east-southeast from the 200 Areas, 30 km southeast of the 100-N Area, 13 km north of the 300 Area, and 11 km northeast of the 400 Area. Except for the Columbia River drinking water pathway, the hypothetical maximally exposed individual at Ringold can be exposed to all the same environmental pathways as the former maximally exposed individual was at Riverview.

The following exposure pathways were included in the calculation of doses potentially received by the hypothetical maximally exposed individual for 1989: inhalation of and submersion in airborne effluents, consumption of foods contaminated by radionuclides deposited on the ground from airborne materials and by irrigation with water from the Columbia River, direct exposure to radionuclides deposited on the ground, consumption of fish taken from the Columbia River, and direct exposure to radionuclides while using the Columbia River for recreation. The hypothetical maximally exposed individual for 1989 was postulated to be an individual who:

- was a resident of the Ringold area 26 km east-southeast of the 200 Areas

- consumed homegrown foodstuffs irrigated with Columbia River water

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

- drank water from deep wells not affected by Hanford effluents.

Doses to the hypothetical maximally exposed individual were calculated using the effluent data in Tables G.1 and G.5, Appendix G, and measurements of ^{3}H, ^{99}Tc, and ^{129}I in the Columbia River as input to the GENII code. The calculated committed dose equivalents to specific organs and the effective dose equivalent for the hypothetical maximally exposed

individual are summarized in Table 4.2. These values include the doses received from exposure to liquid and airborne effluents during 1989, as well as from potential exposure beyond 1989 from radionuclides that were deposited in the body during 1989 via inhalation and ingestion of fish and farm products. Site-specific parameters for food pathways, diet, and recreational activity used for the dose calculations are defined in Tables F.9 through F.12, Appendix F.

The total effective dose equivalent to the hypothetical maximally exposed individual in 1989 was calculated to be 0.05 mrem (0.0005 mSv) compared to 0.08 mrem (0.0008 mSv) in 1988. The primary pathways contributing to this dose were:

- consumption of food irrigated with Columbia River water (60%)
- consumption of food containing radionuclides deposited from the air (20%)
- consumption of fish from the Columbia River (20%).

Effective dose equivalent limits for any member of the general public from all routine DOE operations are 500 mrem/yr (5 mSv/yr) for occasional annual exposures and 100 mrem/yr (1 mSv/yr) for prolonged exposure periods. The calculated effective dose for the hypothetical maximally exposed individual was 0.05% of the prolonged exposure limit. The dose limit for any individual organ is 5000 mrem/yr

TABLE 4.2. Calculated Committed Dose Equivalents and Effective Dose Equivalent to the Hypothetical Maximally Exposed Individual from 1989 Hanford Operations (mrem)

Pathway		Committed Dose Equivalents					Effective Dose Equivalent[b]
		Red Marrow	Bone Surfaces	Lung	GI[a]	Thyroid	
Air	- Direct[c]	0.002	0.01	0.007	0.001	0.01	0.002
	- Food[d]	0.002	0.002	0.002	0.002	0.3	0.009
Water[e]	- Foods[f]	0.03	0.06	0.005	0.03	0.2	0.03
	- River Recreation[g]	0.03	0.06	0.004	0.009	0.01	0.009
	Total	0.06	0.1	0.02	0.05	0.4	0.05

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

(50 mSv/yr). In the maximally exposed individual, the organ calculated to receive the highest dose was the thyroid. The dose to this organ was 0.4 mrem or 0.008% of the limit.

The effective dose equivalent from 1989 Hanford operations for a hypothetical maximally exposed individual located at Ringold is compared with the doses reported for 1985 through 1988 in Figure 4.48. The calculated committed organ dose equivalents and effective dose equivalent for 1985 through 1989 are given in Table 4.3.

Comparison of 1989 radiation doses with values reported for previous years is complex. During the past few years, computer codes used for dose calculations have gradually evolved into the new system of radiation dosimetry required by DOE. The newer International Commission on Radiological Protection (ICRP) system was initiated in 1985 through the use of a temporary code, PABKID, that replaced the older dose-conversion factors with those recommended by the ICRP. PABKID was used to calculate radiation doses reported for

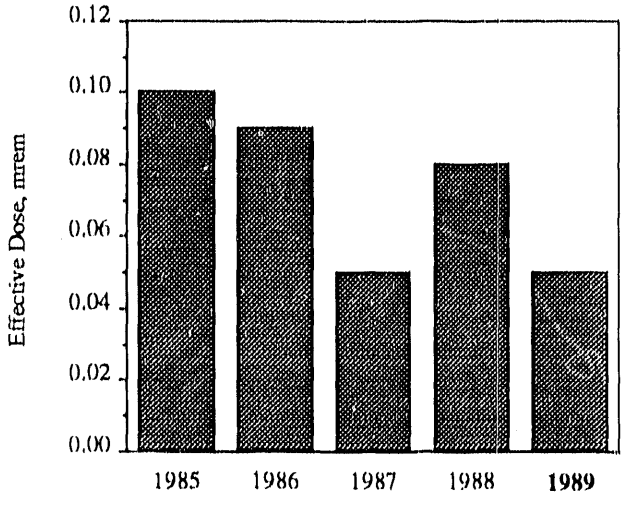


FIGURE 4.48. Calculated Effective Dose Equivalent to the Hypothetical Maximally Exposed Individual, 1985 Through 1989

CY 1985 and 1986. For the CY 1987, 1988, and 1989 reports, the doses were calculated with the new computer code, GENII (Napier et al. 1988a, 1988b, 1988c), designed to fully implement recommendations of the ICRP. However, for CY 1988 and 1989 dose calculations, a different location (Ringold) was selected for the hypothetical maximally exposed individual as explained previously. The principal reason for the difference between the 1987 and 1988 doses to the maximally exposed individual is this change of location. Soldat (1989) presents a comparison of the doses for the 5-year period 1983 through 1987 as calculated by these different methods.

COMPARISON WITH CLEAN AIR ACT STANDARDS

Additional limits for the air pathway in effect for CY 1989 are provided in 40 CFR 61, Subpart H of the Clean Air Act (EPA 1988e): 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 1989 air emissions resulted in doses of 0.01 mrem to the whole body and 0.3 mrem to the maximally exposed organ (thyroid). These doses are 0.04% and 0.4% of the whole-body and organ dose limits, respectively. Thus, the calculated maximum hypothetical annual doses for 1989 Hanford airborne effluent releases were well below the Clean Air Act standard. The doses calculated to demonstrate compliance with the Clean Air Act were performed using AIRDOS-EPA and RADRISK, which include dose factors generated specifically for EPA. These EPA dose factors differ somewhat from those specified in DOE publications (DOE 1988a, 1988b). For this reason, the results from calculations performed with AIRDOS-EPA are not directly comparable with those obtained with GENII.

TABLE 4.3. Calculated Committed Dose Equivalents and Effective Dose Equivalent to the Hypothetical Maximally Exposed Individual from Hanford Operations, 1985 Through 1989 (mrem)

Committed Dose Equivalents[a]	1985	1986	1987	1988	1989
Red Marrow	0.3	0.3	0.07	0.07	0.06
Bone Surfaces	0.7	0.6	0.1	0.01	0.1
Lung	0.07	0.03	0.02	0.03	0.02
GI[b]	0.09	0.04	0.03	0.03	0.05
Thyroid	1.0	0.09	0.9	2	0.4
Effective Dose Equivalent[c]	0.1	0.09	0.05	0.08	0.05

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

POPULATION DOSE

The regional population dose from 1989 Hanford operations was estimated by calculating the radiation dose to the population residing within an 80-km radius of the onsite operating areas. Pathways of exposure to the population from release of radionuclides to the atmosphere include inhalation, air submersion, and consumption of contaminated food. Pathways of exposure associated with Hanford-generated radionuclides in the Columbia River include consumption of drinking water and fish, consumption of foods irrigated at Riverview, and external exposure during aquatic recreation. Population doses are expressed in units of person-rem. Results are shown in Table 4.4, in terms of the committed dose equivalents and the effective dose equivalent. Site-specific population distribution characteristics and food pathway, dietary, residency, and recreational activity parameters assumed for these calculations are given in Tables F.1 through F.4 and F.9 through F.12, Appendix F.

The potential effective dose equivalent to the population was 1 person-rem (0.01 person-Sv) in 1989, compared to 5 person-rem (0.05 person-Sv) in 1987. The decrease in the estimated radiation doses for 1989 reflects the significant decrease in the reported release rate of ^{129}I to the environment from the PUREX Plant stack, coupled with a decrease in the annual average atmospheric dispersion factor from 1.7×10^{-3} s/m^3 in 1988 to 9.3×10^{-4} s/m^3 in 1989.

Comparison of the 80-km population doses attributed to 1985 through 1989 Hanford operations is given in Figure 4.49 and Table 4.5.

Primary pathways contributing to the 1989 effective dose equivalent for the population were:

TABLE 4.4. Calculated Committed Dose Equivalents and Effective Dose Equivalent for the 80-km Population from 1989 Hanford Operations (person-rem)

Pathway		Committed Dose Equivalents: Red Marrow	Bone Surfaces	Lung	GI[a]	Thyroid	Effective Dose Equivalent[b]
Air	- Direct[c]	0.2	2	1	0.1	0.3	0.3
	- Foods[d]	0.2	0.2	0.2	0.3	26	0.9
Water[e]	- Foods[f]	0.04	0.07	0.005	0.03	0.2	0.03
	- Drinking Water	0.2	0.2	0.1	0.2	0.4	0.2
	- River Recreation[g]	0.01	0.02	0.002	0.004	0.05	0.004
	Total	0.7	2	1	0.6	27	1

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

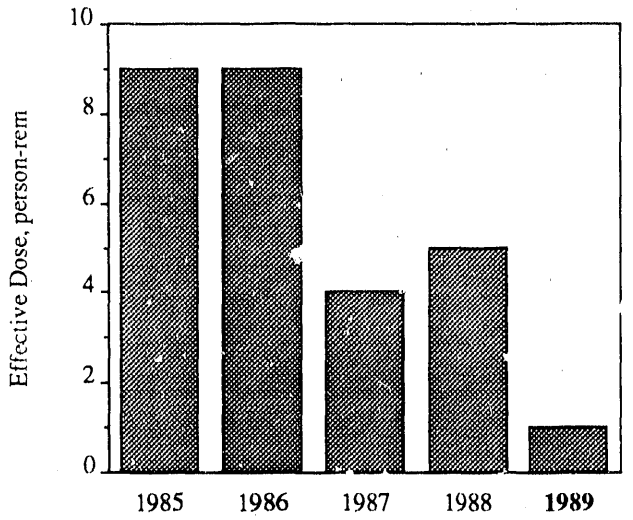


FIGURE 4.49. Calculated Effective Dose Equivalent to the 80-km Population, 1985 Through 1989

- consumption of foodstuffs contaminated with radionuclides, principally ^{129}I, released with gaseous effluents from the PUREX Plant stack (70%)

- inhalation of and submersion in radionuclides, principally the radioactive daughters of ^{220}Rn, that were released to the air from the PUREX Plant stack (20%)

- consumption of drinking water contaminated with radionuclides, principally ^{3}H, released to the Columbia River at Hanford (10%).

Inhalation of radionuclides from the 200 Areas also accounted for 76% of the radiation dose to the bone surface, and plutonium accounted for about one half of this radiation dose. The dose to the thyroid resulted primarily from consumption of food containing the long-lived radionuclide ^{129}I, released with the gaseous effluents from the PUREX Plant stack.

The average per capita effective dose from 1989 Hanford operations, based on a population of 340,000 within 80 km, was 0.004 mrem

TABLE 4.5. Calculated Committed Organ Dose Equivalents and Effective Dose Equivalent to the 80-km Population from Hanford Operations, 1985 Through 1989 (person-rem)

Committed Dose Equivalents[a]	1985	1986	1987	1988	1989
Red Marrow	6	5	0.9	1	0.7
Bone Surfaces	30	10	2	3	2
Lung	10	7	1	2	1
GI[b]	4	4	0.7	0.8	0.6
Thyroid	100	120	110	140	27
Effective Dose Equivalent[c]	9	9	4	5	1

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

(0.00004 mSv). This dose estimate may be compared with doses from other routinely encountered sources of radiation, such as natural terrestrial and cosmic background radiation, medical treatment and x-rays, natural internal body radioactivity, and inhalation of radon. The national average radiation doses from these sources are illustrated in Figure 4.50. The estimated per capita dose to individual members of the public from Hanford sources is only a small fraction of the annual per capita effective dose equivalent (300 mrem) from natural background and medical sources of radiation in the Tri-Cities area of Washington State. The contribution of radon (200 mrem) to the effective dose from natural background sources has only recently been quantified by authoritative U.S. organizations (NCRP 1987).

The effective dose equivalent to the hypothetical maximally exposed individual and the 80-km population from Hanford effluents are compared to appropriate standards and natural background radiation in Table 4.6. This table shows that the doses from Hanford operations in 1989 are a small percentage of the standards and of natural background.

POTENTIAL RADIATION DOSES FROM PAST OPERATIONS

Measured levels of certain radionuclides in the Columbia River have been attributed to past operations at Hanford (see "Surface-Water Surveillance," Section 4.2). The primary environmental impacts resulting from past operations were residual radionuclides deposited along the Columbia River shoreline in sediments and the seepage of ground water into the river from the unconfined aquifer.

Environmental radiation dose rates resulting from residual radionuclides along the shoreline were discussed in "Maximum 'Fence-Post' Dose Rate," in this section. (See also "Penetrating-Radiation Surveillance," Section 4.6.)

Although ^{129}I was not released directly to the Columbia River from Hanford facilities in 1989 (Table G.5, Appendix G), this radionuclide was

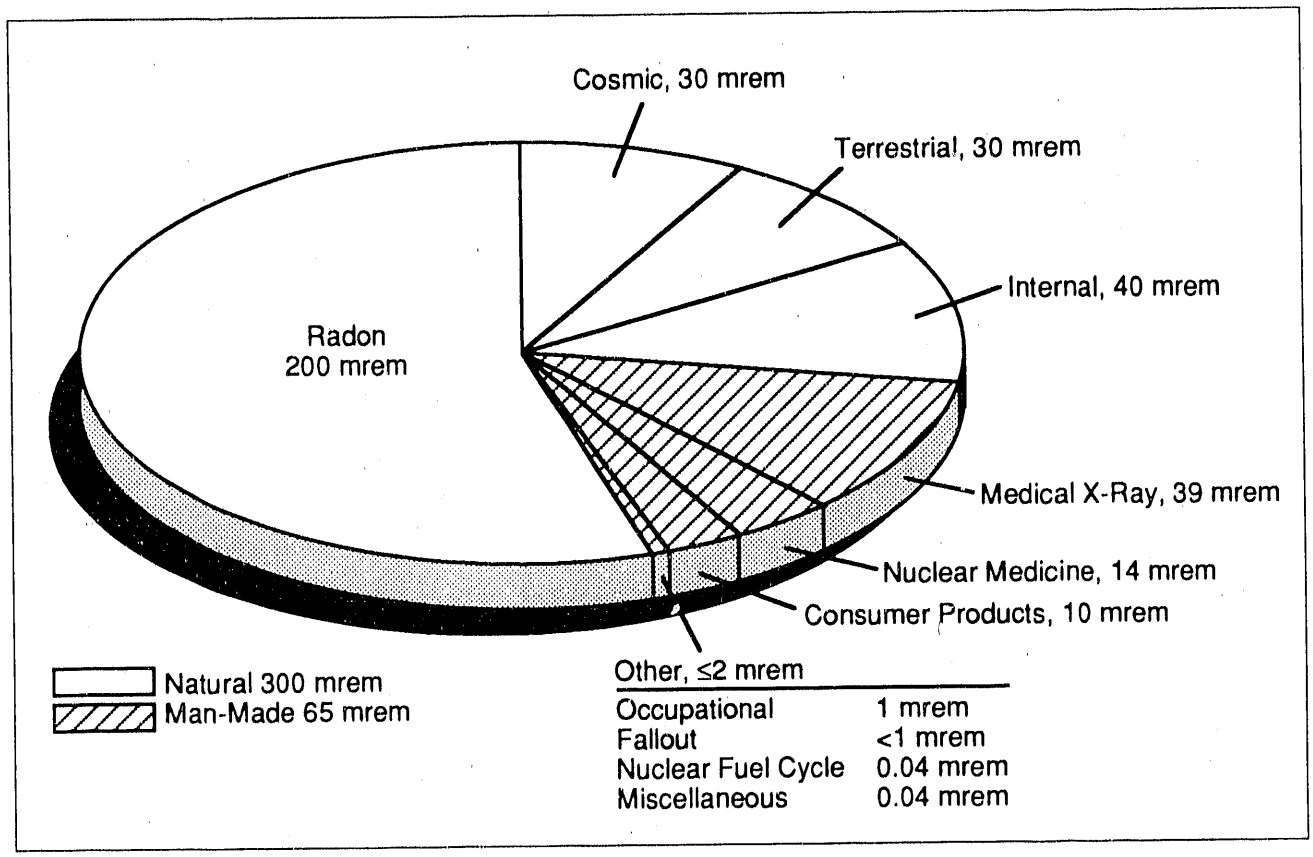


FIGURE 4.50. Annual Radiation Doses from Various Sources (mrem) (NCRP 1987)

TABLE 4.6. Summary of Effective Dose Equivalent from Various Sources in 1989

Source	Maximum Individual (mrem)	80-km Population (person-rem)
All Hanford Effluents	0.05	1
DOE Standard	100	---
Percent of DOE Standard	0.05%	---
Background Radiation	300	100,000
Percent of Background	0.02%	0.001%
Gaseous Effluents from Hanford via AIRDOS-EPA	0.01	---
EPA Air Standard	25	---
Percent of EPA Standard	0.04%	---

measured at low concentrations at the Richland Pumphouse. In addition, the measured concentrations of ^{3}H and ^{99}Tc at the Richland Pumphouse were higher than those predicted from measurements made in effluents from Hanford facilities further upstream. The differences for all three radionuclides can be attributed to seepage of contaminated ground water from the unconfined and confined aquifers beneath the Hanford Site.

The effective dose equivalent attributable to the differences in the annual average concentrations of ^{3}H, ^{99}Tc, and ^{129}I in the river is estimated to be 0.02 mrem (0.0002 mSv) to the hypothetical maximally exposed individual and 0.2 person-rem (0.002 person-Sv) to the 340,000 people within 80 km. The extra contributions from ^{3}H, ^{99}Tc, and ^{129}I are included in the doses from individual water exposure pathways and in the total doses listed in Tables 4.2 and 4.4. Also included are the small radiation doses calculated assuming that the small quantities of radionuclides disposed to the ground in the 300 Area (Table G.3, Appendix G) reached the river without delay or absorption in the soil.

POTENTIAL RADIATION DOSES FROM PUREX PLANT OPERATIONS

In addition to the dose contributions identified earlier from PUREX Plant operations, other minor dose contributions are discussed here.

The annual average air concentration of ^{129}I at Ringold for 1989, predicted from the reported release of 0.11 Ci from the PUREX Plant stack, was 2.3×10^{-5} pCi/m^{3}. This result is about 20 times the average of 1.1×10^{-6} pCi/m^{3} for the concentrations measured at Ringold during the last three quarters of 1989. Measurements were not available for the first quarter of the year because of a power failure at that location. In addition, concentrations of ^{129}I in both the effluent and the ambient air are extremely low and difficult to measure accurately. In view of these difficulties, the higher value and its corresponding doses as predicted by the GENII code were used for the dose summary in Table 4.2. The predicted doses were a dose equivalent to the thyroid of 0.3 mrem (0.003 mSv) and an effective dose equivalent of 0.008 mrem (0.00008 mSv).

During 1989, 11 composite milk samples from six local dairy areas were analyzed for ^{129}I. Six composite samples were collected in February, and composites were collected again during the summer from five of these areas. (The results are listed in Table C.14, Appendix C.) Average ^{129}I concentrations in the milk from the various areas were 0.001 pCi/L at Moses Lake, 0.002 pCi/L at Sunnyside and Wahluke East, 0.004 pCi/L at Benton City and Riverview, and 0.008 pCi/L at Sagemoor. The potential radiation dose to the thyroid of an adult consuming 270 L/yr of milk containing 0.008 pCi ^{129}I/L was 0.02 mrem.

The concentration of ^{129}I in milk calculated by the GENII computer code at Ringold (used for the dose to the hypothetical maximally exposed individual) based on the release of 0.11 Ci of ^{129}I from the PUREX Plant stack in 1989 was 0.06 pCi/L. The corresponding potential radiation dose to the thyroid from milk consumption calculated by the GENII code was 0.1 mrem.

In 1989, there was 0.00082 Ci of $^{239,240}Pu$ in airborne emissions from the PUREX Plant stack (see Table G.1, Appendix G) compared to 0.0002 Ci in 1988. Plutonium-239,240 was a minor contributor to the calculated dose from 1989 Hanford operations, with a maximum

potential effective dose equivalent of 0.0004 mrem (0.000004 mSv) to the hypothetical maximally exposed individual.

RADIATION DOSES FROM ONSITE DRINKING WATER WELLS

During 1989, ground water was used as a drinking water source at the 400 Area (FFTF), the Yakima Barricade Guardhouse, the Rattlesnake Mountain Observatory, the Arid Lands Ecology Headquarters, and the Hanford Patrol Training Academy. Samples were collected from these systems throughout the year in accordance with applicable drinking water regulations. Radionuclide concentrations during 1989 were well below applicable drinking water standards.

Results for 1989 were similar to those observed in 1988. Average concentrations of ^{3}H measured in the FFTF drinking water decreased from 22,000 pCi/L in 1985 to less than 10,000 pCi/L after a deeper well was drilled. The average concentration measured in 1989 was 8300 pCi/L, compared to 7300 pCi/L in 1988. The potential effective dose equivalent to a worker drinking 250 L of water containing the concentration of ^{3}H measured at FFTF in 1989 was calculated to be 0.1 mrem (0.001 mSv). The maximum dose to any organ was also 0.1 mrem (0.001 mSv) or 3% of the Washington State drinking water standard of 4 mrem/yr.

One sample of FFTF drinking water was analyzed for ^{129}I in 1989. The result was 0.0055 pCi/L. The effective dose from consuming 250 L of such water would be 0.0004 mrem (0.000004 mSv); the corresponding thyroid dose would be 0.01 mrem (0.0001 mSv). These doses are below the Washington State drinking water standard. Nonradiological and radiological results from the Hanford Sanitary Water Quality Surveillance Program are discussed in more detail and reported annually by the Hanford Environmental Health Foundation (Somers 1989).

During 1989, the FFTF drinking water well was also tested for the following radionuclides: ^{22}Na, ^{60}Co, ^{65}Zn, ^{90}Sr, ^{106}Ra, and ^{137}Cs; their concentrations were all below their respective detection limits.

5.0 Ground-water Protection and Surveillance Program

5.0 GROUND-WATER PROTECTION AND MONITORING PROGRAM

Radiological and chemical constituents in ground water were monitored during 1989 throughout the Hanford Site in support of the overall objectives described in "Environmental Program Information," Section 3.0. Monitoring activities were conducted to 1) determine the distribution of mobile radionuclides and NO_3^-, 2) relate the distribution of these constituents to Site operations, and 3) identify chemicals present in ground water as a result of Site operations. To comply with the Resource Conservation and Recovery Act (RCRA), additional monitoring was conducted to assess the impact that specific facilities have had on ground-water quality (Smith and Gorst 1990). The quality of ground water in the 200 Areas and surrounding region was evaluated by Westinghouse Hanford Company to ensure compliance with DOE monitoring guidelines, to assess the performance of waste disposal and storage, and to determine the impacts of operations on the ground water. During 1989, 567 Hanford Site wells were sampled to satisfy ground-water monitoring needs. As discussed in Section 4, four additional wells east of the Columbia River were sampled to determine if Hanford operations had affected water quality off Site.

Analytical results for samples were compared to EPA Drinking Water Standards (DWS) (Tables B.2 and B.3, Appendix B) and DOE's Derived Concentration Guides (DCG) (Table B.6, Appendix B). Ground water beneath the Hanford Site is used for drinking at five locations, as described in "Potential Radiation Doses from 1989 Hanford Operations," Section 4.8. In addition, water supply wells for the city of Richland are located adjacent to the southern boundary of the Hanford Site.

Radiological monitoring results indicated that gross alpha, gross beta, ^{3}H, ^{60}Co, ^{90}Sr, ^{99}Tc, ^{129}I, and ^{137}Cs concentrations in wells in or near operating areas were at levels above the DWS. Concentrations of uranium in the 200-West Area were above the DCG. Concentrations of ^{3}H in the 200 Areas and ^{90}Sr in the 100-N and 200-East Areas were also above the DCG. Iodine-131 and ^{103}Ru in ground water remained below detectable levels as a result of the N Reactor continuing in cold standby mode. Tritium continued to move slowly with the general ground-water flow and discharge to the Columbia River.

Certain chemicals regulated by the EPA and the State of Washington were also present in Hanford ground water near operating areas. Nitrate concentrations exceeded the DWS at isolated locations in the 100, 200, and 300 Areas and in several 600 Area locations. Chromium concentrations were above the DWS at 100-D, 100-H, and 100-K Areas, and the surrounding areas. Chromium concentrations above the DWS were also found in the 200-East and 200-West Areas. Cyanide was detected in ground water north of the 200-East Area. High concentrations of carbon tetrachloride were found in wells in the 200-West Area. Trichloroethylene was found at levels exceeding the DWS at wells in and near the 100-F Area, 300 Area, and Solid Waste Landfill. Sampling at monitoring wells near Richland water supply wells showed that concentrations of regulated ground-water constituents in this area are below DWS and in general below detection levels.

In the past, comprehensive review of all ground-water monitoring work on the Site was published semiannually (see Evans et al. 1989a; Evans et al. 1989b). Results for 1989 will be published as an annual report. These reports contain complete listings of all radiological and chemical data collected during the reporting periods.

SAMPLE COLLECTION AND ANALYSIS

Ground-water samples were collected from 567 monitoring wells during 1989. These samples were collected as part of the Hanford Ground-Water Environmental Surveillance Program and numerous projects to assess the effect of specific facilities on ground-water quality. Ground-water monitoring was conducted at the facilities listed in Table 5.1 to comply with RCRA. The RCRA monitoring is the responsibility of the contractor operating the facility. This work was accomplished by Westinghouse Hanford Company and Pacific Northwest Laboratory (PNL). Additional monitoring was conducted by Westinghouse Hanford Company to evaluate ground-water quality in the 200 Areas and surrounding region, to ensure compliance with DOE monitoring guidelines, and to assess the performance of waste disposal and storage facilities (Serkowski 1989).

Although these three programs are managed by different organizations, all samples are collected by PNL sampling teams following a single set of procedures. United States Testing Company, Inc., analyzed the samples for all programs, and a common database is used so that each program has access to all data collected on Site.

Most ground-water monitoring wells on the Site are 15 or 20 cm in diameter and are constructed of steel casing. Several small-diameter (5-cm) wells are sampled for radionuclides only. Monitoring wells for the unconfined aquifer are constructed with well screens or perforated casing generally in the upper 3 to 6 m of the aquifer. This construction allows sample collection near the top of the aquifer, where maximum concentrations for some radionuclides were measured at a few locations on the Hanford Site (Eddy et al. 1978). Wells

TABLE 5.1. Facility-Specific Monitoring Projects

Area	Facility
100-H	183-H Solar Evaporation Basins
100-N	1301/1325-N Liquid Waste Disposal Facilities
100-N	1324-NA Facility
200 Areas	216-A-10 Crib
200 Areas	216-A-29 Ditch
200 Areas	216-A-36B Crib
200 Areas	Low-Level Burial Grounds
200 Areas	2101-M Pond
300 Area	Process Trenches
600 Area	Nonradioactive Dangerous Waste (NRDW) Landfill
600 Area	Solid Waste Landfill
600 Area	216-B-3 Pond

monitoring the confined aquifer have screens or perforated casing within the monitored aquifer. Wells drilled before 1985 were generally constructed with carbon steel casing. Wells recently constructed for RCRA monitoring projects have been constructed with stainless steel casing.

Samples were collected following documented sampling procedures (PNL 1989a) based on EPA guidelines (EPA 1986b). Wells fitted with submersible pumps were sampled after pumping for a sufficient time to allow temperature, pH, and specific conductivity to equilibrate. Purging ensured that stagnant water in the well was removed, allowing collection of a sample that was representative of ground water near the well. Specific conductance and pH were measured in the field at the time of sample collection. Samples for total organic halogens (TOX) or volatile organic analyses (VOA) were taken without head space in the sample bottle to prevent loss of volatile constituents and were sealed immediately with septum-sealed caps. For filtered trace metals, a disposable, 0.45-µm pore-sized filter pack was connected to a Teflon®[a] sampling line. The filter was purged with 500 mL of well water; then a sample was collected in a plastic bottle. Trace metal and some radiochemical samples were preserved by acidification at the time of collection. All samples were immediately placed in ice chests and transferred the same day or early the next day to the laboratory for immediate analysis of species with short holding times (e.g., NO_3^-, TOX, and VOA). Samples were stored at 4°C from the time of sampling until they were analyzed. All samples were tracked by chain-of-custody procedures from sampling through analysis and disposal.

Analytical techniques used are described in "Analytical Procedures and Sampling Summary," Appendix D. All analyses were performed by United States Testing Company, Inc. A list of the species analyzed for is presented in Table 5.2.

During 1989, the Washington State Department of Ecology, EPA, and DOE began discussions to identify appropriate methods for disposing of ground water purged from wells before collecting samples. Before these discussions, purge water from all but the most contaminated wells was allowed to flow onto the ground near the well being sampled. Sample collection was

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

TABLE 5.2. Radionuclides and Chemicals Analyzed for the Hanford Ground-Water Environmental Surveillance Program

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

temporarily halted at many wells on the Hanford Site until purge water containment vessels could be placed at wells suspected of requiring containment.

As a result of this suspension of sample collection, many wells discussed in previous reports were not sampled during 1989. Wells not sampled included those providing access to ground water containing fluoride above the DWS, maximum concentrations of cyanide and tritium, significant areas of carbon tetrachloride and nitrate, and maximum concentrations of chromium in the 200-West Area.

Radiological Analysis

Most ground-water samples for the Hanford Ground-Water Environmental Surveillance Program and Westinghouse Hanford Company operational monitoring were analyzed for ^{3}H. Selected samples were subjected to more extensive radiological analysis by alpha-, beta-, and gamma-counting techniques, in many cases accompanied by selective radiochemical separations. A list of radionuclides analyzed for is presented in Table 5.2. The radiological monitoring network for most areas on the Hanford Site is shown in Figure 5.1. Figures 5.2 and 5.3 show environmental surveillance, operational, and RCRA monitoring wells in the 200-East and 200-West Areas, respectively.

Chemical Analysis

A subset of the radiological monitoring network was used for chemical surveillance. Chemical sampling wells were selected primarily for their proximity to known active and inactive chemical disposal sites in the 100, 200, 400, and 600 Areas, and for the wells' waste inventories (Stenner et al. 1988). Table 5.3 lists major contaminants found in each area.

During 1989, 56 wells were sampled for chemical constituents as part of the Hanford Ground-Water Environmental Surveillance Program. This number is significantly reduced from the number sampled in the previous 2 years because of the purge water disposal considerations discussed previously. Chemical data were gathered from an additional 200 wells in RCRA compliance networks during 1989. Table 5.4 summarizes the number of wells sampled, the number of samples collected, and the number of results obtained during 1989. The list of chemicals analyzed for is presented in Table 5.2.

RESULTS

Detailed discussions of monitoring results for the year, including tables of all results for each well and constituent, are reported in another document (Evans et al. 1989a). Highlights of those results are discussed below. Summaries for selected constituents are included in Tables C.39 through C.45, in Appendix C. Ground-water monitoring information for the 200 Areas and surrounding region is reported by Westinghouse Hanford Company (e.g., Serkowski et al. 1989) and for drinking water supplies on the Hanford Site by Hanford Environmental Health Foundation (e.g., Somers 1989). Tables presented by Westinghouse Hanford Company contain some of the same data reported here. Average concentrations may be different because the average of all data for a single constituent for each well is presented in Appendix C tables, and Westinghouse Hanford Company's reports generally present only data collected for the Westinghouse Hanford Company monitoring program.

Concentrations of radionuclides and chemicals in ground water were compared to EPA's DWS and DOE's DCG (Tables B.2, B.3, and B.6,

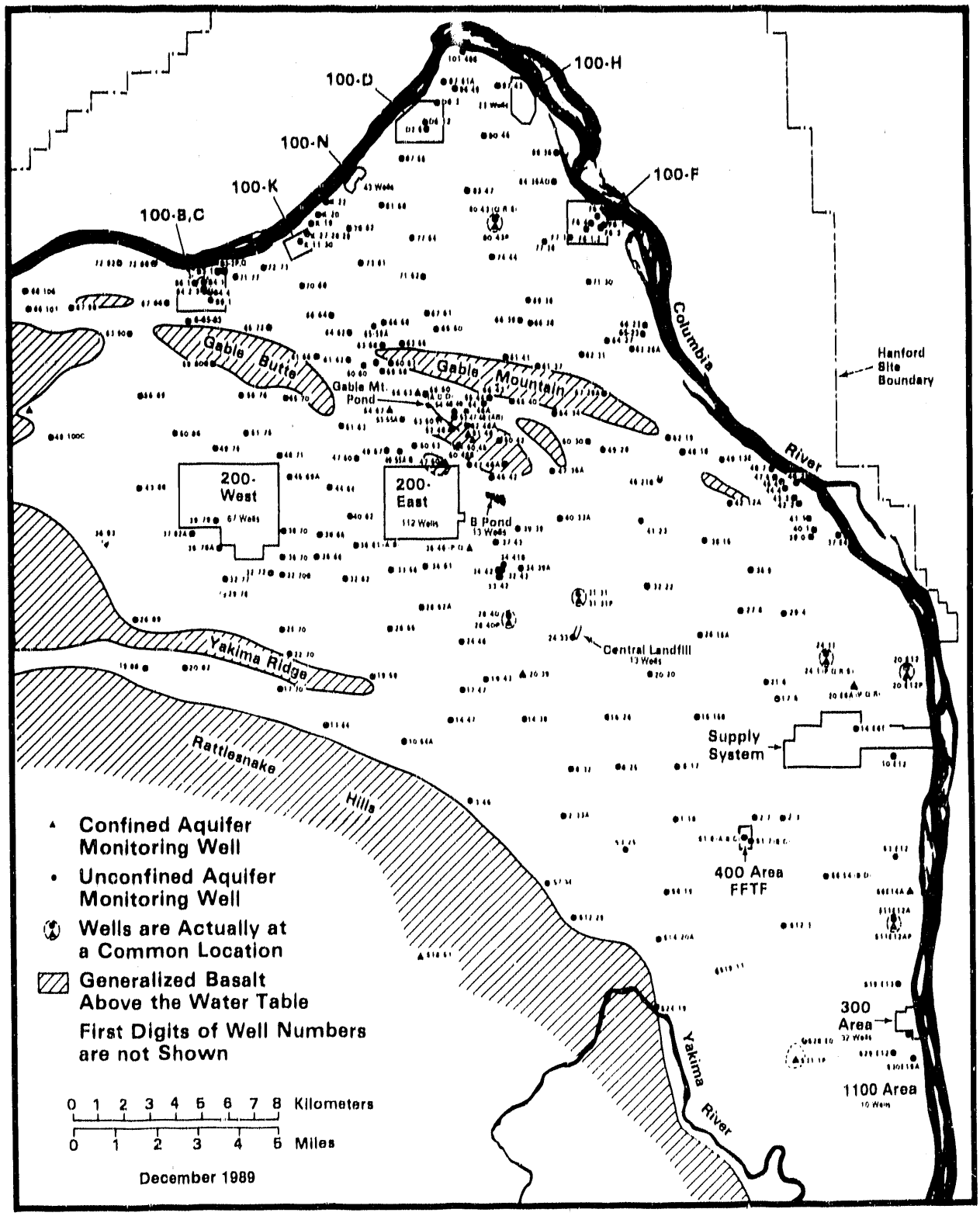


FIGURE 5.1. Hanford Site Monitoring Well Locations

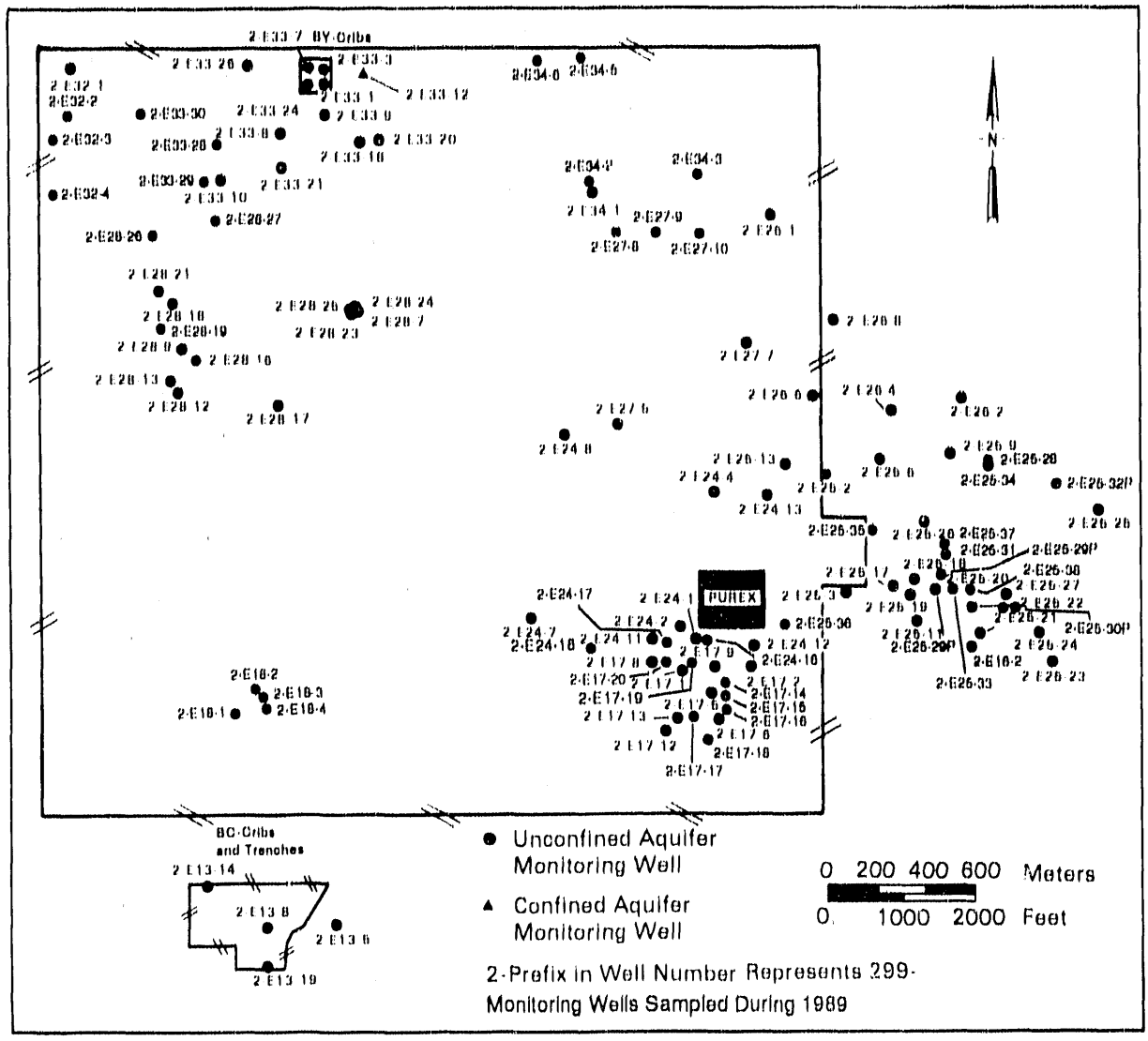


FIGURE 5.2. 200-East Area Monitoring Well Locations

Appendix B). Although none of the wells discussed is a drinking water supply well, the standards provide a basis for evaluating levels of contamination. Onsite drinking water supply wells are discussed in "Potential Radiation Doses from 1989 Hanford Operations," Section 4.8. Drinking Water Standards are more restrictive than the DCG because the DWS are based on an annual dose to the affected organ of 4 mrem/yr and the DCG are based on an effective dose equivalent of 100 mrem/yr (see "Applicable Standards and Permits and Environmental Compliance Documentation," Appendix B). The DCG are available only for radionuclides. Derived Concentration Guides used through the end of 1989 are proposed guidelines derived from DOE Order 5480.1A.

Radiological Monitoring Results for the Unconfined Aquifer

Radiological constituents monitored were selected based on known operational and waste management practices, physical and chemical

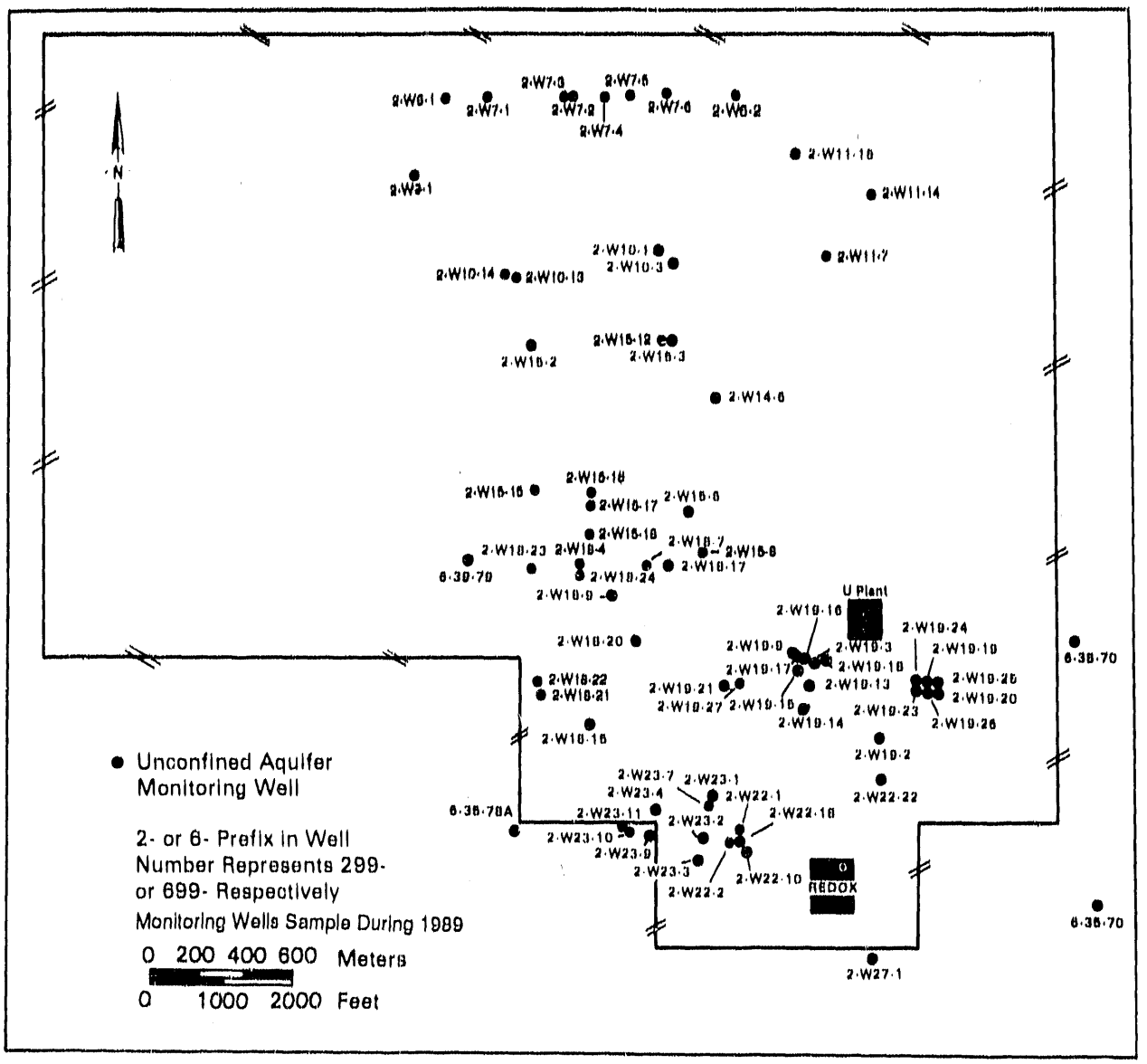


FIGURE 5.3. 200-West Area Monitoring Well Locations

properties of radionuclides of interest, and potential dose considerations. How radiological monitoring constituents ^{3}H, ^{60}Co, ^{90}Sr, ^{99}Tc, ^{129}I, ^{137}Cs, and uranium relate to Site operations is shown in Table 5.3.

Tritium Concentrations

Tritium is present in many waste streams discharged to the soil column and is the most mobile radionuclide on Site. As a result, ^{3}H reflects the extent of contamination in the ground water from Site operations and is the radionuclide most frequently monitored at the Hanford Site. Figure 5.4 shows the 1989 distribution of ^{3}H in the unconfined aquifer resulting from over 45 years of Site operations. Contours of tritium concentrations were based on the analysis of ground-water samples collected from monitoring wells. An average value from

TABLE 5.3. Major Chemical and Radiological Ground-Water Contaminants and Their Link to Site Operations

Facilities Type	Area	Constituents
Reactor Operations	100	^{3}H, ^{60}Co, ^{90}Sr, Cr^{6+}, SO_4^{2-}
Irradiated Fuel Processing	200	^{3}H, ^{137}Cs, ^{90}Sr, ^{129}I, ^{99}Tc, NO_3^-, Cr^{6+}, CN^-, F^- Uranium, Plutonium
Plutonium Purification	200	CCl_4, $CHCl_3$
Fuel Fabrication	300	Uranium, ^{99}Tc, Cr^{6+}, Trichloroethylene

TABLE 5.4. Number of Wells Sampled, Samples Collected, and Analytical Results for Ground-Water Monitoring Programs in 1989

Area	Number of Wells Sampled	Number of Samples Collected[a]	Number of Analytical Results
100	91	340	44,036
200	179	551	47,158
300	32	132	15,765
400	4	4	4
600	261	647	18,114
Total	567[a]	1674	125,077

(a) Total of samples collected for surveillance, for RCRA compliance, and for compliance with Westinghouse Hanford Company and DOE monitoring guidelines.

up to eight ^{3}H measurements was used for each well. A summary of ^{3}H concentrations in wells sampled during 1989 is presented in Table C.39, Appendix C.

Tritium concentrations greater than the 20,000-pCi/L DWS were detected in portions of the 100-B, 100-D, 100-K, 100-N, 200-East, 200-West, 400, and 600 Areas. Well 199-K-30 continued to contain the highest ^{3}H concentration within the 100 Areas with a maximum concentration of 882,000 pCi/L, somewhat lower than the maximum of 1,220,000 pCi/L in 1988. Well 199-K-27, by contrast, showed a large increase in ^{3}H concentrations with a maximum of 172,000 pCi/L in October 1989, up from an average of 2295 pCi/L for 1988. Wells 199-K-28 and 199-K-29, located between and in proximity to the other two wells, had relatively low tritium concentrations (2200 and 8530 pCi/L, respectively). The explanation for these changes is not known.

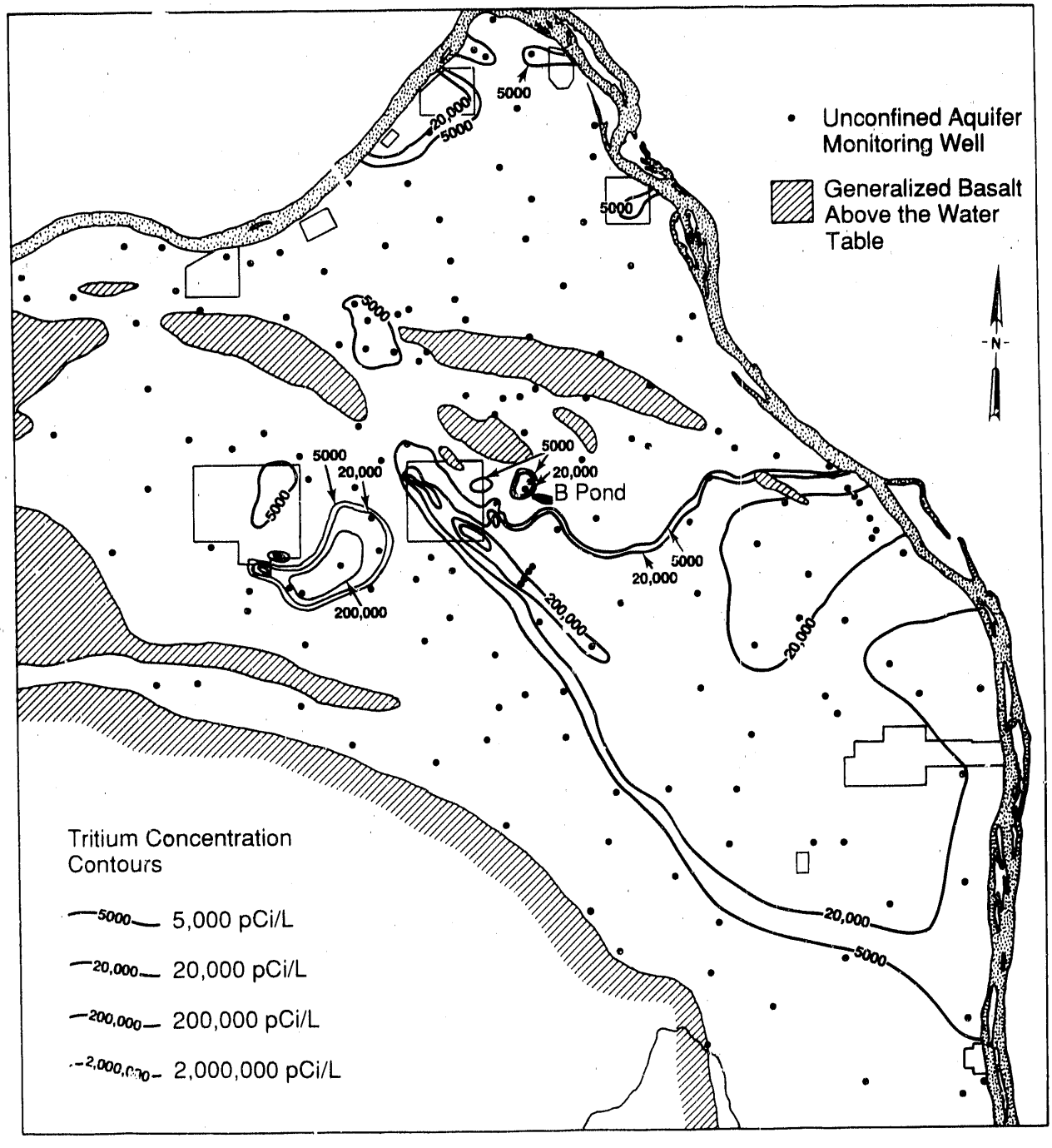


FIGURE 5.4. Tritium (^3H) Concentrations in the Hanford Site Unconfined Aquifer in 1989

Concentrations greater than the 2,000,000-pCi/L DCG were detected in 12 wells in the 200-East Area. The highest ^3H concentrations in the 200-East Area, and throughout the Hanford Site, continued to be in wells near cribs that have received effluents from the Plutonium Uranium Extraction (PUREX) Plant. Tritium concentrations greater than the DCG were present in wells near the 216-A-10, 216-A-36B, 216-A-37-1, and 216-A-45 cribs. The highest ground-water ^3H concentration measured in 1989 was 5,360,000 pCi/L in well 299-E17-1 (January 1989). Tritium concentrations exceeding the DWS continued to occur in most other wells affected by these cribs.

The movement of the widespread ^3H plume (see Figure 5.4) extending from the southeastern portion of the 200-East Area to the Columbia River was consistent with patterns noted earlier (Jaquish and Bryce 1989; Evans et al. 1989a). Separate ^3H pulses associated with the two episodes of PUREX operations can be distinguished in the plume. The 200,000- to 2,000,000-pCi/L lobe east of the 200-East Area near the Columbia River is a result of discharges to ground water during the operation of the PUREX Plant from 1956 to 1972. Following an 11-year shutdown, plant operation began again in 1983. Elevated ^3H concentrations measured in several wells (e.g., wells 699-32-43, 699-33-42, and 699-36-46) downgradient from the 200-East Area represent the formation of a second pulse of ^3H moving away from PUREX waste disposal facilities. The more recent, short-term interruptions of PUREX operations are not discernible in the ground-water monitoring data for the plume immediately downgradient of the 200-East Area.

The eastern portion of the plume continues to move to the east-southeast and discharge into the Columbia River. Migration of the plume continued farther to the south, as indicated by increased ^3H concentrations in wells near the 300 Area. Figure 5.5 shows the trend of tritium concentrations in well 699-S19-E13, located just north of the 300 Area. In recent years, this well has shown a steady increase in tritium, having reached a new maximum value of 8410 pCi/L in October 1989. The configuration of the western portion of the plume closely matches previous predictions of the direction of contaminant movement from the 200-East Area (Freshley and Graham 1988). Movement to the south may be enhanced by the spreading ground-water mound beneath B Pond. This mound is spreading as a result of increased discharge of steam condensate and process cooling water to B Pond since 1984 when Gable Mountain Pond was deactivated.

The movement of ^3H plumes in the 200-West Area was also consistent with previous observations. The plume extending from near the Reduction Oxidation (REDOX) Plant in the southern part of the 200-West Area continued to move slowly to the east and north. None of the 200-West Area wells sampled in 1989 had

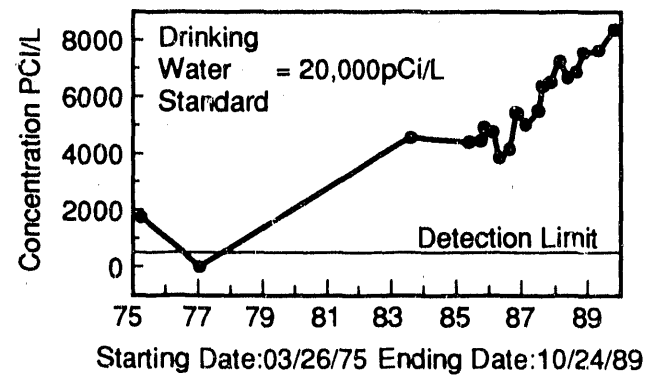


FIGURE 5.5. Tritium Concentrations in Well 699-S19-E13

^3H concentrations exceeding the DCG; however, well 299-W22-9 was not sampled during 1989 because of the purge water disposal considerations discussed earlier. That well had shown the highest ground-water tritium levels on Site in 1987 and 1988. The maximum concentration in that well in 1988 was 7,560,000 pCi/L. Tritium concentrations in well 299-W23-4 increased rapidly, reaching a maximum of 5,450,000 pCi/L in February 1988, followed by a rapid decrease to below the DCG during the remainder of the year. That trend continued during 1989, with the level down to 23,500 pCi/L by October 1989. The explanation of this oscillation remains unclear because that well showed negligible ^3H levels during 1987. Tritium concentrations in nearby wells within the 200-West Area and in the adjacent 600 Area remained above the DWS and were relatively constant throughout 1988. Movement of the ^3H plume extending north and east from the REDOX Plant was indicated by changes in the ^3H concentrations in several wells in the plume. Concentrations in well 699-35-70 continued to decrease slightly, suggesting that peak concentrations may have moved beyond this well although at least part of the decrease can be accounted for by decay. Concentrations in wells near the center of the plume remained relatively constant while concentrations in well 699-40-62 continued to increase slightly as the plume moved northward. The northernmost extent of the plume appeared to be near well 699-40-62. Well 699-44-64, north of well 699-40-62, has shown a small but steady increase over the last 18 months but still contains ^3H concentrations near the 300-pCi/L detection limit.

Gross Alpha Concentrations

Gross alpha concentrations were detected in ground water from wells in several areas and may be attributable to the presence of isotopes of plutonium and/or uranium; however, plutonium concentrations in all but three wells were below the detection limit attainable by the analytical laboratory. The DWS for gross alpha is 15 pCi/L, not including uranium. Those wells in the 100-F, 200, and 300 Areas where gross alpha exceeded 15 pCi/L contained uranium at levels that would account for the gross alpha level detected. Several wells in the 100-H Area also contained gross alpha levels exceeding the DWS. Although levels in a few wells in the 200-East Area remained somewhat above the DWS, gross alpha levels in most wells in the 200-East Area were low. The highest gross alpha levels measured on Site continue to be in wells adjacent to the inactive 216-U-1 and 216-U-2 cribs. Concentrations in these wells continued to decrease over the last year. Wells adjacent to the 216-U-1 and 216-U-2 cribs contained uranium levels that would account for the gross alpha levels detected. A summary of uranium levels in wells sampled during 1989 is presented in Table C.40, Appendix C.

Gross Beta Concentrations

Gross beta concentrations greater than the 50-pCi/L DWS were found in wells throughout the Site. Gross beta levels can be attributed to one or more of the following radionuclides in ground water: ^{40}K (naturally occurring); ^{60}Co, ^{90}Sr, ^{99}Tc, ^{106}Ru, ^{125}Sb, ^{137}Cs, ^{234}Th, and ^{234}Pa (uranium radioactive decay products); and to a lesser extent ^{129}I. Occasionally, some shorter-lived beta emitters, such as ^{131}I, may also be present. Tritium is normally not detected by the method used for assay of gross beta. Gross beta activity above natural background in most cases derives from a combination of uranium and ^{99}Tc activity. Known exceptions include some wells in the 100-N Area and a few wells

in the 200-East Area that contain ^{90}Sr at concentrations high enough to be detected with the gross beta technique.

Although gross beta levels greater than the DWS were widespread, the highest levels were in wells near several waste disposal facilities in the 100-N, 200-East, and 200-West Areas, and in the 600 Area adjacent to the 200 Areas. Wells in the 200-East Area with the highest gross beta levels in 1989 reflect past disposal of liquid waste to the inactive 216-B-5 reverse well, BY cribs, and cribs near the PUREX Plant. Gross beta levels in wells 299-E28-23 (8500 pCi/L) and 299-E28-25 (8100 pCi/L) near the 216-B-5 reverse well were some of the highest measured on Site in 1989. All wells near this reverse well contained elevated levels of ^{90}Sr, and two wells also contained measurable ^{137}Cs. The 216-B-5 reverse well received an estimated 27.9 Ci of ^{90}Sr and 31.8 Ci of ^{137}Cs (both values decayed through April 1, 1986) when used from 1945 to 1947 (Stenner et al. 1988). The BY cribs received waste scavenged from U Plant. Wells monitoring the BY cribs (located at the north end of the 200-East Area) showed gross beta levels greater than the DWS, ranging up to 1440 pCi/L (well 699-50-53). The BY crib monitoring wells generally contained ^{60}Co and ^{99}Tc.

The highest gross beta levels in the 200-West Area were found in wells near U Plant. Gross beta levels in wells near the 216-U-1 and 216-U-2 cribs remained above the DWS but are generally decreasing. Gross beta levels in these wells are dominated by uranium radioactive decay products. Gross beta levels remained above the DWS in several wells near Gable Mountain Pond. These wells contain relatively high concentrations of ^{90}Sr, which would account for the gross beta level measured.

The highest gross beta levels on Site in 1989 were found in wells monitoring the 1301-N Liquid Waste Disposal Facility (LWDF). Well 199-N-67 showed a gross beta concentration of 24,100 pCi/L in October 1989. The observed concentrations at this location are primarily due to ^{90}Sr.

Cobalt-60 Concentrations

Most ^{60}Co concentrations were consistently near or below the detection limit (20 pCi/L), except in the 100-N Area and in isolated portions of the 200-East Area and adjacent 600 Area. Concentrations of ^{60}Co were above detection but have dropped below the 100-pCi/L DWS in several wells near the 1325-N LWDF. The highest concentrations of ^{60}Co in Hanford Site ground water during 1989 were in well 699-50-53 (532 pCi/L), directly north of 200-East Area; these concentrations were essentially unchanged from a year ago. Cobalt-60 in this well appears to be highly mobile, probably because of the presence of a soluble cobalt-cyanide (or ferrocyanide) complex associated with the plume originating in the BY cribs. No wells exceeded the 5000-pCi/L DCG for ^{60}Co.

Strontium-90 Concentrations

Concentrations of ^{90}Sr were above the 8-pCi/L DWS in wells in the 100-B, 100-D, 100-F, 100-K, 100-N, 200-East, 200-West, and 600 Areas. Concentrations of ^{90}Sr were greater than the 1000-pCi/L DCG in the 100-N and 200-East Areas, ranging up to 23,400 pCi/L in the 100-N Area and up to 5740 pCi/L in the 200-East Area near the 216-B-5 reverse well. Concentrations of ^{90}Sr above the DWS (maximum of 301 pCi/L in well 699-53-48B) but less than the DCG were detected in several wells near Gable Mountain Pond. A summary of ^{90}Sr

concentrations in wells sampled during 1989 is presented in Table C.41, Appendix C.

Technetium-99 Concentrations

An extensive program to analyze ground-water samples for ^{99}Tc was continued during 1989. Concentrations greater than the 900-pCi/L DWS were detected in wells in the 100-H, 200-East, and 200-West Areas and in portions of the 600 Area. None of the wells had concentrations exceeding the 100,000-pCi/L DCG. The highest concentrations of ^{99}Tc on the Site were measured in well 299-W19-24 (41,000 pCi/L), downgradient of the inactive 216-U-1 and 216-U-2 cribs in the 200-West Area. The ^{99}Tc plume associated with well 299-W19-24 does appear to have originated from the 216-U-1 and 216-U-2 cribs, which had received a large amount of uranium recovery waste in the past. Technetium-99 levels in that group of wells generally continued to increase during 1989.

Ruthenium-106 Concentrations

Because of its short half-life (367 days), ^{106}Ru was detected in the past principally in wells located in areas near operating reactors and is detected currently near active fuel reprocessing facilities. Past examples have included the 100-N Area and the 200-East Area near the PUREX Plant. Concentrations in wells in the 100-N Area were at most marginally detectable in 1987 and continued to decline in 1988 because the N Reactor was in cold standby. Ruthenium-106 was undetectable in the 100-N Area in 1989 by routine detection methods. Concentrations of ^{106}Ru in wells near LWDFs receiving effluents from the PUREX Plant generally increased in 1988, with well 299-E24-12 reaching a maximum of 547 pCi/L (DWS is 200 pCi/L) in April 1988. That trend reversed in 1989 as a result of interruption in the operation of PUREX, with the ^{106}Ru concentrations in well 299-E24-12 dropping to below detectable levels. A ^{106}Ru concentration of 257 pCi/L was found in well 299-E17-15 in September 1989. That was the only well showing detectable ^{106}Ru during 1989.

Antimony-125 Concentrations

Antimony-125 (^{125}Sb), a gamma emitter, was measured in 100-N Area wells near the 1325-N LWDF. Results ranged up to 93.6 pCi/L in well 199-N-32. Well 199-N-45, which had the highest ^{125}Sb in 1988, was not assayed for that radionuclide in 1989. The DWS for ^{125}Sb is 300 pCi/L, and the DCG is 60,000 pCi/L.

Iodine-129 Concentrations

The presence of ^{129}I in ground water is significant, because of its relatively long half-life (16 million years), its potential for accumulation in the environment as a result of long-term releases from nuclear fuel reprocessing facilities (Soldat 1976), and its relatively low DWS (1 pCi/L). At Hanford, the main contributor of ^{129}I to ground water has been liquid discharges to cribs in the 200 Areas. The expanded ^{129}I monitoring effort that began in 1988 was continued in 1989. The highest concentration reported in 1989 was 11.1 pCi/L in well 699-35-70, located just outside the 200-West Area boundary and downgradient from the REDOX Plant. Many wells sampled in the 200-West and 200-East Areas had concentrations above the DWS; however, none were above the DCG (500 pCi/L). A few wells sampled in the 600 Area ^{3}H plume also had ^{129}I concentrations slightly above the DWS. A summary of ^{129}I concentrations in wells sampled during 1989 is presented in Table C.42, Appendix C.

Cesium-137 Concentrations

Concentrations of ^{137}Cs were below the detection limit (23 pCi/L) except in three wells located near the 216-B-5 reverse well. Ground water sampled at well 299-E28-23 contained 844 pCi/L; ground water at well 299-E28-25 contained 1070 pCi/L. The concentration in well 299-E28-25 represents a ten- to twenty-fold increase over previous measurements. A similar increase occurred in plutonium concentrations measured concurrently on separate samples from the same well. The increase appears to be associated with a change in sample collection protocol involving acidification of the collected sample; previously, samples for radiological analysis were untreated in the field. In addition, ^{137}Cs was detected for the first time in nearby well 299-E28-24 (33 pCi/L). The 216-B-5 reverse well received an estimated 31.8 Ci of ^{137}Cs (decayed through April 1, 1986) during its operation from 1945 to 1947 (Stenner et al. 1988). The DWS for ^{137}Cs is 200 pCi/L, and the DCG is 3000 pCi/L.

Uranium Concentrations

The highest uranium levels in Hanford ground water occur in wells adjacent to the inactive 216-U-1 and 216-U-2 cribs. Uranium concentrations in these wells have been decreasing over the last 3 years following remediation activities associated with those cribs. The total uranium concentration in well 299-W19-3 dropped from 16,000 pCi/L in January 1987 to 2000 pCi/L in March 1989. Uranium concentrations in other nearby wells also tended to decrease over the past 3 years and now appear to have stabilized. Uranium levels increased sharply in two 100-F Area wells in 1987. Levels in well 199-F8-1 reached a maximum of 414 pCi/L in January 1988 and generally have decreased thereafter, dropping to a low of 91 pCi/L in October 1989. A similar trend occurred in well 199-F8-2. A plume of uranium exists in the unconfined aquifer beneath the 300 Area in the vicinity of uranium fuel fabrication facilities and inactive waste sites known to have received uranium waste. The extent of the plume was limited to an area downgradient from active and inactive LWDFs. Uranium concentrations in wells in and adjacent to the 300 Area ranged up to 255 pCi/L during 1989. These concentrations were similar to those measured in previous years. A summary of uranium concentrations in wells sampled during 1989 is presented in Table C.40, Appendix C.

Plutonium Concentrations

As was the case for ^{137}Cs, concentrations of ^{239}Pu were below the detection limit in all wells, except three wells located near the 216-B-5 reverse well. Both plutonium and radiocesium bind strongly to sediments and thus have limited mobility in the aquifer. Ground water sampled at well 299-E28-23 contained 7.2 pCi/L of ^{239}Pu; ground water at well 299-E28-25 contained 72 pCi/L. The measurement in well 299-E28-25 represents a ten- to twenty-fold increase over previous measurements. A similar increase was also seen in ^{137}Cs concentrations measured concurrently on separate samples from the same well. The increase is believed to be the result of a change in sample collection protocol (see discussion of ^{137}Cs results). In addition, ^{239}Pu was detected for the first time in nearby well 299-E28-24 (72 pCi/L). The 216-B-5 reverse well received an estimated 244 Ci of ^{239}Pu during its operation from 1945 to 1947 (Stenner et al. 1988). The DCG of 300 pCi/L for ^{239}Pu has been reduced to 30 pCi/L effective February 1990. There is no explicit DWS for ^{239}Pu; however, the gross alpha DWS of 15 pCi/L would be applicable.

Chemical Monitoring Results for the Unconfined Aquifer

Chemical monitoring in 1989 continued to document the distribution of chemical contaminants from Hanford operations. Although the extensive distribution of NO_3^- from Hanford operations is documented in numerous reports, some of the other chemical results represent relatively recent findings (i.e., since 1987). Species of interest include NO_3^-, cyanide, fluoride, chromium, carbon tetrachloride, and trichloroethylene.

Nitrate Concentrations

Although NO_3^- is associated primarily with process condensate liquid wastes, other liquids discharged to ground also contain NO_3^-. Nitrate contamination in the unconfined aquifer reflects the extensive use of nitric acid in decontamination and chemical reprocessing operations. Nitrate, like ^3H, can be used to define the extent of contamination because NO_3^- is present in many waste streams and is mobile in ground water. The distribution of NO_3^- on the Hanford Site is shown in Figure 5.6.

Most ground-water samples collected in 1989 were analyzed for NO_3^-. Nitrate was measured at concentrations greater than the DWS (45 mg/L as NO_3^- ion) in wells in all operational areas, except the 400 Area.

The highest NO_3^- concentrations in the 200-East Area continued to be found near LWDFs that received effluent from PUREX operations. Nitrate concentrations in wells near the 216-A-10 and 216-A-36B cribs continued to decrease during 1989 but remained above the DWS even though these facilities were removed from service in 1987.

The configuration of the NO_3^- plume emanating from the 200-East Area shows the influence of two periods of PUREX operation and recent changes in the operation of B Pond. The location of B Pond is shown in Figure 5.1. Increases in the volume of process cooling water discharged to B Pond may have resulted in the expanding area of lower NO_3^- concentrations in ground water to the east and south of that facility (see Figure 5.6).

Nitrate concentrations above the DWS were widespread in ground water beneath the 200-West Area. Highest concentrations were centered in three locations: 1) wells near U Plant, 2) wells in the northwestern part of the 200-West Area, and 3) wells near the 216-S-25 crib. The highest NO_3^- concentrations across the Site continued to be found in wells east of U Plant near the 216-U-17 crib. The presence of nitrate in wells near this crib was observed before February 1988 when the crib went into operation. The source of NO_3^- is believed to be wastes disposed of in the 216-U-1 and 216-U-2 cribs. These cribs received over 1 million kg of NO_3^- during their operation from 1951 to 1967 (Stenner et al. 1988). A maximum NO_3^- concentration of 1300 mg/L was measured in newly installed well 299-W19-26, and similar concentrations were seen in other nearby wells. Nitrate concentrations in wells located near the 216-U-1 and 216-U-2 cribs west of U Plant continued to decrease in 1988, with concentrations in several of the wells dropping below the DWS. Nitrate concentrations in those wells stabilized during 1989.

Several wells in the northwestern part of the 200-West Area continued to contain NO_3^- at concentrations greater than the DWS. These wells are located near several inactive LWDFs that received waste from early T Plant

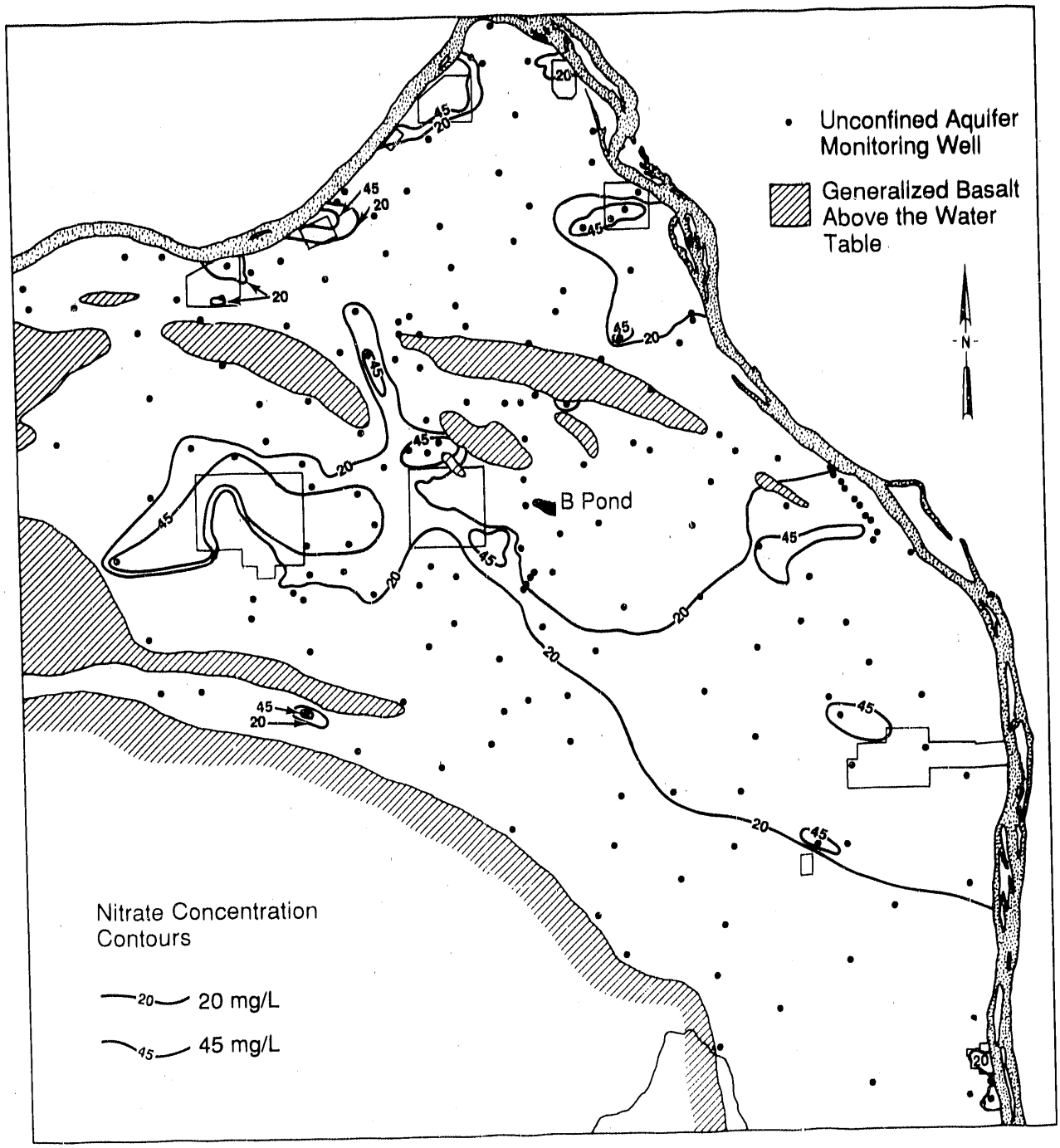


FIGURE 5.6. Nitrate (NO_3^-) Concentrations in the Hanford Site Unconfined Aquifer in 1989

operations. Maximum concentrations in these wells in 1988 ranged up to 699 mg/L in well 299-W15-4. The pattern in that area was similar in 1989; however, less information was available because of the purge water disposal considerations discussed earlier, which limited the sampling effort in 1989 in the most contaminated areas. A summary of NO_3^- concentrations in wells sampled during 1989 is presented in Table C.43, Appendix C.

Cyanide Concentrations

Cyanide was detected in samples collected from wells in and directly north of the 200-East Area. The cyanide source is believed to be wastes containing ferrocyanide disposed of in the BY cribs. Samples taken in January 1989 had a maximum cyanide concentration of 574 µg/L in well 699-50-53, with lesser amounts present in four other wells in or near the northern side of the 200-East Area. Wells containing cyanide also contained concentrations of several radionuclides, including ^{60}Co. Although ^{60}Co is normally immobile in the subsurface, it appears to be chemically complexed and mobilized by cyanide or ferrocyanide. Cyanide also has been detected in four widely spaced wells in the 200-West Area; the highest level reported in 1988 was 69 µg/L in well 299-W14-2. No samples were taken from well 299-W14-2 in 1989 because of considerations associated with disposal of purge water. No DWS has been established for cyanide.

Fluoride Concentrations

Fluoride concentrations above the DWS occurred in a few wells in the 200-West Area near T Plant. The maximum concentration in 1988 was 12.8 mg/L in well 299-W15-4. Because of considerations associated with disposal of purge water, no 200-West Area wells in the fluoride plume were sampled in 1989. All wells sampled outside the 200-West Area contained fluoride levels below the DWS. The DWS for fluoride is 2.0 mg/L.

Chromium Concentrations

Chromium has been found in ground water from wells in the 100-B, 100-D, 100-H, and 100-K Areas. In addition, at least one well in the 100-F Area had detectable hexavalent chromium. The highest measured chromium concentrations on Site in 1989 continued to be found in well 199-D5-12 at 692 µg/L, down more than a factor of two from measurements in 1987. Detectable chromium was also found in various parts of the 600 Area, particularly near the 100-D and 100-H Areas. The highest concentration was found in well 699-97-43 (approximately 1 km west of the 100-H Area) at 192 µg/L, four times the DWS. Two other wells in the same area had chromium levels greater than the DWS in 1989. Chromium contamination was previously found at several locations in the 200-West Area; however, only one of those wells (299-W6-2) was sampled in 1989. Chromium concentrations in well 299-W6-2 were similar to those observed in 1988. The maximum chromium concentration found in the 200-West Area during 1988 was 339 µg/L in well 299-W22-20. Ground-water samples from at least 12 other 200-West Area wells sampled in 1988 had detectable chromium. A few wells in the 200-East Area also showed evidence of minor chromium contamination. The highest level found was in well 299-E13-14, with a chromium concentration of 67 µg/L in November 1988. That well was not sampled in 1989 because of considerations associated with purge water disposal. A summary of chromium concentrations in wells sampled during 1989 is presented in Table C.44, Appendix C.

Carbon Tetrachloride Concentrations

Extensive carbon tetrachloride contamination was found in the unconfined aquifer beneath much of the 200-West Area. The contamination is believed to be from waste disposal operations associated with Z Plant before 1973. A concentration of 8100 µg/L was found in a well near Z Plant first monitored in October 1988 (well 299-W15-16). Carbon tetrachloride concentrations in well 299-W15-16 were similar in 1989, reaching a maximum of 8250 µg/L. Numerous other wells in the area had carbon tetrachloride levels ranging from 1000 to 5000 µg/L in 1987 and 1988; however, because of restrictions on disposal of purge water, many of those wells were not sampled in 1989. The maximum contaminant level, or target concentration, of carbon tetrachloride for remediation under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 and the Superfund Amendments and Reauthorization Act of 1986 is 5 µg/L. The DWS is also 5 µg/L. In addition to carbon tetrachloride, minor amounts of other chlorinated hydrocarbon solvents were found in 200-West Area ground water, including trichloroethylene and chloroform. A summary of detectable carbon tetrachloride concentrations in wells sampled during 1989 is presented in Table C.45, Appendix C.

Trichloroethylene Concentrations

Trichloroethylene contamination in excess of the 5-µg/L DWS was found at several sites in 1989. Trichloroethylene was found in 600 Area wells on the west side of the 100-F Area. The highest level reported in 1989 was 32 µg/L in well 699-77-36. Trichloroethylene concentrations in that well appear to be constant with time. Several wells at the Solid Waste Landfill contained trichloroethylene close to but slightly below the DWS. Solid Waste Landfill wells had shown trichloroethylene concentrations above the DWS in previous years. Trichloroethylene and some of its partial degradation products [i.e., cis-dichloroethylene (1,2-DCE)] were found in wells monitoring the lower portion of the unconfined aquifer in the 300 Area near the North Process Pond. Maximum concentrations were 21 µg/L trichloroethylene and 79 µg/L DCE in well 399-1-16B. Similar levels were found in nearby well 399-1-16C, which monitors the upper portion of the confined aquifer. Trichloroethylene was not found in well 399-1-16A, which monitors the upper portion of the unconfined aquifer. Trichloroethylene contamination had been detected in 1988 at levels exceeding the DWS in two locations inside the 200-West Area. Neither group of wells was sampled during 1989 because of purge water disposal considerations.

Radiological and Chemical Monitoring Results for the Confined Aquifer

The uppermost (Rattlesnake Ridge) confined aquifer was monitored to determine the extent of ground-water interaction between the confined and unconfined aquifers. Intercommunication between aquifers was identified by Graham et al. (1984). Ground-water samples from the confined aquifer were analyzed for ^{3}H, NO_3^-, ^{129}I, and gamma-emitting radionuclides. Results for ^{3}H and NO_3^- are summarized in Tables C.39 and C.43, respectively. Wells open to the confined aquifer are indicated by footnotes in each table. In most cases, background levels of constituents were detected in these wells. Detection of radionuclides in well 299-E33-12 is attributed to contamination by high-salt waste that migrated by density flow into the borehole when it was open to both the

unconfined and the confined aquifer during drilling (Graham et al. 1984). Contaminant concentrations in this well were similar to those measured in previous years.

Intercommunication between the Rattlesnake Ridge confined aquifer and the unconfined aquifer north of the 200-East Area was indicated by the concentrations of NO_3^- in well 699-47-50. This well is located near an erosional window (i.e., near an area where the confining layer is absent) in the confining basalt flow (Graham et al. 1984). Elevated levels of tritium (3830 pCi/L) were present in ground water from the Rattlesnake Ridge interbed in well 699-42-40C. Elevated levels of ^{129}I (0.15 pCi/L) have previously been observed in the same well. The direct counting method employed in 1989 to analyze ^{129}I samples was not capable of detecting ^{129}I at levels below the DWS.

Ground-Water Quality Near Richland Water Supply Wells

During 1989, ground water from 12 monitoring wells in the southern portion of the Hanford Site was sampled and analyzed for hazardous chemicals and radiological constituents to assess water quality in the vicinity of the Richland water supply wells. Five of these monitoring wells were constructed adjacent to the North Richland well field by Westinghouse Hanford Company during 1988. No contaminants were observed in concentrations above the DWS.

Trace levels of a single organic constituent were observed in ground-water samples from well 11-41-13C. Samples contained 8 µg/L trichloroethane. The DWS for trichloroethane is 200 µg/L. The origin of trichloroethane in this well is uncertain. This region is currently being characterized through a remedial investigation under the Comprehensive Environmental Response, Compensation, and Liability Act.

6.0 Quality Assurance

6.0 QUALITY ASSURANCE

A comprehensive quality assurance (QA) program is maintained to ensure the quality of data collected through the surveillance programs. Quality assurance plans were developed for all surveillance activities that defined the appropriate controls and documentation required to meet DOE orders and the American Society of Mechanical Engineers NQA-1 QA program document.

In the surface- and ground-water surveillance programs, extensive environmental data were obtained to eliminate unrealistic reliance on only a few results. Newly collected data 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 ensure consistency. Samples were analyzed by documented standard analytical procedures. Data quality was verified by a continuing program of analytical laboratory quality control, participation in interlaboratory cross-checks, replicate sampling and analysis, and exchanging samples with other laboratories.

Ground-water surveillance included procedures for 1) documenting instrument calibrations and procedures used in the field and the laboratory, 2) scheduling maintenance of wells to ensure well integrity, 3) inspecting wells using downhole video cameras and other devices, and 4) using dedicated sampling pumps to avoid cross-contamination.

PNL QUALITY ASSURANCE

The surveillance programs and related programs such as processing of thermoluminescent dosimeters (TLDs) and dose calculations are subject to the overall PNL QA program. This program implements the requirements of DOE Order 5700.6B, "Quality Assurance," and is based on NQA-1, "Quality Assurance Program Requirements for Nuclear Facilities." The program is defined in the PNL QA manual (PNL 1989b). The manual provides guidance for implementation by addressing 18 QA elements. These are

1. Organization
2. Quality Assurance Program
3. Design Control
4. Procurement Document Control
5. Instructions, Procedures, and Drawings
6. Document Control
7. Control of Purchased Items and Services
8. Identification and Control of Items
9. Control of Processes
10. Inspection
11. Test Control
12. Control of Measuring and Test Equipment
13. Handling, Storage, and Shipping
14. Inspection, Test, and Operating Status
15. Control of Nonconforming Items
16. Corrective Action
17. Quality Assurance Records
18. Audits.

Each surveillance project has a current QA plan that describes the specific QA elements that apply to the project. These plans are monitored by the QA organization within PNL, which

conducts surveillances and audits to verify compliance with the plans. Work performed through contracts, such as sample analysis, must meet the same QA requirements and is reviewed through regular audits.

SAMPLE COLLECTION QUALITY ASSURANCE

Surface- and ground-water samples were collected by trained radiation protection technologists using documented procedures. Continuity of sampling locations was maintained through documentation in logbooks. Sample collection for chemical monitoring was performed according to written procedures. 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 the EPA for Resource Conservation and Recovery Act (RCRA) monitoring programs.

ANALYTICAL LABORATORY QUALITY ASSURANCE

Routine radiochemical analyses for environmental surveillance were performed by United States Testing Company, Inc. (UST). An internal quality control program maintained by UST involved routine calibration of counting instruments, frequent source and background counts, routine yield determinations of radiochemical procedures, replicate analyses to check precision, analysis of spiked samples, and analyses of reagents to ensure purity of chemicals. Quality assurance data were summarized by UST in quarterly and annual reports to PNL.

When available, calibration standards traceable to the National Institute of Standards and Technology were used for radiochemical calibrations. United States Testing Company, Inc., participated in the DOE Quality Assessment Program and EPA's Laboratory Intercomparison Studies Program. These programs provide standard samples of various environmental media (water, milk, air filters, soil, foodstuffs, and tissue ash) containing known amounts of one or more radionuclides. After sample analysis, the results were forwarded to DOE and EPA for comparison with known values and results from other laboratories. Both EPA and DOE have established criteria for evaluating the accuracy of results (Jarvis and Siu 1981; Sanderson 1985). These programs provided a way to evaluate results and identify where corrective actions were needed. Summaries of the 1989 UST results for the programs are provided in Tables 6.1 and 6.2. Tables C.46 and C.47 provide the analytical results on each sample analyzed by UST and the expected value. About 90% of the results during the year were within 3-sigma control limits (±3 standard errors of the mean). This level of performance was determined to be adequate to assess the expected concentrations of radionuclides in the environment. All PNL results were within 3-sigma control limits.

United States Testing Company, Inc., participated in the EPA Water Pollution Performance Evaluation Study Number 22. This study involved the analysis of standard water samples with known concentrations of nonradioactive water pollutants. The EPA gave UST an evaluation of excellent, with a score of 132 out of 134 samples (a 99% acceptance level).

In 1989, UST was under investigation by the EPA for alleged wrongdoing concerning EPA contract laboratory work. This investigation was not related to the work UST does on the Hanford Site. However, in light of the allegations, a detailed review of UST was performed to determine compliance with the contract

TABLE 6.1. United States Testing Company Performance on DOE Quality Assessment Program Samples in 1989

Sample Media	Radionuclides	Samples Analyzed	Number Within Control Limits[a]
Air Filters	^{7}Be, ^{54}Mn, ^{60}Co, ^{90}Sr, ^{125}Sb, ^{134}Cs, ^{137}Cs, ^{144}Ce, ^{239}Pu, ^{241}Am, ^{234}U, ^{238}U, U(mass)	22	19
Soil	^{40}K, ^{90}Sr, ^{137}Cs, ^{239}Pu, ^{234}U, ^{238}U, U(pCi), ^{241}Am	12	9
Vegetation	^{40}K, ^{90}Sr, ^{137}Cs, ^{239}Pu, ^{241}Am, ^{234}U, ^{238}U	13	11
Water	^{3}H, ^{54}Mn, ^{57}Co, ^{60}Co, ^{90}Sr, ^{134}Cs, ^{137}Cs, ^{144}Ce, ^{239}Pu, ^{241}Am, ^{234}U, ^{238}U, U(mass)	26	26

(a) Control limits from Sanderson (1985).

TABLE 6.2. United States Testing Company Performance on EPA Intercomparison Program Samples in 1989

Sample Media	Radionuclides	Samples Analyzed	Number Within Control Limits[a]
Water	Gross Alpha, Gross Beta, ^{51}Cr, ^{65}Zn, ^{60}Co, ^{106}Ru, ^{131}I, ^{134}Cs, ^{137}Cs	28	28
Water	^{226}Ra, ^{228}Ra, ^{238}U, U(nat), ^{239}Pu	14	14
Water	^{89}Sr, ^{90}Sr	8	8
Water	^{3}H	3	3
Milk	^{89}Sr, ^{90}Sr, ^{131}I, ^{137}Cs	3	3
Air filters	Gross Alpha, Gross Beta, ^{90}Sr, ^{137}Cs	6	6

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

requirements. The current UST contract was awarded in 1989. At that time, a pre-award QA survey showed four deficiencies and two observations. Corrective actions were accepted and the contract was awarded. A formal audit was conducted by the PNL Process Quality Department in 1989. The audit resulted in three findings and two observations. The corrective actions were accepted after a verification audit. No evidence indicated erroneous data as a result of analyses conducted by UST.

SURFACE MONITORING

In addition to DOE and EPA interlaboratory quality control and the laboratories' internal programs, a quality control program was maintained by PNL to evaluate precision and accuracy and to conduct special intercomparisons as necessary. All data were reviewed by a computerized data system that checked each entry against established limits.

Replicate samples were routinely collected to check sampling and analysis precision. Replicate data showed no significant deviations from results of previous years. Estimated precision (or reproducibility) of results (coefficient of variation) was generally less than 20% for samples with activities greater than 2.5 times the minimum detectable amount.

Each month, three pairs of dosimeters were exposed to known levels of radiation and processed. A summary of 1989 results is shown in Figure 6.1. An average bias of approximately +3.2% was observed between known and measured exposures. The bias was calculated from $\sum \left(\frac{\text{measured-known value}}{\text{known value}} \cdot 100\right)$.

During 1989, PNL and the State of Washington Department of Health (WDOH) shared 21 environmental dosimeter locations on and around

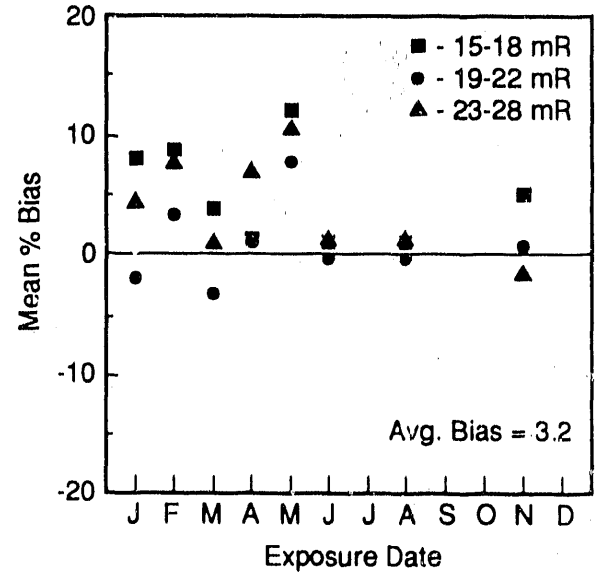


FIGURE 6.1. Comparison of Thermoluminescent Dosimeter Results with Known Exposures

the Hanford Site, the U.S. Ecology site, and the Washington Public Power Supply System WNP-2 Plant. The dosimeters were put in place and collected at the same times. Quarterly mean daily exposure rates determined by PNL and WDOH are shown in Table C.48, Appendix C. The difference between the PNL and WDOH dosimeter results $\left(\frac{\text{PNL-WDOH}}{\text{PNL}} \cdot 100\right)$ ranged from -33% to +55%. Results from PNL average 13% higher than WDOH results. There is no standard for an acceptable difference between co-located dosimeters. The low levels of radiation that are measured by a dosimeter result in wide variability. The 13% difference between the two measurements is not considered excessive. A joint sampling of Columbia River seep springs and wells was conducted in September 1989. Participants included the States of Washington and Oregon, Washington Public Power Supply System, Search Technical Associates, and PNL. Samples of water and vegetation were collected and divided among

the participants. Analytical results from all participants were not available at the printing of this report.

GROUND-WATER MONITORING

The ground-water monitoring program at PNL included a comprehensive approach to assess overall data quality. The effort consisted of evaluating various aspects of data analysis through blanks, duplicate samples, interlaboratory comparisons, and blind standards. Blanks were used to determine sample contamination, both during sampling and in the laboratory. Duplicate samples were submitted to indicate sampling and analysis variability. Interlaboratory comparisons involved duplicate samples taken at the sampling site and sent to one or more alternate laboratories for confirmatory analysis. Blind standards were submitted as ground-water samples to determine accuracy and precision for various analytical methods.

Four types of blank samples were submitted: bottle blanks to check for contamination arising from sample containers, trip blanks to check for both bottle and analysis contaminations, and two volatile organic analysis (VOA) blanks (i.e., transfer and transport blanks) specifically designed to check for volatile organic contamination arising during sampling or transport of volatile samples. Few blanks indicated contamination; of the few showing contamination, common laboratory volatile solvents were the attributed source.

Duplicate samples were collected and submitted on a regular basis to determine both sampling and analysis reproducibility and variability. Both sampling techniques and laboratory practices were highly reproducible for all analyses performed.

Interlaboratory comparisons (split samples submitted for analysis to an alternate laboratory) were made for common anions, volatile organics, metals, gross alpha, and gross beta. Sample results reported for these comparisons showed a high degree of correlation (i.e., PNL results compared well with UST results).

Blind standards for numerous constituents were submitted regularly to UST and PNL. Blind standards for VOAs were submitted monthly; anions, metals, and other organic and inorganic constituents were submitted quarterly. Blind standards were submitted as ground-water samples, for which the constituency and concentration were known to the supplier but not to the analyzing laboratory. Blind standards were used to assess accuracy but may also be used to assess precision. Analyses of blind standards showed that accuracy was good, with correlations between laboratories high.

United States Testing Company, Inc., also participated in performance evaluations sponsored by EPA for both water supply (drinking water) and water pollution (waste water) studies. These studies covered a range of constituents, including metals, anions, pesticides, herbicides, VOAs, and semi-volatiles. Performance by UST was generally very good.

References

REFERENCES

Note: DOE orders and acts mentioned in this report are listed following the references.

Beasley, T. M., L. A. Ball, and J. E. Andrews III. 1981. "Hanford-Derived Plutonium in Columbia River Sediments." **Science** 214(20):913-915.

Bisping, L. E. 1989. **Environmental Monitoring Master Sampling Schedule, January-December 1989**. PNL-6816, Pacific Northwest Laboratory, Richland, Washington.

Bjornstad, B. N., and K. R. Fecht. 1989. "Pre-Wisconsin Glacial-Outburst Floods: Pedogenic and Paleomagnetic Evidence from the Pasco Basin and Adjacent Channeled Scabland." **Geological Society of America Program** 21(5):58 (Abstract).

Chatters, J. C. 1989. **Hanford Cultural Resources Management Plan.** PNL-6942, Pacific Northwest Laboratory, Richland, Washington.

Coony, F. M., D. B. Howe, and L. J. Voight. 1988. **Westinghouse Hanford Company Effluent Releases and Solid Waste Management Report for 1987: 200/600/1100 Areas.** WHC-EP-0141, Westinghouse Hanford Company, Richland, Washington.

Corley, J. P., and C. B. Woolridge. 1969. **Evaluation of Radiological Conditions in the Vicinity of Hanford for 1967**. BNWL-983, Pacific Northwest Laboratory, Richland, Washington.

Corley, J. P. 1970. **Evaluation of Radiological Conditions in the Vicinity of Hanford for 1969**. BNWL-1505, Pacific Northwest Laboratory, Richland, Washington.

Corley, J. P. 1973. **Environmental Surveillance at Hanford for CY-1970**. BNWL-1669, Pacific Northwest Laboratory, Richland, Washington.

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

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

DOE - See U.S. Department of Energy.

Eberhardt, L. E., L. L. Cadwell, K. R. Price, and D. W. Carlile. 1989. **Trends in Radionuclide Concentrations for Selected Wildlife and Food Products Near the Hanford Site from 1971 Through 1988.** PNL-6992, Pacific Northwest Laboratory, Richland, Washington.

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

EPA - See U.S. Environmental Protection Agency.

Evans, J. C., R. W. Bryce, and D. R. Sherwood. 1989a. **Hanford Site Ground-Water Monitoring for January Through June 1988.** PNL-6886-1, Pacific Northwest Laboratory, Richland, Washington.

Evans, J. C., R. W. Bryce, D. R. Sherwood, M. L. Kemner, and D. R. Newcomer. 1989b. **Hanford Site Ground-Water Monitoring for July Through December 1988.** PNL-7120, Pacific Northwest Laboratory, Richland, Washington.

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

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

Fisher, W. L., and C. B. Wilson. 1970. **Evaluation of Radiological Conditions in the Vicinity of Hanford for 1968.** BNWL-1341, Pacific Northwest Laboratory, Richland, Washington.

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

Foster, R. F., and R. H. Wilson. 1964. **Evaluation of Radiological Conditions in the Vicinity of Hanford for 1963.** HW-80991, U.S. Atomic Energy Commission, Washington, D.C.

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

Foster, R. F. 1966. **Evaluation of Radiological Conditions in the Vicinity of Hanford for 1965.** BNWL-316, Pacific Northwest Laboratory, Richland, Washington.

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

Gee, G. W. 1987. **Recharge at the Hanford Site: Status Report.** PNL-6403, Pacific Northwest Laboratory, Richland, Washington.

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

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

Graham, M. J., M. D. Hall, S. R. Strait, and W. R. Brown. 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.

Honstead, J. F. 1967. **Evaluation of Radiological Conditions in the Vicinity of Hanford for 1966.** BNWL-439, Pacific Northwest Laboratory, Richland, Washington.

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

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

Jaquish, R. E., and P. J. Mitchell. 1988. **Environmental Monitoring at Hanford for 1987.** PNL-6464, Pacific Northwest Laboratory, Richland, Washington.

Jaquish, R. E., and R. W. Bryce. 1989. **Hanford Site Environmental Report for Calendar Year 1988.** PNL-6825, Pacific Northwest Laboratory, Richland, Washington.

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

Last, G. V., B. N. Bjornstad, M. P. Bergeron, D. W. Wallace, D. R. Newcomer, J. A. Schramke, M. A. Chamness, C. S. Cline, S. P. Airhart, and J. S. Wilbur. 1989. **Hydrogeology of the 200 Areas Low-Level Burial Grounds - An Interim Report.** PNL-6820, 2 volumes, Pacific Northwest Laboratory, 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.

Millikin, E. J. 1989. **Annual Status Report for the Plan and Schedule to Discontinue Disposal of Contaminated Liquid into the Soil Column at the Hanford Site.** WHC-ET-0196-2, Westinghouse Hanford Company, Richland, Washington.

Napier, B. A., R. A. Peloquin, D. L. Strenge, and J. V. Ramsdell. 1988a. **Conceptual Representation.** Volume 1 of **GENII - The Hanford Environmental Radiation Dosimetry Software System.** PNL-6584, Vol. 1, Pacific Northwest Laboratory, Richland, Washington.

Napier, B. A., R. A. Peloquin, D. L. Strenge, and J. V. Ramsdell. 1988b. **User's Manual.** Volume 2 of **GENII - The Hanford Environmental Radiation Dosimetry Software System.** PNL-6584, Vol. 2, Pacific Northwest Laboratory, Richland, Washington.

Napier, B. A., R. A. Peloquin, D. L. Strenge, and J. V. Ramsdell. 1988c. **Code Maintenance Manual.** Volume 3 of **GENII - The Hanford Environmental Radiation Dosimetry Software System.** PNL-6584, Vol. 3, Pacific Northwest Laboratory, Richland, Washington.

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

Pacific Northwest Laboratory (PNL). 1989a. **Procedures for Ground-Water Investigations.** PNL-6894, Pacific Northwest Laboratory, Richland, Washington.

Pacific Northwest Laboratory (PNL). 1989b. **Quality Assurance Manual.** PNL-7000, Pacific Northwest Laboratory, Richland, Washington.

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

Rathbun, L. A. 1989. **The Determination of the Penetrating Radiation Dose at Hanford.** PNL-7124, Pacific Northwest Laboratory, Richland, Washington.

Robertson, D. E., and J. J. Fix. 1977. **Association of Hanford Origin Radionuclides with Columbia River Sediment.** BNWL-2305, Pacific Northwest Laboratory, Richland, Washington.

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

Serkowski, J. A., W. A. Jordan, and A. G. Law. 1989. **Operational Ground Water Monitoring at the Hanford Site - 1988.** WHC-EP-0260, Westinghouse Hanford Company, Richland, Washington.

Smith, R. M., and W. R. Gorst. 1990. **RCRA Ground-Water Monitoring Projects for Hanford Facilities: Annual Progress Report for 1989.** PNL-7305, Pacific Northwest Laboratory, Richland, Washington.

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

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

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

Soldat, J. K. 1989. **Offsite Radiation Doses from Hanford Operations for the Years 1983 Through 1987: A Comparison of Results Calculated by Two Methods.** PNL-7135, Pacific Northwest Laboratory, Richland, Washington.

Somers, S. R. 1989. **Hanford Sanitary Water Quality Surveillance, CY-1988.** HEHF-74, Hanford Environmental Health Foundation, Richland, Washington.

Sommer, D. J., R. G. Rau, and D. C. Robinson. 1981. **Population Estimates for the Areas Within a 50-Mile Radius of Four Reference Points on the Hanford Site.** PNL-4010, Pacific Northwest Laboratory, Richland, Washington.

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.

Stenner, R. D., K. H. Cramer, K. A. Higley, S. J. Jette, D. A. Lamar, T. J. McLaughlin, D. R. Sherwood, and N. C. Van Houten. 1988. **Hazard Ranking System Evaluation of CERCLA Inactive Waste Sites at Hanford.** PNL-6456, Pacific Northwest Laboratory, Richland, Washington.

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

Sula, M. J., and K. R. Price. 1983. **PUREX Environmental Radiological Surveillance--Preoperational and Operational Support Program Conducted by Pacific Northwest Laboratory.** PNL-4822, Pacific Northwest Laboratory, Richland, Washington.

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

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

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

U.S. Department of Energy (DOE). 1987c. **Effluent Information System (EIS)/Onsite Discharge Information System (ODIS).** DOE/ID-187 (87), Idaho Operations Office, Idaho Falls, Idaho.

U.S. Department of Energy (DOE). 1988a. **Internal Dose Conversion Factors for Calculation of Dose to the Public.** DOE/EH-0071, DOE, Richland, Washington.

U.S. Department of Energy (DOE). 1988b. **External Dose-Rate Conversion Factors for Calculation of Dose to the Public.** DOE/EH-0070, DOE, Richland, Washington.

U.S. Department of Energy (DOE). 1988c. **SP-100 Ground System Test Site.** DOE/EA-0318, DOE, Washington, D.C.

U.S. Department of Energy (DOE). 1989a. **Tier Two Emergency and Hazardous Chemical Inventory.** DOE/RL 89-04, DOE, Richland, Washington.

U.S. Department of Energy (DOE). 1989b. **Toxic Chemical Release Inventory.** DOE/RL 89-11, DOE, Richland, Washington.

U.S. Department of Energy (DOE). 1989c. **Environmental Restoration and Waste Management Five-Year Plan.** DOE/S-0070, DOE, Washington, D.C.

U.S. Department of Energy (DOE). 1989d. **Implementation Plan for Hanford Site Compliance with U.S. Department of Energy Order 5820A.** DOE/RL 89-05, DOE, Richland, Washington.

U.S. Department of Energy (DOE). 1989e. **Decommissioning the Eight Shutdown Production Reactors Located at the Hanford Site, Richland, Washington.** DOE/EIS-0119D, DOE, Richland, Washington.

U.S. Department of Energy (DOE). 1990. **Hanford Site Annual Dangerous Waste Report for 1989.** DOE/RL 90-10, DOE, Richland, Washington.

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

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

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

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

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

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

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

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

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

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

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

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

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

U.S. Environmental Protection Agency (EPA). 1987c. **Environmental Radiation Data.** Report 49, January 1987 - March 1987, EPA 520/5-87-018, Office of Radiation Programs, Eastern Environmental Radiation Facility (EERF), Montgomery, Alabama.

U.S. Environmental Protection Agency (EPA). 1987d. **Environmental Radiation Data.** Report 50, April-June 1987, EPA 520/5-88-001, Office of Radiation Programs, Eastern Environmental Radiation Facility (EERF), Montgomery, Alabama.

U.S. Environmental Protection Agency (EPA). 1988a. **Environmental Radiation Data.** Report 51, July-September 1987, EPA 520/5-88-013, Office of Radiation Programs, Eastern Environmental Radiation Facility (EERF), Montgomery, Alabama.

U.S. Environmental Protection Agency (EPA). 1988b. **Environmental Radiation Data.** Report 52, October-December 1987, EPA 520/5-88-054, Office of Radiation Programs, Eastern Environmental Radiation Facility (EERF), Montgomery, Alabama.

U.S. Environmental Protection Agency (EPA). 1988c. **Environmental Radiation Data.** Report 53, January-March 1988, EPA 520/5-88-057, Office of Radiation Programs, Eastern Environmental Radiation Facility (EERF), Montgomery, Alabama.

U.S. Environmental Protection Agency (EPA). 1988d. **Off-Site Environmental Monitoring Report, Radiation Monitoring Around United States Nuclear Test Areas, Calendar Year 1987.** EPA-60014-88-021, Environmental Monitoring Systems Laboratory, Las Vegas, Nevada.

U.S. Environmental Protection Agency (EPA). 1988e. **National Emission Standard for Hazardous Air Pollutants; Standards for Radionuclides.** 40 CFR 61, U.S. Government Printing Office, Washington, D.C.

U.S. Environmental Protection Agency (EPA). 1989a. **Off-Site Environmental Monitoring Report, Radiation Monitoring Around United States Nuclear Test Areas, Calendar Year 1988.** EPA-60014-89-019, Environmental Monitoring Systems Laboratory, Las Vegas, Nevada.

U.S. Environmental Protection Agency (EPA). 1989b. **Environmental Radiation Data.** Report 57, January-March 1989, EPA 520/5-89-021, Office of Radiation Programs, Eastern Environmental Radiation Facility (EERF), Montgomery, Alabama.

U.S. Environmental Protection Agency (EPA). 1989c. **Environmental Radiation Data.** Report 58, April-June 1989, EPA 520/5-89-034, Office of Radiation Programs, Eastern Environmental Radiation Facility (EERF), Montgomery, Alabama.

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

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

U.S. DEPARTMENT OF ENERGY ORDERS

DOE Order 5484.1, 1981, "Environmental Protection, Safety, and Health Protection Information Reporting Requirements."

DOE Order 5440.1C, 1985, "The National Environmental Policy Act."

DOE Order 5480.1B, 1986, "Environmental Safety and Health Programs for DOE Operations."

DOE Order 5700.6B, 1986, "Quality Assurance."

DOE-RL Order 5440.1A, 1987, "Implementation of the National Environmental Policy Act at the Richland Operations Office."

DOE Order 5400.1, 1988, "General Environmental Protection Program."

DOE Order 5820.2A, 1988, "Radioactive Waste Management."

ACTS

American Indian Religious Freedom Act. Public Law 95-341, August 11, 1978, 92 Stat 469, Title 42.

Archaeological Resources Protection Act of 1979. Public Law 96-95, October 31, 1979, 93 Stat 721, Title 16.

Atomic Energy Act of 1946. August 1, 1946, ch. 724, 60 Stat 755.

Atomic Energy Act of 1954. August 30, 1954, ch. 1073, 68 Stat 919, Title 42.

Clean Air Act. 1986. Public Law 88-206, as amended, 42 USC 7401 et seq.

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

National Environmental Policy Act (NEPA). 1969. Public Law 91-190, as amended, 42 USC 4321 et seq.

National Historic Preservation Act. Public Law 89-665, October 15, 1966, 80 Stat 915-919, Title 16.

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

Safe Drinking Water Act. Public Law 93-523, December 16, 1974, 88 Stat 1660, Title 21.

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

Toxic Substances Control Act. Public Law 94-469, as amended, 15 USC 2601 et seq.

BIBLIOGRAPHY OF PREVIOUSLY ISSUED PNL ENVIRONMENTAL MONITORING REPORTS

Reports for the Offsite Environment

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

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

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

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

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

Reports for the Onsite Environment

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

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

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

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

Reports for the Onsite Ground Water

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

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

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

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

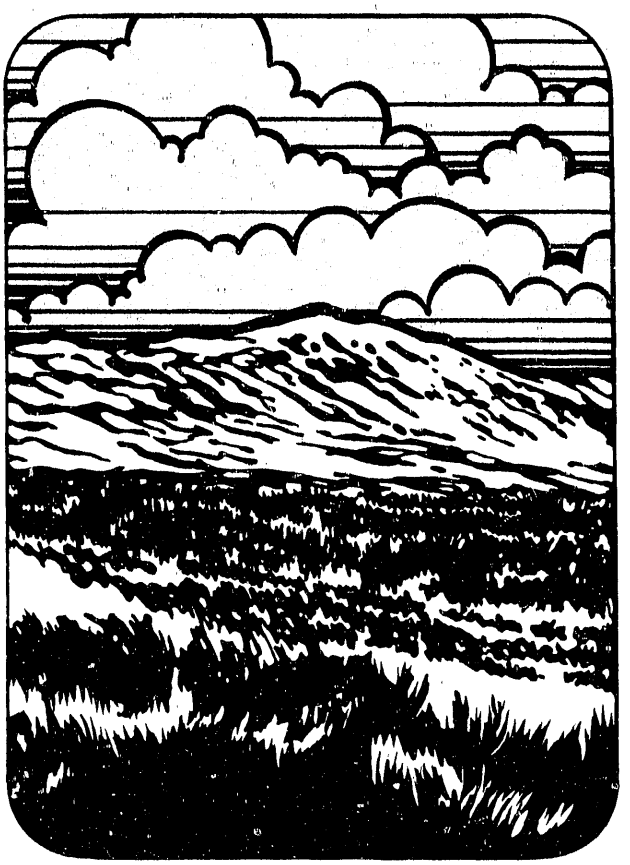
Cline, C. S., J. T. Rieger, and J. R. Raymond. 1985. **Ground-Water Monitoring at the Hanford Site, January-December 1984**. PNL-5408, Pacific Northwest Laboratory, Richland, Washington.

Combined Report

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

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

Jaquish, R. E., and P. J. Mitchell. 1988. **Environmental Monitoring at Hanford for 1987**. PNL-6464, Pacific Northwest Laboratory, Richland, Washington.



Appendixes

APPENDIX A

GLOSSARY

APPENDIX A

GLOSSARY

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

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

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

Background Radiation - Radioactivity in the environment, including cosmic rays from space and radiation that exists elsewhere in the air, in the earth, and in manmade materials that surround us. In the United States, the average person receives about 300 millirems (mrem) of background radiation per year.

Bankstorage - Hydrologic term that describes river water that flows into and is retained in permeable stream banks during periods of high river stage. Flow is reversed during periods of low river stage.

Becquerel (Bq) - Unit of activity equal to one nuclear transformation per second (1 Bq = 1 s^{-1}). The former special-named unit of activity, the curie, is related to the becquerel according to 1 Ci = 3.7×10^{10} Bq.

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

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

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

Controlled Area - An area to which access is controlled to protect individuals from exposure to radiation or radioactive and/or hazardous materials.

Cosmic Radiation - High-energy subatomic particles and electromagnetic radiation from outer space that bombard the earth. Cosmic radiation is part of natural background radiation.

Counting Error - Variability caused by the inherent random nature of radioactive disintegration and the detection process.

Curie (Ci) - A unit of radioactivity equal to 37 billion (3.7×10^{10}) nuclear disintegrations per second.

Derived Concentration Guides (DCG) - Concentrations of radionuclides in air and water that could be continuously consumed or inhaled and not exceed an effective dose equivalent of 100 mrem/yr.

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

Dispersion - Process whereby effluents are spread or mixed as they are transported by ground water or air.

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

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

Effluent - Liquid or gaseous waste streams released to the environment from a facility.

Effluent Monitoring - Sampling or measuring specific liquid or gaseous effluent streams for the presence of pollutants.

Exposure - Subjecting a target (usually living tissue) to radiation or chemicals.

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

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

Fission (fissioned) - Splitting or breaking apart a nucleus into at least two other nuclei. For example, when a heavy atom, such as uranium, is split, large amounts of energy including radiation and neutrons are released.

Fission Products - Elements or compounds formed from fissioning. Many fission products are radioactive.

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

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

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

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

Half-Life - Length of time in which a radioactive substance will lose one half of its radioactivity. Half-lives range from a fraction of a second to millions of years.

Ion Exchange - The reversible exchange of ions for different ions in solution.

Isotopes - Different forms of the same chemical element that are distinguished by 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 will exist for an extended period.

- **Short-Lived Isotope** - A radionuclide that decays so rapidly that a given quantity is transformed almost completely into decay products within a short period.

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

Lithology - Description of the physical characteristics of rocks that make up geologic units.

This description may include such characteristics as color, mineralogic composition, and grain size.

Maximally Exposed Individual - Hypothetical individual who remains in an uncontrolled area and would receive the greatest possible effective dose equivalent when all potential routes of exposure from a facility's operations are considered.

Mean - Average value of a series of measurements.

Median - Middle value in a set of results when the data are ranked in increasing or decreasing order.

Millirem (mrem) - A unit of radiation dose equivalent that is equal to one one-thousandth of a rem. An individual member of the public can receive up to 100 mrem per year according to DOE standards. This limit does not include radiation received for medical treatment or the approximately 300 mrem that people receive annually from background radiation.

Minimum Detectable Concentration - Smallest amount or concentration of a radioactive or nonradioactive element that can be reliably detected in a sample.

Noble Gas - Any of a group of chemically and biologically inert gases that includes krypton and xenon. These gases are not retained in the body following inhalation. The principal exposure pathways from radioactive noble gases are direct external dose from the surrounding air (see "Air Submersion Dose") and internal irradiation while the inhaled air is in the lung.

Offsite Locations - Sampling and measurement locations outside the Hanford Site boundary.

Onsite Locations - Sampling and measurement locations within the Hanford Site boundary.

Outfall - End of a drain or pipe that carries waste water or other effluents into a ditch, pond, or river.

Plume - Distribution of a pollutant in air or water after being released from a source.

Plutonium - A heavy, radioactive, manmade metallic element. One important isotope is ^{239}Pu, which is produced by the irradiation of ^{238}U. Routine analysis cannot distinguish between the ^{239}Pu and ^{240}Pu isotopes, hence, the term $^{239,240}Pu$.

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

Radiation - The process of emitting energy in the form of rays or particles such as those thrown off by disintegrating atoms. The rays or particles emitted may consist of alpha, beta, or gamma radiation.

> **Alpha Radiation** - Least penetrating type of radiation. Alpha radiation can be stopped by a sheet of paper or the outer dead layer of skin.
>
> **Beta Radiation** - One form of radiation emitted from a nucleus during radioactive decay. Beta radiation can be stopped by an inch of wood or a thin sheet of aluminum.
>
> **External Radiation** - Radiation originating from a source outside the body, such as cosmic radiation or natural and manmade radionuclides.

Gamma Radiation - Form of electromagnetic, high-energy radiation emitted from a nucleus. Gamma rays are essentially the same as x-rays and require heavy shieldings, such as concrete or steel, to be stopped.

Gray (Gy) - Unit of absorbed dose in the International System of Units (SI) equal to 1 joule per kilogram. 1 Gy = 100 rad.

Internal Radiation - Radiation originating from a source within the body as a result of the inhalation, ingestion, or implantation of natural or manmade radionuclides in body tissues.

Radiation Dose - For the purpose of this report, radiation doses are defined as follows:

Absorbed Dose - Amount of energy deposited by radiation in a given amount of material. Absorbed dose is measured in units of "rads" or "gray." (See "Dose Equivalent" below.)

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

Committed Dose Equivalent - Total dose equivalent accumulated in an organ or tissue in the 50 years following a single intake of radioactive materials into the body.

Cumulative Dose Equivalent - Total dose one could receive in a period of 50 years following release of the radionuclides to the environment, including the dose that could occur as a result of residual radionuclides remaining in the environment beyond the year of release.

Dose Equivalent - Product of the absorbed dose, the quality factor, and any other modifying factors. The dose equivalent is a quantity for comparing the biological effectiveness of different kinds of radiation on a common scale. The unit of dose equivalent is the rem. A millirem is one one-thousandth of a rem.

Effective Dose Equivalent - An estimate of the total risk of potential health effects from radiation exposure. This estimate is the sum of the committed effective dose equivalent from internal deposition and the effective dose equivalent from external penetrating radiation received during a calendar year. The committed effective dose equivalent is the sum of the individual organ committed dose equivalents (50 year) multiplied by weighting factors that represent the proportion of the total random risk that each organ would receive from uniform irradiation of the whole body.

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

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

Radionuclide - Radioactive nuclide. There are several hundred known radioactive nuclides, both manmade and naturally occurring. Nuclides are characterized by the number of neutrons and protons in an atom's nucleus.

Rem - Acronym for Roentgen Equivalent Man; a unit of dose equivalent that indicates the potential impact on human cells.

Roentgen - Unit of x-ray or gamma radiation exposure in air. Exposure of 1 Roentgen (R) is approximately equal to 1 rem dose to human tissue.

Sievert (Sv) - Unit of dose equivalent in the International System of Units (SI) equal to 1 joule per kilogram. 1 Sv = 100 rem.

Spent Fuel - Nuclear fuel that has been exposed in a nuclear reactor; this fuel contains uranium, activation products, fission products, and plutonium. At Hanford, spent fuel is processed in the Plutonium Uranium Extraction (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 Dosimeter (TLD) - A material that, after being exposed to radiation, emits light when heated. The amount of light emitted is proportional to the amount of radiation (dose) to which the TLD has been exposed.

Unconfined Aquifer - An aquifer containing ground water that is not confined above by relatively impermeable rocks. The pressure at the top of the unconfined aquifer is equal to that of the atmosphere. At Hanford, the unconfined aquifer is the uppermost aquifer and is most susceptible to contamination from Site operations.

Uncontrolled Area - Area on or near a nuclear facility to which public access is not restricted.

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

Whole-Body Dose - Radiation dose that involves exposure of the entire body. Whole-body dose is composed of internal and external radiation.

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

$\overline{X}$/Q' (chi over que) - A dispersion factor calculated from average annual meteorological data using an atmospheric dispersion model. This factor is used to estimate the air concentration from the rate of release of a radionuclide to the air. The resulting estimates of average annual air concentrations at specific locations away from the source can be used to calculate potential doses.

APPENDIX B

APPLICABLE STANDARDS AND PERMITS AND ENVIRONMENTAL COMPLIANCE DOCUMENTATION

APPENDIX B

APPLICABLE STANDARDS AND PERMITS AND ENVIRONMENTAL COMPLIANCE DOCUMENTATION

Operations at the Hanford Site must conform to a variety of federal and state standards and permits designed to ensure the radiological, chemical, biological, and physical quality of the environment for either aesthetic or public health considerations. Standards and permits applicable to Hanford operations in 1989 are listed in the following tables. The State of Washington has promulgated water quality standards for the Columbia River (WDOE 1982). Of interest to Hanford operations is the designation of the Hanford Reach of the Columbia River as Class A (Excellent). This designation requires that the water be usable for substantially all needs, including drinking water, recreation, and wildlife. Class A water standards are summarized in Table B.1. Drinking water standards promulgated by the EPA (EPA 1976) are summarized in Tables B.2 and B.3. Benton-Franklin-Walla Walla Counties Air Pollution Control Authority air quality standards are shown in Table B.4. Environmental radiation protection standards are published in DOE Order 5480.1A, "Environmental Protection, Safety, and Health Protection Program for DOE Operations." These standards are based on guidelines originally recommended by the Federal Radiation Council and other scientific groups, such as the International Commission on Radiological Protection and the National Council on Radiation Protection and Measurements. In September 1985, the DOE issued a revision to this order that incorporates a system for evaluating and controlling radiation exposures to members of the public in uncontrolled areas. The revised standards are shown in Table B.5, which also includes standards pursuant to the Clean Air Act for sources of radionuclide emissions to the air (EPA 1983). These standards govern allowable exposures to ionizing radiation from DOE operations.

The DOE has also prepared draft tables of Derived Concentration Guides (DCGs) that reflect the concentrations of individual nuclides in water or air that would result in an effective dose equivalent of 100 mrem caused by ingestion of water or inhalation (Table B.6). The DCGs are useful reference values but do not generally represent concentrations that ensure compliance with either the DOE or the Clean Air Act dose standards.

Permits required for regulated releases to water and air have been issued by the EPA under the National Pollution Discharge Elimination System (NPDES) of the Clean Water Act and the Prevention of Significant Deterioration (PSD) requirements of the Clean Air Act. Permits for collecting wildlife for environmental sampling are issued by the Washington State Department of Wildlife and the U.S. Fish and Wildlife Service. Current permits are listed in Table B.7.

TABLE B.1. Washington State Water Quality Standards for the Hanford Reach of the Columbia River

Parameter	Permissible Levels
Fecal coliform	1) ≤100 organisms/100 mL 2) ≤10% of samples may exceed 200 organisms/100 mL
Dissolved oxygen	>8 mg/L
Temperature	1) ≤20°C (68°F) due to human activities 2) When natural conditions exceed 20°C, no temperature increase of greater than 0.3°C allowed. 3) Increases not to exceed 34/(T+9), where T = highest existing temperature in °C outside of dilution zone.
pH	1) 6.5 to 8.5 range 2) <0.5 unit induced variation
Turbidity	≤5 NTU[a] over background turbidity
Toxic, radioactive, or deleterious materials	Concentrations shall be below those of public health significance, or which cause acute or chronic toxic conditions to the aquatic biota, or which may adversely affect any water use.
Aesthetic value	Shall not be impaired by the presence of materials or their effects, excluding those of natural origin, which offend the senses of sight, smell, touch, or taste.

(a) NTU = nephelometric turbidity units.

TABLE B.2. Radiological Drinking Water Standards: U.S. Environmental Protection Agency, National Interim Primary Drinking Water Regulations; and State of Washington, Rules and Regulations of the State Board of Health Regarding Public Water Systems

Contaminant	Limit
Gross alpha (excluding uranium)	15 pCi/L
Combined ^{226}Ra and ^{228}Ra	5 pCi/L
Radium-226 (State of Washington only)	3 pCi/L
Gross beta and gamma radioactivity from manmade radionuclides	Annual average concentration shall not produce an annual dose from manmade radionuclides equivalent to the total body or any internal organ dose greater than 4 mrem/yr. If two or more radionuclides are present, the sum of their annual dose equivalents shall not exceed 4 mrem/yr. Compliance may be assumed if annual average concentrations for gross beta activity, ^{3}H, and ^{90}Sr are less than 50, 20,000, and 8 pCi/L, respectively.

The following list provides the annual average concentrations for manmade radionuclides of interest. These radionuclides are assumed to yield an annual dose of 4 mrem to the indicated organ. Data are taken from the National Interim Primary Drinking Water Regulations, Table IV-2A (EPA 1976).

Radionuclide	Critical Organ	Concentration, pCi/L
^{3}H	Whole body	20,000
^{14}C	Fatty tissue	2,000
^{60}Co	GI (LLI)[a]	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
^{99}Tc	GI (LLI)	900
^{103}Ru	GI (LLI)	200
^{106}Ru	GI (LLI)	30
^{125}Sb	GI (LLI)	300
^{129}I	Thyroid	1
^{131}I	Thyroid	3
^{134}Cs	GI (S)[b]	20,000
^{137}Cs	Whole body	200

(a) Gastrointestinal tract (lower large intestine).
(b) Stomach.

TABLE B.3. Chemical Drinking Water Standards: U.S. Environmental Protection Agency, *National Interim Primary Drinking Water Regulations* (EPA 1976); and State of Washington, *Public Water Supplies* (WDSHS 1983)

Chemical Constituent	Concentration
As	50 μg/L
Ba	1 mg/L
Cd	10 μg/L
CCl_4	5 μg/L
Cr	50 μg/L
Cu	1 mg/L
F	2 mg/L
Hg	2 μg/L
NO_3^-	45 mg/L
Pb	50 μg/L
Se	10 μg/L

TABLE B.4. Benton-Franklin-Walla Walla Counties Air Pollution Control Authority Ambient Air Quality Standards[a]

Parameter	Type of Standard[b]	Sampling Period	Permissible Level
NO_2	Secondary and primary	Annual average	0.05 ppm

(a) Benton-Franklin-Walla Walla Counties Air Pollution Control Authority 1980.
(b) Primary standards for ambient air quality define levels of air quality to protect the public health. Secondary standards define levels of air quality to protect the public welfare from any known or anticipated adverse effects of a pollutant.

TABLE B.5. Radiation Standards for Protection of the Public in the Vicinity of DOE Facilities

DOSE LIMITS

ALL PATHWAYS

The effective dose equivalent for any member of the public from all routine DOE operations[a] (natural background and medical exposures excluded) shall not exceed the values given below.[b]

	Effective Dose Equivalent[c]	
	mrem/yr	(mSv/yr)
Occasional Annual Exposures	500	(5)
Prolonged Period of Exposure[d]	100	(1)

No individual organ shall receive a committed effective dose equivalent of 5 rem/yr (50 mSv/yr) or greater.

AIR PATHWAYS ONLY [Limits from 40 CFR 61 (DOE 1988e)]

	Dose Equivalent	
	mrem/yr	(mSv/yr)
Whole-Body Dose	25	(0.25)
Any Organ	75	(0.75)

(a) "Routine DOE operations" implies normal, planned operations and does not include actual or potential accidental or unplanned releases.
(b) Memo from W. A. Vaughan, Assistant Secretary for Environment, Safety and Health, U.S. Department of Energy, to DOE Field Offices, August 5, 1985.
(c) Effective dose equivalent is expressed in rem (or millirem) with the corresponding value in sievert (or millisievert) in parentheses.
(d) For the purposes of these standards, a prolonged exposure is one that lasts, or is predicted to last, longer than 5 years.

TABLE B.6. Derived Concentration Guides[a,b,c]

Radionuclide	Water, pCi/L (10^{-9} µCi/mL)	Air, pCi/m^3 (10^{-12} µCi/mL)
^{3}H	2,000,000	200,000
$^{14}C(CO_2)$	70,000	500,000
^{51}Cr	1,000,000	60,000
^{54}Mn	50,000	2,000
^{60}Co	5,000	80
^{65}Zn	9,000	600
^{85}Kr	NS	60,000
^{89}Sr	20,000	300
^{90}Sr	1,000	9
^{99}Tc	100,000	2,000
^{103}Ru	50,000	2,000
^{106}Ru	6,000	30
^{125}Sb	60,000	1,000
^{129}I	500	70
^{131}I	3,000	400
^{137}Cs	3,000	400
^{144}Ce	7,000	30
^{234}U	500	0.09
^{235}U	600	0.1
^{238}U	600	0.1
^{238}Pu	400	0.03
^{239}Pu	300	0.02

(a) Concentrations of radionuclides in water and air that could be continuously consumed or inhaled and not exceed a committed effective dose equivalent of 100 mrem/yr.
(b) Values from May 6, 1987, memo from R. E. Gerton, Director, DOE Environment, Safety, and Health Division to Hanford contractors.
(c) Derived from DOE Order 5480.1A (DOE 1981).
NS No standard.

TABLE B.7. Environmental Permits

NPDES Permits

NPDES Permit No. WA-000374-3, issued to the DOE-Richland Operations Office by Region 10 of the EPA, covers nonradioactive discharges to the Columbia River from eight outfalls. The following are measurements required for NPDES-permitted discharges at Hanford:

	Location		
Measurement	100-K Area (2 discharges)	100-N Area (5 discharges)	300 Area (1 discharge)
Flow Rate	X	X	X
Suspended Solids	X	X	X
Temperature	X	X	---[a]
pH	X	X	X
Chlorine	X	X	---
Oil and Grease	---	X	---
Heat Discharged	---	X	---
Settleable Solids	---	---	X
Iron	---	X	---
Ammonia	---	X	---
Chromium	---	X	---

(a) Dashed line indicates no measurement required.

PSD Permits

PSD Permit No. PSD-X80-14, issued to the DOE-Richland Operations Office by Region 10 of the EPA, covers emission of NO_x to the atmosphere from the Plutonium Uranium Extraction (PUREX) Plant and the Uranium Oxide (UO_3) Plant. No expiration date.

Wildlife Sampling Permits

Scientific Study or Collection Permit No. 040, issued by Washington State Department of Wildlife to Pacific Northwest Laboratory for 1989, 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. No expiration date.

Copies of the regulations concerning NPDES, PSD, and wildlife sampling permits may be obtained from the following organizations:

State of Washington
Department of Ecology
Olympia, WA 98504

U.S. Environmental Protection Agency
Region 10
1200 Sixth Avenue
Seattle, WA 98101

U.S. Department of Energy
Richland Operations Office
Richland, WA 99352

APPENDIX C

MONITORING RESULTS FOR 1989

TABLE C.1. Strontium-90 (^{90}Sr) Concentrations in Canada Goose Eggshells, pCi/g Dry Weight, from Island 12 (Plow Island) in the Columbia River, 1986-1989

	1986	1987	1988	1989	Total
	0.67	1.95	2.13	0.95	
	0.91	1.51	1.28	1.65	
	0.99	1.15	0.82	1.26	
	1.20	1.71	1.14	0.91	
	0.49	1.49	1.67	2.25	
	1.58	0.58	0.95	1.18	
	1.01	1.75	1.43	0.46	
	0.65	1.41	2.04	1.28	
	0.86	1.08	1.06	2.87	
	0.86	0.65	0.66	1.03	
	1.15	1.62	2.07	1.87	
	1.14	1.30	2.45	1.24	
	0.71	0.84		0.76	
	1.39	0.90		0.35	
	0.53			0.71	
	1.88				
No. of samples =	16	14	12	15	57
Average =	1.00	1.49	1.47	1.25	1.3
Maximum =	1.58	1.95	2.13	2.87	
Minimum =	0.49	0.58	0.66	0.35	

TABLE C.2. Monthly Climatological Data from the Hanford Meteorology Station for 1989

	Temperatures (°C)								Precipitation (cm)				Relative Humidity (%)		50-Foot Wind[a]				
	Averages				Extremes						Snowfall						Peak Gusts		
Month	Daily Minimum	Daily Maximum	Monthly	Departure[b]	Highest	Date	Lowest	Date	Total	Departure	Total	Departure	Average	Departure	Average Speed (km/h)	Departure	Speed (km/h)	Direction	Date
J	7.5	-1.7	2.9	+3.9	19.4	30	-9.4	24	0.5	-1.9	0.5	-13.2	72.2	-4.2	10.5	0	93	SW	16
F	2.2	-7.4	-2.6	-5.8	11.7	27	-20.6	5	4.2	+2.8	43.2	+38.6	74.8	+4.1	8.4	-3.1	63	NNE	3
M	12.2	0.9	6.6	-0.3	19.4	11	-10.0	3	4.0	+3.0	7.9	+6.6	65.1	+9.2	10.0	-3.9	68	WSW	21
A	20.9	6.4	13.7	+2.4	26.7	14+[c]	1.7	3	2.1	+1.1	T[d]	0	47.6	+0.7	11.9	-2.9	79	W	19
M	23.6	9.2	16.4	+0.1	31.1	31+	3.9	18	1.5	+0.2	T	0	44.5	+1.5	11.4	-2.9	79	WSW	17
J	30.1	14.3	22.2	+1.5	36.1	5	7.8	17	T	-1.1	-[e]		33.7	-6.0	12.7	-2.3	69	NE	3
J	32.8	15.5	24.2	-0.6	38.3	14	9.4	4	T	-0.4	-		34.3	+2.1	11.3	-2.6	69	WSW	31
A	30.6	15.4	23.0	-0.7	39.4	7	11.1	25	0.7	-0.1	-		41.1	+5.5	9.8	-3.1	68	W	27
S	28.4	11.2	19.8	+0.8	34.4	15	6.7	19	0.1	-0.7	-		37.0	-4.6	9.8	-2.1	68	SSE	25
O	18.9	5.6	12.2	+0.5	26.7	10+	-2.8	29	1.1	-0.1	0	0	54.7	-2.1	8.4	-1.9	74	WSW	23
N	11.3	2.4	6.8	+2.7	22.8	10+	-6.1	29	2.6	+0.6	0	-3.6	73.4	0	9.7	0	66	WSW	9
D	3.3	-1.9	0.7	+0.1	14.4	8	-7.2	13	0.7	-1.7	3.6	-8.1	88.5	+8.5	6.3	-3.5	58	SW	8
Y[f]	18.5	5.8	12.2	+0.4	39.4	Aug 7	-20.6	Feb 5	17.5	+1.7	55.2	+20.3	55.6	+1.2	10.0	-2.4	93	SW	Jan 16

(a) Measured on a tower fifty feet above the ground.
(b) Departure columns indicate positive or negative departure of meteorological parameters from 30-year (1951-1980) climatological normals.
(c) + after date indicates latest of several occurrences.
(d) Trace.
(e) - No record of any snowfall during these months.
(f) Yearly averages, extremes, and totals.

TABLE C.3. Temperature Summary of Monthly and Annual Temperatures (°C) from the Hanford Telemetry Network for 1989

Stn Nbr	Station Name	Month												
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1	ProsBrcd	2.4	-3.7	6.3	13.2	15.8	20.9	22.3	22.1	18.3	10.8	6.7	1.3	11.4
2	EOC	2.7	-3.2	5.8	12.9	15.3	20.6	22.1	21.9	19.7	12.0	6.7	0.1	11.4
3	ArmyLoop	2.4	-3.3	6.3	13.5	BD	BD	BD	22.2	19.3	11.4	6.9	0.2	*
4	RsnkSpr	2.6	-3.2	6.3	13.2	16.3	21.2	22.5	22.4	19.1	11.4	6.9	0.4	11.6
5	Edna	2.2	-3.6	6.5	13.4	15.9	20.9	22.5	22.3	18.7	11.5	6.6	0.4	11.4
6	200-E	2.7	-3.2	6.6	14.0	16.6	21.6	23.2	22.9	20.0	12.2	7.2	0.6	12.0
7	200-W	2.1	-3.2	6.2	13.1	16.1	21.2	22.7	22.5	18.3	10.6	6.6	0.0	11.4
8	Wahluk	2.1	-3.1	5.8	13.2	15.3	19.5	20.8	21.3	18.8	11.1	5.8	0.3	10.9
9	FFTF	2.7	-3.7	6.6	13.6	16.1	21.1	22.4	22.5	19.2	11.7	6.9	0.4	11.6
10	Ykm Brcd	1.7	-3.4	5.4	12.9	15.8	20.8	22.4	22.4	19.2	11.1	5.9	-0.4	11.2
11	300 Area	3.1	-3.6	6.8	13.6	15.9	20.9	22.1	22.1	18.5	11.3	7.2	0.8	11.6
12	Wye Brcd	1.8	-3.9	5.9	13.1	15.5	20.6	22.0	21.9	18.6	10.9	6.2	-0.4	11.0
13	100-N	2.1	-4.5	6.3	13.4	16.1	21.1	22.4	22.4	18.9	11.6	6.4	0.6	11.4
14	WPPSS	2.3	-3.7	6.4	13.3	15.6	20.9	22.3	22.1	18.4	10.9	6.7	0.2	11.3
15	FrankCty	2.6	-3.8	6.0	13.0	14.7	19.1	20.7	20.9	18.2	10.9	6.5	0.1	10.7
16	GableMtn	1.8	-3.5	5.2	12.9	15.1	20.2	21.7	21.7	19.6	11.6	5.9	-0.7	11.0
17	Ringold	2.1	-3.7	6.3	12.9	15.1	19.5	20.6	20.6	16.8	10.5	6.1	-0.6	10.5
18	Rich Arpt	3.7	-3.3	7.0	13.9	16.3	20.9	22.2	22.3	19.0	11.9	7.7	1.1	11.9
19	Sagehill	2.0	-3.4	5.8	13.0	14.9	19.3	20.6	20.6	18.4	10.9	5.8	0.2	10.6
20	RsnkMtn	-0.8	-4.5	1.0	8.1	9.9	15.1	17.4	16.9	15.6	7.9	1.8	0.5	7.4
21	HMS	2.2	-3.9	5.9	13.3	16.1	21.1	22.5	22.5	19.4	11.5	6.5	0.1	11.4
22	PascoArpt	3.8	-3.2	7.3	13.9	16.4	21.1	22.3	22.4	18.4	11.6	8.2	1.1	11.9
23	Gable-W	1.8	-3.8	5.6	12.4	15.6	20.7	22.2	22.0	18.1	10.3	6.4	-0.7	10.9
24	100-F	2.4	-3.3	6.8	13.6	16.1	21.3	22.6	22.5	18.9	11.4	6.7	0.7	11.6
25	Vernita	2.1	-3.6	5.8	12.9	15.9	20.6	22.4	22.6	19.3	11.7	6.3	0.2	11.4

BD Bad data.
* Incomplete record due to bad data.

TABLE C.4. Air Sampling Locations and Sample Composite Groups

Composite Group	Sampling Location	Map Location[a]
ON SITE		
100 Areas	100-K	1
	100-N	2
	100-D	3
	Fire Station	4
200-East Area	S of 200-East	5
	E of 200-East	6
	200-East SE	7
North of 200 Areas	Rt. 11A, Mi. 9	8
	N of 200-East	9
200-West Area	SW of BC Cribs	10
	Army Loop Camp	11
	GTE Building	12
200-West SE	200-West SE	13
300 Area	300 Pond	14
	ACRMS (3614A Bldg.)	15
	300-South Gate	16
300 NE	300 NE	17
400 Area	400-East	18
	400-West	19
	400-South	20
	400-North	21
B Pond	B Pond	22
Hanford Townsite	Hanford Townsite	23
Wye Barricade	Wye Barricade	24
PERIMETER		
Northeast Perimeter	Berg Ranch	25
	Sagehill	26
	Ringold	27
East Perimeter	Fir Road	28
	Pettett	29
Southeast Perimeter	Byers Landing	30
	RRC No. 64	31
Prosser Barricade	Horn Rapids Rd. Substation	32
	Prosser Barricade	33
ALE	ALE	34
West Perimeter	Rattlesnake Spring	35
	Yakima Barricade	36

TABLE C.4. Air Sampling Locations and Sample Composite Groups (contd)

Composite Group	Sampling Location	Map Location[a]
Northwest Perimeter	Vernita Bridge	37
	Wahluke Slope No. 2	38
NEARBY COMMUNITIES		
Northeast Communities	Othello	39
	Connell	40
Tri-Cities	Pasco	41
	Richland	42
	Kennewick	43
Benton City	Benton City	44
	Prosser	45
Eltopia	Eltopia	46
Mattawa	Mattawa	47
DISTANT COMMUNITIES		
Outer Northeast	Moses Lake	48
	Washtucna	49
Outer Southeast	Walla Walla	50
	McNary Dam	51
Sunnyside	Sunnyside	52
Yakima	Yakima	53

(a) Locations are identified in Figure 4.1.

TABLE C.5. Ambient Nitrogen Dioxide (NO_2) Concentrations in the Hanford Environs for 1989

Location	Map Location[b]	Number of 24-h Samples	Annual Average[a] (ppm NO_2)	% Samples Less Than Detection Limit (0.003 ppm NO_2)	Maximum 24-h Sample (ppm NO_2)
100-B	1	165	<0.007 ± 0.0012	59	0.084
200-West	2	228	<0.004 ± 0.0005	24	0.041
Army Barracks	3	216	<0.005 ± 0.0007	28	0.058

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

TABLE C.6. Airborne Radionuclide Concentrations in the Hanford Environs for 1989

Radionuclide	Composite Group[b]	No. of Samples	Concentration, pCi/m³[a] (10^{-12} µCi/mL) Maximum		Minimum		Average		Concentration Guide, pCi/m³[c]
^{3}H	On Site	77	4.5	± 1.3	-0.6	± 0.7	1.4	± 0.2	200,000
	100 Areas	25	2.5	± 0.7	-0.6	± 0.7	1.0	± 0.3	
	200 Areas	26	3.1	± 0.9	0.2	± 0.8	1.6	± 0.3	
	300 Area	13	4.5	± 1.3	0.3	± 0.8	2.1	± 0.6	
	400 Area	13	2.4	± 1.1	-0.5	± 1.0	1.3	± 0.4	
	Perimeter	100	2.9	± 1.2	-1.3	± 1.0	0.9	± 0.2	
	Nearby Communities	13	2.0	± 0.6	0.2	± 0.8	1.2	± 0.3	
	Distant Communities	26	2.4	± 1.3	-0.7	± 0.8	0.8	± 0.3	
^{14}C	On Site	19	2.30	± 0.12	0.90	± 0.07	1.40	± 0.18	500,000
	100 Areas	7	2.30	± 0.12	1.00	± 0.07	1.40	± 0.34	
	200 Areas	6	2.00	± 0.14	1.00	± 0.07	1.40	± 0.33	
	300 Area	6	1.90	± 0.12	0.90	± 0.07	1.30	± 0.30	
	Distant Communities	14	1.60	± 0.09	1.00	± 0.04	1.40	± 0.10	
^{85}Kr	On Site	21	42	± 9.0	11	± 9	22	± 3	60,000
	200 Areas	11	42	± 9.0	16	± 9	25	± 5	
	300 Area	10	29	± 8.0	11	± 9	19	± 4	
	Perimeter	45	30	± 9.0	10	± 8	18	± 1	
	Nearby Communities	46	34	± 9.0	3	± 6	18	± 2	
	Distant Communities	25	28	± 9.0	14	± 8	20	± 2	
^{90}Sr	On Site	37	0.000150	± 0.000049	-0.000170	± 0.000290	0.000012	± 0.000018	9
	100 Areas	4	0.000070	± 0.000040	-0.000004	± 0.000022	0.000024	± 0.000033	
	200 Areas	18	0.000150	± 0.000049	-0.000170	± 0.000290	0.000010	± 0.000031	
	300 Area	7	0.000038	± 0.000096	-0.000052	± 0.000063	-0.000006	± 0.000021	
	400 Area	4	0.000150	± 0.000035	-0.000013	± 0.000034	0.000043	± 0.000073	
	Perimeter	24	0.000066	± 0.000037	-0.000070	± 0.000071	0.000005	± 0.000014	
	Nearby Communities	20	0.000120	± 0.000073	-0.000041	± 0.000032	0.000016	± 0.000020	
	Distant Communities	15	0.000030	± 0.000041	-0.000024	± 0.000021	-0.000002	± 0.000008	
^{106}Ru	On Site	111	0.0120	± 0.0078	-0.0310	± 0.0310	-0.0003	± 0.0010	30
	100 Areas	12	0.0041	± 0.0050	-0.0040	± 0.0051	0.0000	± 0.0013	
	200 Areas	54	0.0120	± 0.0078	-0.0140	± 0.0130	0.0004	± 0.0013	
	300 Area	21	0.0060	± 0.0053	-0.0310	± 0.0310	-0.0009	± 0.0033	
	400 Area	12	0.0039	± 0.0057	-0.0081	± 0.0064	-0.0010	± 0.0020	
	Perimeter	72	0.0100	± 0.0087	-0.0098	± 0.0120	0.0000	± 0.0011	
	Nearby Communities	60	0.0120	± 0.0100	-0.0110	± 0.0280	0.0005	± 0.0013	
	Distant Communities	48	0.0120	± 0.0100	-0.0100	± 0.0120	0.0006	± 0.0013	

TABLE C.6. Airborne Radionuclide Concentrations (contd)

Radionuclide	Composite Group[b]	No. of Samples	Concentration, pCi/m³[a] (10^{-12} µCi/mL) Maximum	Minimum	Average	Concentration Guide, pCi/m³[c]
^{129}I	On Site	4	0.000090000 ± 0.000007700	0.000013000 ± 0.000001700	0.000053000 ± 0.000038000	70
	200 Areas	4	0.000090000 ± 0.000007700	0.000013000 ± 0.000001700	0.000053000 ± 0.000038000	
	Perimeter	7	0.000004100 ± 0.000000600	0.000001400 ± 0.000000057	0.000002500 ± 0.000000740	
	Distant Communities	4	0.000000300 ± 0.000000015	0.000000091 ± 0.000000005	0.000000200 ± 0.000000110	
^{131}I	On Site	179	0.0068 ± 0.0068	-0.0055 ± 0.0045	-0.0001 ± 0.0003	400
	100 Areas	50	0.0034 ± 0.0038	-0.0046 ± 0.0041	-0.0001 ± 0.0005	
	200 Areas	78	0.0068 ± 0.0068	-0.0039 ± 0.0039	0.0002 ± 0.0005	
	300 Area	26	0.0040 ± 0.0045	-0.0055 ± 0.0045	-0.0012 ± 0.0008	
	400 Area	25	0.0030 ± 0.0040	-0.0034 ± 0.0054	0.0003 ± 0.0007	
	Perimeter	129	0.0039 ± 0.0033	-0.0048 ± 0.0038	-0.0005 ± 0.0003	
	Nearby Communities	50	0.0078 ± 0.0078	-0.0037 ± 0.0042	0.0007 ± 0.0006	
	Distant Communities	51	0.0033 ± 0.0052	-0.0041 ± 0.0050	-0.0001 ± 0.0005	
^{137}Cs	On Site	111	0.0010 ± 0.0008	-0.0023 ± 0.0053	0.0000 ± 0.0001	400
	100 Areas	12	0.0009 ± 0.0007	-0.0007 ± 0.0007	-0.0001 ± 0.0002	
	200 Areas	54	0.0010 ± 0.0008	-0.0023 ± 0.0053	0.0000 ± 0.0002	
	300 Area	21	0.0006 ± 0.0004	-0.0008 ± 0.0010	0.0001 ± 0.0002	
	400 Area	12	0.0007 ± 0.0007	-0.0003 ± 0.0006	0.0001 ± 0.0002	
	Perimeter	72	0.0011 ± 0.0011	-0.0014 ± 0.0013	-0.0001 ± 0.0001	
	Nearby Communities	60	0.0016 ± 0.0011	-0.0019 ± 0.0028	0.0001 ± 0.0002	
	Distant Communities	48	0.0009 ± 0.0012	-0.0014 ± 0.0017	0.0001 ± 0.0002	
U(total)[d]	On Site	29	0.001600 ± 0.000046	0.000013 ± 0.000004	0.000180 ± 0.000130	0.1
	100 Areas	4	0.000110 ± 0.000020	0.000013 ± 0.000004	0.000052 ± 0.000043	
	200 Areas	14	0.000480 ± 0.000071	0.000013 ± 0.000004	0.000072 ± 0.000063	
	300 Area	7	0.001600 ± 0.000046	0.000096 ± 0.000011	0.000530 ± 0.000430	
	Perimeter	8	0.000110 ± 0.000028	0.000054 ± 0.000011	0.000078 ± 0.000014	
	Distant Communities	7	0.000076 ± 0.000012	0.000024 ± 0.000008	0.000038 ± 0.000014	
^{238}Pu	On Site	37	0.0000027 ± 0.0000020	-0.0000008 ± 0.0000012	0.0000004 ± 0.0000003	0.03
	100 Areas	4	0.0000018 ± 0.0000014	0.0000001 ± 0.0000003	0.0000008 ± 0.0000008	
	200 Areas	18	0.0000027 ± 0.0000020	-0.0000008 ± 0.0000012	0.0000003 ± 0.0000005	
	300 Area	7	0.0000015 ± 0.0000016	-0.0000002 ± 0.0000000	0.0000002 ± 0.0000005	
	400 Area	4	0.0000009 ± 0.0000008	-0.0000001 ± 0.0000000	0.0000002 ± 0.0000005	
	Perimeter	24	0.0000007 ± 0.0000016	-0.0000009 ± 0.0000009	-0.0000001 ± 0.0000002	
	Nearby Communities	20	0.0000008 ± 0.0000012	-0.0000008 ± 0.0000006	-0.0000001 ± 0.0000002	
	Distant Communities	15	0.0000020 ± 0.0000020	-0.0000007 ± 0.0000005	0.0000001 ± 0.0000004	

TABLE C.6. Airborne Radionuclide Concentrations (contd)

Radionuclide	Composite Group[b]	No. of Samples	Concentration, pCi/m³[a] (10^{-12} µCi/mL) Maximum		Minimum		Average		Concentration Guide, pCi/m³[c]
^{239}Pu	On Site	37	0.0000860	± 0.0000110	-0.0000011	± 0.0000016	0.0000040	± 0.0000048	0.02
	100 Areas	4	0.0000002	± 0.0000007	-0.0000004	± 0.0000010	-0.0000001	± 0.0000002	
	200 Areas	18	0.0000860	± 0.0000110	-0.0000001	± 0.0000010	0.0000079	± 0.0000097	
	300 Area	7	0.0000018	± 0.0000016	-0.0000011	± 0.0000016	0.0000003	± 0.0000003	
	400 Area	4	0.0000007	± 0.0000007	-0.0000002	± 0.0000005	0.0000002	± 0.0000003	
	Perimeter	24	0.0000011	± 0.0000013	-0.0000007	± 0.0000006	0.0000002	± 0.0000003	
	Nearby Communities	20	0.0000010	± 0.0000014	-0.0000013	± 0.0000010	0.0000001	± 0.0000002	
	Distant Communities	15	0.0000010	± 0.0000012	-0.0000007	± 0.0000006	0.0000001	± 0.0000003	
Beta	On Site	516	0.0580	± 0.0025	0.0003	± 0.0007	0.0180	± 0.0008	
	100 Areas	76	0.0530	± 0.0024	0.0054	± 0.0010	0.0180	± 0.0024	
	200 Areas	219	0.0510	± 0.0023	0.0013	± 0.0007	0.0170	± 0.0012	
	300 Area	97	0.0560	± 0.0025	0.0003	± 0.0007	0.0190	± 0.0020	
	400 Area	99	0.0580	± 0.0025	0.0021	± 0.0008	0.0180	± 0.0019	
	Perimeter	354	0.0540	± 0.0025	0.0006	± 0.0007	0.0180	± 0.0010	
	Nearby Communities	232	0.0540	± 0.0024	0.0045	± 0.0009	0.0180	± 0.0013	
	Distant Communities	156	0.0640	± 0.0034	0.0046	± 0.0011	0.0170	± 0.0014	
Alpha	On Site	491	0.01100	± 0.00120	-0.00005	± 0.00015	0.00045	± 0.00006	
	100 Areas	24	0.00140	± 0.00043	-0.00004	± 0.00014	0.00041	± 0.00014	
	200 Areas	219	0.00180	± 0.00048	-0.00005	± 0.00015	0.00036	± 0.00004	
	300 Area	71	0.01100	± 0.00120	-0.00005	± 0.00015	0.00080	± 0.00036	
	400 Area	99	0.00400	± 0.00081	0.00003	± 0.00016	0.00044	± 0.00010	
	Perimeter	252	0.00240	± 0.00057	-0.00028	± 0.00031	0.00050	± 0.00005	
	Nearby Communities	51	0.00230	± 0.00056	0.00004	± 0.00017	0.00052	± 0.00012	
	Distant Communities	52	0.00140	± 0.00045	-0.00007	± 0.00019	0.00035	± 0.00008	

(a) Maximum and minimum single sample results ±2 sigma counting errors. Averages of all samples ±2 times the standard error of the calculated mean. Most entries have been rounded to two significant figures; however, an equal number of digits has been maintained for each radionuclide set to make visual comparisons easier.
(b) Onsite, perimeter, nearby communities, and distant sampling locations are identified in Figure 4.1 and Table C.4.
(c) From DOE Derived Concentration Guide (see Appendix B).
(d) Summation of ^{234}U, ^{235}U, and ^{238}U.

TABLE C.7. Radionuclide Concentrations Measured in Columbia River Water at Priest Rapids Dam in 1989

Radionuclide[b]	No. of Samples	Concentration, pCi/L[a] (10^{-9} µCi/mL) Maximum			Minimum			Average			Drinking Water Standard[c]
Composite System											
Gross Alpha	12	2.3	±	0.6	-0.004	±	0.279	0.83	±	0.33	15
Gross Beta	12	3.8	±	1.2	-0.22	±	1.80	1.50	±	0.68	50
^{3}H	12	79	±	4	53	±	3	63	±	5	20,000
^{89}Sr	12	0.002	±	0.086	-0.07	±	0.06	-0.035	±	0.015	20
^{90}Sr	12	0.12	±	0.04	0.05	±	0.04	0.08	±	0.01	8
^{99}Tc	12	4.1	±	1.2	-2.1	±	1.1	0.07	±	0.95	900
^{234}U	12	0.34	±	0.08	0.20	±	0.04	0.25	±	0.02	---[d]
^{235}U	12	0.039	±	0.017	-0.003	±	0.005	0.009	±	0.007	---
^{238}U	12	0.24	±	0.05	0.15	±	0.04	0.20	±	0.02	---
U-Total	12	0.53	±	0.09	0.34	±	0.06	0.46	±	0.03	---
Continuous System											
^{60}Co P	25	0.002	±	0.001	-0.002	±	0.002	0.00002	±	0.0003	100
D	25	0.003	±	0.003	-0.003	±	0.003	0.0012	±	0.0005	---
^{129}I D	4	0.000007	±	0.000002	0.000004	±	0.0000005	0.000005	±	0.000001	1
^{131}I P	25	0.006	±	0.007	-0.002	±	0.005	0.0002	±	0.0006	---
D	25	0.014	±	0.007	-0.010	±	0.017	0.003	±	0.002	3
^{137}Cs P	25	0.005	±	0.002	-0.0006	±	0.0019	0.002	±	0.001	200
D	25	0.005	±	0.003	-0.0002	±	0.0024	0.002	±	0.001	---
$^{239,240}Pu$ P	4	0.00002	±	0.00001	0.00001	±	0.00001	0.00002	±	0.000004	---
D	4	0.00003	±	0.00004	-0.00003	±	0.00002	0.000004	±	0.000018	---

(a) Maximum and minimum values ±2 sigma counting errors. Averages ±2 times the standard error of the calculated mean.
(b) Radionuclides measured using the continuous system show the particulate (P) and dissolved (D) fractions separately. Other radionuclides are based on samples collected by the composite system (see text).
(c) The drinking water standard is in pCi/L. From State of Washington and EPA (see Table B.2, Appendix B).
(d) Dashes indicate no concentration guides provided in drinking water standard.

TABLE C.8. Radionuclide Concentrations Measured in Columbia River Water at the 300 Area in 1989

Radionuclide[b]	No. of Samples	Concentration, pCi/L[a] (10^{-9} µCi/mL) Maximum			Minimum			Average			Drinking Water Standard[c]
Composite System											
Gross Alpha	4	1.4	±	1.0	0.7	±	0.4	1.0	±	0.3	15
Gross Beta	4	2.4	±	1.0	-1.1	±	1.8	1.0	±	1.5	50
^{3}H	4	195	±	6	119	±	5	161	±	35	20,000
^{89}Sr	4	0.20	±	0.19	0.06	±	0.10	0.14	±	0.09	20
^{90}Sr	4	0.12	±	0.04	0.08	±	0.04	0.09	±	0.03	8
^{99}Tc	4	3.00	±	0.38	-2.74	±	1.18	-0.05	±	2.52	900
^{234}U	4	0.44	±	0.07	0.23	±	0.05	0.31	±	0.09	---[d]
^{235}U	4	0.040	±	0.021	-0.005	±	0.006	0.012	±	0.020	---
^{238}U	4	0.30	±	0.05	0.20	±	0.04	0.25	±	0.06	---
U-Total	4	0.77	±	0.09	0.43	±	0.06	0.57	±	0.16	---
Continuous System											
^{60}Co P	23	0.007	±	0.002	-0.001	±	0.002	0.001	±	0.001	100
D	23	0.008	±	0.003	-0.0006	±	0.0028	0.0033	±	0.0009	---
^{129}I D	4	0.00026	±	0.00002	0.000089	±	0.000003	0.00017	±	0.00001	1
^{131}I P	23	0.0036	±	0.0039	-0.002	±	0.0025	0.0004	±	0.0006	3
D	23	0.0154	±	0.0053	-0.012	±	0.013	0.0021	±	0.0023	---
^{137}Cs P	23	0.56	±	0.001	-0.0002	±	0.0013	0.026	±	0.048	200
D	23	0.0046	±	0.0042	-0.0005	±	0.0027	0.0025	±	0.0006	---
$^{239,240}Pu$ P	4	0.002	±	0.0001	0.000002	±	0.00001	0.0005	±	0.0010	---
D	4	0.00005	±	0.00005	-0.000015	±	0.000037	0.000008	±	0.00003	---

(a) Maximum and minimum values ±2 sigma counting errors. Averages ±2 times the standard error of the calculated mean.
(b) Radionuclides measured using the continuous system show the particulate (P) and dissolved (D) fractions separately. Other radionuclides are based on samples collected by the composite system (see text).
(c) The drinking water standard is in pCi/L. From State of Washington and EPA (see Table B.2, Appendix B).
(d) Dashes indicate no concentration guides provided in drinking water standard.

TABLE C.9. Radionuclide Concentrations Measured in Columbia River Water at the Richland Pumphouse in 1989

Radionuclide[b]	No. of Samples	Concentration, pCi/L[a] (10^{-9} µCi/mL) Maximum		Minimum		Average		Drinking Water Standard[c]
Composite System								
Gross Alpha	12	1.3	± 1.1	0.08	± 0.51	0.60	± 0.19	15
Gross Beta	12	2.6	± 2.1	0.27	± 0.40	1.3	± 0.4	50
^{3}H	12	172	± 6	71	± 4	129	± 18	20,000
^{60}Co	12	0.55	± 0.54	-0.81	± 0.69	0.06	± 0.26	100
^{89}Sr	12	0.03	± 0.07	-0.20	± 0.07	-0.05	± 0.04	20
^{90}Sr	12	0.12	± 0.04	0.03	± 0.04	0.07	± 0.02	8
^{99}Tc	12	4.0	± 1.2	-1.9	± 1.1	0.5	± 0.9	900
^{234}U	12	0.30	± 0.05	0.08	± 0.03	0.23	± 0.04	---[d]
^{235}U	12	0.019	± 0.016	-0.003	± 0.004	0.008	± 0.005	---
^{238}U	12	0.27	± 0.05	0.03	± 0.03	0.19	± 0.04	---
U-Total	12	0.56	± 0.08	0.11	± 0.04	0.44	± 0.07	---
Continuous System								
^{60}Co P	24	0.01	± 0.002	-0.0021	± 0.0018	0.001	± 0.001	100
D	24	0.005	± 0.003	-0.0013	± 0.0025	0.0017	± 0.0007	---
^{129}I D	4	0.00016	± 0.000007	0.00005	± 0.000004	0.00012	± 0.000006	1
^{131}I P	24	0.0031	± 0.0047	-0.0028	± 0.0031	0.0002	± 0.0006	3
D	24	0.01	± 0.013	-0.0058	± 0.0203	0.0029	± 0.0017	---
^{137}Cs P	24	0.0057	± 0.0018	-0.0007	± 0.0018	0.0024	± 0.0006	200
D	24	0.0049	± 0.0037	-0.0007	± 0.0024	0.0018	± 0.0007	---
$^{239,240}Pu$ P	4	0.000035	± 0.000018	0.000003	± 0.000009	0.000019	± 0.000014	---
D	4	0.000046	± 0.00005	-0.000004	± 0.000024	0.000022	± 0.000025	---

(a) Maximum and minimum values ±2 sigma counting errors. Averages ±2 times the standard error of the calculated mean.
(b) Radionuclides measured using the continuous system show the particulate (P) and dissolved (D) fractions separately. Other radionuclides are based on samples collected by the composite system (see text).
(c) The drinking water standard is in pCi/L. From State of Washington and EPA (see Table B.2, Appendix B).
(d) Dashes indicate no concentration guides provided in drinking water standard.

TABLE C.10. Radionuclide Concentrations in Columbia River Sediment in 1989

Location	Radionuclide	No. of Samples	Concentration, pCi/g[a] (dry weight) Maximum			Minimum			Average		
Off Site											
Priest Rapids Dam	^{60}Co	4	0.011	±	0.018	-0.010	±	0.016	-0.002	±	0.009
	^{90}Sr	4	0.016	±	0.005	0.011	±	0.004	0.014	±	0.002
	^{106}Ru	4	0.043	±	0.136	-0.007	±	0.125	0.014	±	0.021
	^{134}Cs	4	-0.036	±	0.016	-0.168	±	0.024	-0.079	±	0.061
	^{137}Cs	4	0.298	±	0.032	0.189	±	0.025	0.265	±	0.051
	^{154}Eu	4	0.051	±	0.052	-0.014	±	0.051	0.019	±	0.028
	^{155}Eu	4	0.085	±	0.063	0.027	±	0.051	0.049	±	0.025
	^{235}U[b]	4	0.907	±	0.505	0.599	±	0.315	0.761	±	0.132
	^{238}Pu[b]	4	0.0003	±	0.0002	0.00002	±	0.0001	0.0002	±	0.0001
	$^{239,240}Pu$	4	0.0027	±	0.0006	0.0014	±	0.0005	0.0022	±	0.0006
McNary Dam	^{60}Co	4	0.442	±	0.044	0.144	±	0.025	0.278	±	0.145
	^{90}Sr	4	0.064	±	0.008	0.024	±	0.004	0.037	±	0.018
	^{106}Ru	4	0.022	±	0.185	-0.133	±	0.154	-0.076	±	0.068
	^{134}Cs	4	-0.023	±	0.018	-0.035	±	0.022	-0.028	±	0.006
	^{137}Cs	4	0.864	±	0.054	0.554	±	0.037	0.708	±	0.144
	^{152}Eu	3	1.11	±	0.17	0.399	±	0.125	0.774	±	0.412
	^{154}Eu	4	0.153	±	0.062	0.11	±	0.057	0.125	±	0.019
	^{155}Eu	4	0.100	±	0.078	0.085	±	0.045	0.093	±	0.007
	^{235}U[b]	4	0.200	±	0.148	-0.043	±	0.102	0.065	±	0.104
	^{238}U[b]	4	0.785	±	0.408	0.351	±	0.558	0.624	±	0.197
	^{238}Pu	4	0.0021	±	0.0006	0.0002	±	0.0002	0.0009	±	0.0009
	$^{239,240}Pu$	4	0.022	±	0.002	0.008	±	0.001	0.014	±	0.006
Perimeter											
Hanford Slough	^{60}Co	1	0.036	±	0.024						
	^{90}Sr	1	0.021	±	0.006						
	^{106}Ru	1	0.176	±	0.170						
	^{134}Cs	1	-0.042	±	0.021						
	^{137}Cs	1	0.210	±	0.030						
	^{154}Eu	1	-0.016	±	0.070						
	^{155}Eu	1	0.077	±	0.060						
	^{235}U[b]	1	0.063	±	0.103						
	^{238}U[b]	1	0.696	±	0.280						
	^{238}Pu	1	0.0004	±	0.0002						
	$^{239,240}Pu$	1	0.0035	±	0.0006						

TABLE C.10. Radionuclide Concentrations in Columbia River Sediment in 1989 (contd)

Location	Radionuclide	No. of Samples	Concentration, pCi/g[a] (dry weight) Maximum	Minimum	Average
100-F Slough	^{60}Co	1	0.055 ± 0.020		
	^{90}Sr	1	0.005 ± 0.003		
	^{106}Ru	1	-0.083 ± 0.138		
	^{134}Cs	1	-0.042 ± 0.016		
	^{137}Cs	1	0.231 ± 0.028		
	^{154}Eu	1	0.021 ± 0.055		
	^{155}Eu	1	0.055 ± 0.050		
	^{235}U[b]	1	0.086 ± 0.140		
	^{238}U[b]	1	0.583 ± 0.526		
	^{238}Pu	1	0.0003 ± 0.0002		
	$^{239,240}Pu$	1	0.0013 ± 0.0004		
White Bluffs Slough	^{60}Co	1	0.035 ± 0.022		
	^{90}Sr	1	0.006 ± 0.004		
	^{106}Ru	1	0.210 ± 0.146		
	^{134}Cs	1	-0.032 ± 0.017		
	^{137}Cs	1	0.284 ± 0.032		
	^{154}Eu	1	0.071 ± 0.056		
	^{155}Eu	1	0.091 ± 0.059		
	^{235}U[b]	1	0.090 ± 0.089		
	^{238}U[b]	1	0.639 ± 0.215		
	^{238}Pu	1	0.00005 ± 0.00008		
	$^{239,240}Pu$	1	0.0008 ± 0.0003		

(a) Maximum and minimum values ±2 sigma counting errors. Averages ±2 times the standard error of the calculated mean.
(b) Uranium-235 and ^{238}U by low-energy photon detector method.

TABLE C.11. Columbia River Water Quality Data for 1989

Analysis	Units	Vernita Bridge (upstream) No. of Samples	Maximum	Minimum	Annual Average[a]	Richland Pumphouse (downstream) No. of Samples	Maximum	Minimum	Annual Average[a]	State Standard[b]
PNL Environmental Monitoring										
pH	pH units	13	8.6	7.4	NA	13	8.6	7.3	NA	6.5 - 8.5
Fecal Coliform	#/100 mL	13	170	2	23[c]	13	240	2	34[c]	100
Total Coliform	#/100 mL	13	2400	2	480[c]	13	1600	2	383[c]	—
Biological Oxygen Demand	mg/L	13	3.4	1.2	2.1 ± 0.44	13	4.1	1.4	2.4 ± 0.5	—
Nitrate	mg/L	13	0.15	0.05	0.09 ± 0.02	13	0.24	0.05	0.11 ± 0.3	—
USGS Sampling Program[d]										
Temperature[e]	°C	365	20.5	1.1	11.5	365	20.8	0.3	11.5	20 (maximum)
Dissolved Oxygen	mg/L	6	14.0	9.6	11.55 ± 1.49	4	14.2	9.7	11.65 ± 2.30	8 (minimum)
Turbidity	NTU[f]	6	2.0	0.3	1.2 ± 0.67	4	4.0	1.3	2.25 ± 1.20	5 + background
pH	pH units	6	8.3	8.1	NA	4	8.1	8.0	NA	6.5 - 8.5
Fecal Coliform	#/100 mL	5	5	<1	<1.1[c]	4	13	<1	<6.5[c]	100
Suspended Solids, 105°C	mg/L	4	5	<1	<3.0 ± 1.63	4	13	<1	<5.0 ± 5.66	—
Dissolved Solids, 180°C	mg/L	6	95	69	81 ± 7.23	4	84	66	76 ± 7.6	—
Specific Conductance	µS/cm[g]	6	150	127	140 ± 7.4	4	155	136	146 ± 9.0	—
Hardness, as $CaCO_3$	mg/L	6	74	59	67 ± 4.9	4	74	62	68 ± 5.0	—
Phosphorus, Total	mg/L	6	0.04	0.01	0.02 ± 0.01	4	0.05	0.02	0.028 ± 0.015	—
Chromium, Dissolved	µg/L	4	<1	<1	<1	4	<1	<1	<1	—
Nitrogen, Kjeldahl	mg/L	6	0.4	<0.2	<0.28 ± 0.8	4	0.4	<0.2	<0.25 ± 0.1	—
Total Organic Carbon	mg/L	6	2.1	1.6	1.8 ± 0.15	4	2.4	1.3	1.75 ± 0.48	—
Iron, Dissolved	µg/L	4	9	4	6.5 ± 2.9	4	8	4	5.75 ± 1.71	—
Ammonia, Dissolved (as N)	mg/L	6	0.04	<0.01	<0.017 ± 0.01	4	0.04	<0.01	<0.018 ± 0.015	—

(a) Average values ±2 times the standard error of the calculated mean.
(b) See Appendix B. Dashes indicate no concentration guides provided in state standard.
(c) Annual median.
(d) Provisional data, subject to revision.
(e) Maximum and minimum represent daily averages.
(f) Nephelometric turbidity units.
(g) µ Siemans/cm.
NA Not applicable.

TABLE C.12. Radionuclide Concentrations in Onsite Ponds in 1989

Location	Radionuclide	No. of Samples	Concentration, pCi/L[a] (10^{-9} µCi/mL) Maximum			Minimum			Average		
West Lake	Gross Alpha	5	295	±	160	32	±	15	151	±	94
	Gross Beta	5	346	±	72	56	±	13	181	±	109
	^{3}H	4	548	±	135	298	±	108	436	±	105
	^{90}Sr	4	13	±	0.55	1.2	±	0.11	4.6	±	5.8
	^{137}Cs	4	4.6	±	3.0	0.0	±	2.2	1.6	±	2.2
	^{234}U	5	199	±	8.7	82	±	4.5	122	±	41
	^{235}U	5	21.4	±	2.8	1.4	±	0.64	7.1	±	7.2
	^{238}U	5	197	±	8.6	76.6	±	4.4	116	±	42
	U-Total	5	417	±	12.5	160	±	6.3	245	±	90
B Pond	Gross Alpha	4	4.7	±	1.1	0.43	±	0.67	1.9	±	1.9
	Gross Beta	4	9.6	±	1.6	2.7	±	1.1	5.8	±	3.1
	^{3}H	4	165	±	107	59	±	101	112	±	51.8
	^{90}Sr	3	2.4	±	0.19	0.28	±	0.08	1.1	±	1.3
	^{137}Cs	4	4.0	±	1.8	0.14	±	1.5	1.5	±	1.8
FFTF Pond	Gross Alpha	4	0.55	±	0.58	-0.34	±	0.84	0.09	±	0.37
	Gross Beta	4	25	±	4.1	8.9	±	2.8	16	±	6.8
	^{3}H	4	9200	±	287	6230	±	236	7380	±	1311
	^{137}Cs	4	0.16	±	1.7	-1.4	±	2.5	-0.73	±	0.64
	^{22}Na	4	0.72	±	2.26	-0.77	±	2.2	-0.006	±	0.75

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

TABLE C.13. Radionuclide Concentrations Measured in Offsite Water in 1989

Location	Radionuclide	No. of Samples	Concentration, pCi/L[a] (10^{-9} µCi/mL) Maximum	Minimum	Average	Drinking Water Standard[b]
Domestic Water						
Ringold Hatchery	Gross Alpha	4	2.25 ± 1.11	0.412 ± 0.664	1.23 ± 0.765	15
	Gross Beta	4	9.89 ± 2.88	4.69 ± 1.30	6.66 ± 2.25	50
	^{3}H	4	131 ± 99	-122 ± 90.1	-18.3 ± 107	20,000
	^{129}I	1			0.00016 ± 0.00001	1
	^{234}U	4	4.32 ± 0.188	-0.021 ± 0.004	1.07 ± 2.17	---
	^{235}U	4	0.131 ± 0.034	-0.005 ± 0.00	0.034 ± 0.065	---
	^{238}U	4	3.49 ± 0.169	-0.004 ± 0.008	0.877 ± 1.74	---
	U-Total	4	7.94 ± 0.255	-0.024 ± 0.012	1.98 ± 3.97	---
Mathews Corner	Gross Alpha	4	8.56 ± 3.04	3.95 ± 1.32	5.52 ± 2.11	15
	Gross Beta	4	3.53 ± 2.25	0.807 ± 0.898	1.90 ± 1.21	50
	^{3}H	4	220 ± 127	80.6 ± 99.1	158 ± 61.9	20,000
	^{129}I	1			0.00007 ± 0.000006	1
	^{234}U	4	4.09 ± 0.179	3.33 ± 0.266	3.75 ± 0.318	---
	^{235}U	4	0.180 ± 0.038	0.106 ± 0.051	0.145 ± 0.035	---
	^{238}U	4	3.33 ± 0.161	2.67 ± 0.238	3.12 ± 0.302	---
	U-Total	4	7.59 ± 0.244	6.11 ± 0.361	7.01 ± 0.634	---
White Bluffs Water Assn	Gross Alpha	4	16.1 ± 4.51	5.03 ± 1.77	11.4 ± 4.62	15
	Gross Beta	4	8.63 ± 2.86	4.81 ± 1.33	6.00 ± 1.78	50
	^{3}H	4	172 ± 127	14.3 ± 102	106 ± 76.5	20,000
	^{129}I	1			0.000045 ± 0.000006	1
	^{137}Cs	4	7.69 ± 5.64	-0.843 ± 0.728	1.77 ± 3.97	200
	^{234}U	3	9.32 ± 0.286	8.19 ± 0.284	8.88 ± 0.696	---
	^{235}U	3	0.374 ± 0.062	0.293 ± 0.052	0.332 ± 0.047	---
	^{238}U	3	8.75 ± 0.277	7.61 ± 0.274	8.27 ± 0.684	---
	U-Total	3	18.4 ± 0.402	16.2 ± 0.399	49.2 ± 63.4	---
Alexander Farm	Gross Alpha	4	27.3 ± 6.95	0.395 ± 1.04	16.8 ± 11.8	15
	Gross Beta	4	12.5 ± 1.81	6.93 ± 1.48	9.76 ± 2.45	50
	^{3}H	4	64.6 ± 101	-89.3 ± 120	-29.6 ± 67.4	20,000
	^{129}I	1			0.000004 ± 0.0000016	1
	^{234}U	4	29.6 ± 1.72	-0.015 ± 0.067	19.6 ± 13.3	---
	^{235}U	4	0.721 ± 0.299	-0.026 ± 0.00	0.432 ± 0.339	---
	^{238}U	4	17.3 ± 1.32	-0.0095 ± 0.059	12.1 ± 8.11	---
	U-Total	4	47.6 ± 2.19	-0.05 ± 0.09	32.1 ± 21.7	---
Irrigation Water						
Riverview Canal	Gross Alpha	3	1.15 ± 0.590	0.760 ± 0.681	0.969 ± 0.227	15
	Gross Beta	3	2.22 ± 1.02	0.832 ± 0.884	1.46 ± 0.812	50
	^{3}H	3	27 ± 94	-82 ± 99	-31 ± 63	20,000
	^{137}Cs	3	0.734 ± 0.608	0.075 ± 0.557	0.352 ± 0.395	200
	^{90}Sr	3	0.100 ± 0.034	0.063 ± 0.039	0.086 ± 0.023	8
	^{234}U	3	0.315 ± 0.062	0.235 ± 0.046	0.283 ± 0.049	---
	^{235}U	3	0.026 ± 0.023	0.0029 ± 0.0080	0.012 ± 0.014	---
	^{238}U	3	0.241 ± 0.056	0.154 ± 0.039	0.198 ± 0.050	---
	U-Total	3	0.582 ± 0.087	0.438 ± 0.063	0.493 ± 0.089	---

(a) Maximum and minimum values ±2 sigma counting errors. Averages ±2 times the standard error of the calculated mean.
(b) Dashes indicate no concentration guides provided in drinking water standard.

TABLE C.14. Radionuclide Concentrations in Milk Samples in 1989, pCi/L[a] (10^{-9} µCi/mL)

Location[b]	^{3}H No. of Samples	^{3}H Maximum	^{3}H Average
Wahluke East Area Composite	13	180 ± 100	44 ± 37
Sagemoor Area Composite	13	190 ± 100	100 ± 31
Riverview Area[c]	2	81 ± 100	54 ± 54
Benton City Area	13	190 ± 100	73 ± 33
Sunnyside Area	13	120 ± 82	41 ± 26
Moses Lake Area	12	320 ± 100	180 ± 42

Location[b]	^{90}Sr No. of Samples	^{90}Sr Maximum	^{90}Sr Average	^{129}I No. of Samples	^{129}I Maximum	^{129}I Average
Wahluke East Area Composite	5	1.0 ± 0.5	0.7 ± 0.2	2	0.0041 ± 0.0003	0.0024 ± 0.0034
Sagemoor Area Composite	5	1.2 ± 0.5	0.9 ± 0.1	2	0.013 ± 0.002	0.0076 ± 0.0099
Riverview Area[c]	1	0.5 ± 0.3	---	1	---	0.0037 ± 0.0003
Benton City Area	5	1.5 ± 0.6	1.1 ± 0.3	2	0.0063 ± 0.0004	0.0038 ± 0.0050
Sunnyside Area	5	0.6 ± 0.3	0.6 ± 0.1	2	0.0032 ± 0.0002	0.0018 ± 0.0026
Moses Lake Area	4	0.9 ± 0.3	0.8 ± 0.1	2	0.0018 ± 0.0003	0.0010 ± 0.0015

Location[b]	^{13}I No. of Samples	^{13}I Maximum	^{13}I Average	^{137}Cs No. of Samples	^{137}Cs Maximum	^{137}Cs Average
Wahluke East Area Composite	13	0.29 ± 0.25	0.03 ± 0.07	13	1.3 ± 3.2	-0.4 ± 0.7
Sagemoor Area Composite	26	0.17 ± 0.16	0.02 ± 0.04	26	2.7 ± 3.1	0.2 ± 0.6
Riverview Area[c]	2	0.03 ± 0.15	0.02 ± 0.02	2	3.0 ± 2.8	2.6 ± 0.9
Benton City Area	13	0.38 ± 0.18	0.03 ± 0.08	13	2.7 ± 3.7	1.1 ± 0.7
Sunnyside Area	26	0.17 ± 0.20	0.04 ± 0.04	26	4.5 ± 4.0	0.8 ± 0.7
Moses Lake Area	12	0.68 ± 0.17	0.07 ± 0.12	12	3.7 ± 2.9	0.2 ± 0.9

(a) Maximum values ±2 sigma counting errors. Averages ±2 times the standard error of the calculated mean.
(b) Refer to Figure 4.28.
(c) No milk available after February 1989.

TABLE C.15. Radionuclide Concentrations in Leafy Vegetables in 1989

Location[b]	^{90}Sr, pCi/g, wet weight[a]			^{137}Cs, pCi/g, wet weight[a]			^{129}I, pCi/g, wet weight[a]		
	No. of Samples	Maximum	Average	No. of Samples	Maximum	Average	No. of Samples	Maximum	Average
Wahluke Area	3	0.021 ± 0.003	0.017 ± 0.005	3	0.011 ± 0.013	0.004 ± 0.006	NS	—	—
Sagemoor Area	3	0.006 ± 0.002	0.006 ± 0.001	3	0.007 ± 0.015	0.004 ± 0.004	NS	—	—
Riverview Area[c]	3	0.027 ± 0.004	0.023 ± 0.007	6	0.005 ± 0.010	0.001 ± 0.003	3	0.015 ± 0.035	0.008 ± 0.009
Sunnyside Area	3	0.003 ± 0.003	0.002 ± 0.002	3	0.014 ± 0.014	0.002 ± 0.013	NS	—	—
Prosser	3	0.10 ± 0.006	0.099 ± 0.003	3	0.003 ± 0.007	0.001 ± 0.002	3	0.015 ± 0.015	0.010 ± 0.005

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

TABLE C.16. Radionuclide Concentrations in Vegetables in 1989

Type/Location[b]	^{90}Sr, pCi/g, wet weight[a]			^{137}Cs, pCi/g, wet weight[a]			$^{239,240}Pu$, pCi/g, wet weight[a]		
	No. of Samples	Maximum	Average	No. of Samples	Maximum	Average	No. of Samples	Maximum	Average
Tomatoes									
Riverview Area	3	0.018 ± 0.018	0.014 ± 0.005	3	0.007 ± 0.012	-0.001 ± 0.008	NS	—	—
Carrots									
Riverview Area[c]	3	0.009 ± 0.003	0.008 ± 0.002	3	0.005 ± 0.009	-0.001 ± 0.005	NS	—	—
Potatoes									
Riverview Area[c]	3	0.008 ± 0.003	0.005 ± 0.002	3	0.010 ± 0.007	0.007 ± 0.004	NS	—	—
Sagemoor Area	3	0.005 ± 0.002	0.003 ± 0.003	3	0.005 ± 0.006	0.001 ± 0.004	3	-0.0001 ± 0.0001	-0.0001 ± 0.0001
Wahluke East Area	3	0.003 ± 0.002	0.001 ± 0.001	3	-0.001 ± 0.006	-0.001 ± 0.001	NS	—	—
Sunnyside Area	3	0.001 ± 0.003	-0.001 ± 0.001	3	0.002 ± 0.006	-0.001 ± 0.003	3	-0.0001 ± 0.0001	-0.0001 ± 0.0001

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

TABLE C.17. Radionuclide Concentrations in Fruit in 1989

Type/ Location[b]	^{90}Sr, pCi/g, wet weight[a]			^{137}Cs, pCi/g, wet weight[a]		
	No. of Samples	Maximum	Average	No. of Samples	Maximum	Average
Apples						
Riverview Area[c]	3	0.004 ± 0.003	0.002 ± 0.003	3	0.001 ± 0.001	-0.001 ± 0.001
Sagemoor Area	3	0.001 ± 0.002	0.001 ± 0.001	3	0.004 ± 0.007	0.003 ± 0.001
Cold Creek Area	3	0.001 ± 0.002	0.001 ± 0.001	3	0.006 ± 0.007	0.002 ± 0.005
Sunnyside Area	3	0.002 ± 0.002	0.001 ± 0.001	3	0.008 ± 0.009	0.005 ± 0.003
Wahluke Area	3	0.001 ± 0.002	0.001 ± 0.001	3	0.003 ± 0.008	0.001 ± 0.002
Mattawa Area	3	0.001 ± 0.002	0.001 ± 0.001	3	0.008 ± 0.007	0.006 ± 0.005
Cherries						
Sagemoor Area	3	0.001 ± 0.002	0.001 ± 0.001	3	0.004 ± 0.006	0.001 ± 0.004
Sunnyside Area	3	0.002 ± 0.002	0.001 ± 0.002	3	0.003 ± 0.007	-0.001 ± 0.003
Grapes						
Riverview Area[c]	3	0.004 ± 0.003	0.003 ± 0.001	3	0.005 ± 0.006	-0.005 ± 0.010
Sagemoor Area	3	0.006 ± 0.003	0.003 ± 0.003	3	0.007 ± 0.006	0.003 ± 0.007
Cold Creek Area	3	0.003 ± 0.002	0.002 ± 0.001	3	0.005 ± 0.005	0.001 ± 0.005
Sunnyside Area	3	0.002 ± 0.002	0.001 ± 0.001	3	0.004 ± 0.008	0.001 ± 0.005
Mattawa Area	3	0.005 ± 0.002	0.004 ± 0.001	3	0.002 ± 0.006	-0.001 ± 0.003
Melons						
Riverview Area[c]	3	0.002 ± 0.002	0.002 ± 0.001	3	0.004 ± 0.006	-0.001 ± 0.001

Type/ Location[b]	^{3}H, pCi/L (10^{-9} µCi/mL), water[a]			$^{239,240}Pu$, pCi/g, wet weight[a]		
	No. of Samples	Maximum	Average	No. of Samples	Maximum	Average
Apples						
Riverview Area[c]	3	250 ± 110	150 ± 100	NS	---	---
Sagemoor Area	3	250 ± 100	160 ± 120	3	-0.0001 ± 0.0	-0.0001 ± 0.0001
Cold Creek Area	3	200 ± 100	130 ± 79	NS	---	---
Sunnyside Area	3	110 ± 100	75 ± 70	3	0.0001 ± 0.0001	-0.0001 ± 0.0001
Wahluke Area	3	190 ± 100	152 ± 48	NS	---	---
Mattawa Area	3	500 ± 120	320 ± 190			
Cherries						
Sagemoor Area	3	210 ± 100	160 ± 61	NS	---	---
Sunnyside Area	3	73 ± 95	48 ± 48	NS	---	---
Grapes						
Riverview Area[c]	3	170 ± 100	81 ± 94	NS	---	---
Sagemoor Area	3	72 ± 98	50 ± 23	NS	---	---
Cold Creek Area	3	190 ± 110	160 ± 29	NS	---	---
Sunnyside Area	3	62 ± 100	17 ± 58	NS	---	---
Mattawa Area	3	200 ± 100	180 ± 21			
Melons						
Riverview Area[c]	3	230 ± 93	170 ± 98	NS	---	---

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

TABLF C.18. Radionuclide Concentrations in Local Wine in 1989

Location[b]	No. of Samples	^{3}H, pCi/L[a] (10^{-9} µCi/mL) Maximum	^{3}H, pCi/L[a] (10^{-9} µCi/mL) Average	^{137}Cs, pCi/L[a] (10^{-9} µCi/mL) Maximum	^{137}Cs, pCi/L[a] (10^{-9} µCi/mL) Average
Columbia Basin					
White Wine	3	400 ± 100	280 ± 130	1.2 ± 4.0	0.4 ± 0.8
Red Wine	3	490 ± 110	400 ± 120	3.2 ± 4.4	2.5 ± 1.2
Yakima Valley					
White Wine	3	500 ± 110	380 ± 170	2.6 ± 4.1	-1.9 ± 3.1
Red Wine	3	440 ± 110	390 ± 92	4.6 ± 3.7	1.4 ± 3.5

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

TABLE C.19. Radionuclide Concentrations in Wheat and Alfalfa in 1989

Type/ Location[b]	^{90}Sr, pCi/g, dry weight[a]			^{137}Cs, pCi/g, dry weight[a]			$^{239,240}Pu$, pCi/g, dry weight[a]		
	No. of Samples	Maximum	Average	No. of Samples	Maximum	Average	No. of Samples	Maximum	Average
Wheat									
Wahluke East Area	3	0.007 ± 0.003	0.007 ± 0.001	3	0.008 ± 0.007	0.004 ± 0.005	NS	—	—
Sagemoor Area	3	0.012 ± 0.003	0.007 ± 0.005	3	0.003 ± 0.009	0.001 ± 0.002	3	0.0001 ± 0.0001	0.0001 ± 0.0001
Benton City Area	3	0.009 ± 0.004	0.005 ± 0.004	3	-0.004 ± 0.013	-0.008 ± 0.007	NS	—	—
Moses Lake Area	3	0.010 ± 0.003	0.008 ± 0.003	3	0.003 ± 0.007	0.001 ± 0.003	NS	—	—
Sunnyside Area	3	0.007 ± 0.004	0.004 ± 0.003	3	0.009 ± 0.013	0.002 ± 0.008	3	0.0003 ± 0.0006	0.0001 ± 0.0002
Alfalfa									
Wahluke East Area	3	0.12 ± 0.01	0.10 ± 0.02	3	0.011 ± 0.002	0.005 ± 0.005	NS		
Sagemoor Area	3	0.08 ± 0.01	0.08 ± 0.01	3	0.022 ± 0.012	0.009 ± 0.013	NS		
Riverview Area[c]	3	0.29 ± 0.02	0.24 ± 0.06	3	0.011 ± 0.015	0.005 ± 0.006	NS		
Benton City Area	3	0.15 ± 0.01	0.15 ± 0.01	3	0.019 ± 0.016	0.010 ± 0.013	NS		
Sunnyside Area	3	0.11 ± 0.01	0.11 ± 0.04	3	0.004 ± 0.012	0.002 ± 0.004	NS		
Moses Lake Area	4	0.14 ± 0.01	0.08 ± 0.04	4	0.003 ± 0.014	-0.003 ± 0.011	NS		
Richland	NS	—	—	3	0.003 ± 0.015	-0.001 ± 0.004	NS		

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

TABLE C.20. Radionuclide Concentrations in Beef, Chicken, and Eggs in 1989

Type/Location[b]	^{90}Sr, pCi/g, wet weight[a]			^{137}Cs, pCi/g, wet weight[a]		
	No. of Samples	Maximum	Average	No. of Samples	Maximum	Average
Beef						
Riverview Area	1	---	0.001 ± 0.002	1	---	0.003 ± 0.009
Sagemoor Area	1	---	0.003 ± 0.002	1	---	0.003 ± 0.009
Sunnyside Area	1	---	0.003 ± 0.002	1	---	0.002 ± 0.008
Benton City Area	1	---	0.004 ± 0.002	1	---	0.003 ± 0.008
Chicken						
Sagemoor Area	2	0.004 ± 0.002	0.003 ± 0.004	2	0.018 ± 0.023	0.014 ± 0.007
Sunnyside	2	0.001 ± 0.002	0.001 ± 0.001	2	-0.001 ± 0.011	-0.001 ± 0.001
Eggs						
Sagemoor Area	2	0.007 ± 0.002	0.005 ± 0.004	2	0.005 ± 0.006	0.003 ± 0.006
Sunnyside	2	0.001 ± 0.002	0.001 ± 0.001	2	0.003 ± 0.008	0.001 ± 0.004

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

TABLE C.21. Concentrations of Cesium-137 (^{137}Cs) in Deer Muscle and Plutonium-239,240 ($^{239,240}Pu$) in Deer Liver in 1989

		^{137}Cs, pCi/g, wet weight[a]			$^{239,240}Pu$, pCi/g, wet weight[a]		
Location	Type	No. of Samples	Maximum	Average	No. of Samples	Maximum	Average
Random (road kills)	Muscle	5	0.006 ± 0.006	0.004 ± 0.002	NS	---	---
	Liver	NS	---	---	5	0.00004 ± 0.0006	0.00001 ± 0.00002

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

TABLE C.22. Radionuclide Concentrations in Columbia River Fish in 1989

Type/Location[b]	^{60}Co, pCi/g, wet weight[a]			^{90}Sr, pCi/g, wet weight[a]			^{137}Cs, pCi/g, wet weight[a]		
	No. of Samples	Maximum	Average	No. of Samples	Maximum	Average	No. of Samples	Maximum	Average
Whitefish Muscle									
Upstream of Site Boundary	5	0.033 ± 0.022	0.008 ± 0.016	5	0.019 ± 0.003	0.006 ± 0.006	5	0.026 ± 0.017	0.013 ± 0.007
100-D Area Vicinity	6	0.017 ± 0.015	0.008 ± 0.004	6	0.024 ± 0.004	0.008 ± 0.007	6	0.026 ± 0.019	0.014 ± 0.006
Whitefish Carcass									
Upstream of Site Boundary	NS	---	---	5	0.032 ± 0.003	0.023 ± 0.007	NS	---	---
100-D Area Vicinity	NS	---	---	6	0.022 ± 0.003	0.015 ± 0.004	NS	---	---
Bass Muscle									
100-F Sloughs	5	0.010 ± 0.016	-0.001 ± 0.006	5	0.001 ± 0.002	0.001 ± 0.001	5	0.050 ± 0.023	0.032 ± 0.010
Bass Carcass									
100-F Sloughs	NS	---	---	5	0.066 ± 0.006	0.042 ± 0.014	NS	---	---

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

TABLE C.23. Radionuclide Concentrations in Muscle Tissue of Upland Gamebirds in 1989

Type/ Location[b]	^{60}Co, pCi/g, wet weight[a]			^{137}Cs, pCi/g, wet weight[a]		
	No. of Samples	Maximum	Average	No. of Samples	Maximum	Average
Pheasant						
100 Areas	10	0.010 ± 0.011	0.001 ± 0.004	10	2.0 ± 0.1	0.20 ± 0.39
200 Areas	2	0.001 ± 0.015	0.005 ± 0.017	2	0.29 ± 0.02	0.15 ± 0.40

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

TABLE C.24. Radionuclide Concentrations in Muscle Tissue of Canada Geese and Mallard Ducks in 1989

Type/ Location[b]	^{137}Cs, pCi/g, wet weight[a]		
	No. of Samples	Maximum	Average
Canada Geese			
100-D Area	3	0.03 ± 0.02	0.02 ± 0.02
Mallard Ducks			
200 Area B Pond	10	2.8 ± 0.1	0.82 ± 0.63
300 Area Trench	4	0.04 ± 0.02	0.03 ± 0.01

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

TABLE C.25. Radionuclide Concentrations in Bone, Muscle, and Liver Tissue of Rabbits in 1989

Type/Location[b]	^{90}Sr (bone), pCi/g, wet weight[a]			^{137}Cs (muscle), pCi/g, wet weight[a]			$^{239,240}Pu$ (liver), pCi/g, wet weight[a]		
	No. of Samples	Maximum	Average	No. of Samples	Maximum	Average	No. of Samples	Maximum	Average
Cottontail									
100-N Area	4	160 ± 3	80 ± 91	4	0.15 ± 0.05	0.04 ± 0.07	4	0.001 ± 0.001	0.001 ± 0.001
Jack Rabbit									
200-W Area	5	140 ± 39	29 ± 57	5	0.15 ± 0.03	0.04 ± 0.06	5	0.001 ± 0.001	0.001 ± 0.001
200-E Area	5	1.1 ± 0.1	0.70 ± 0.27	5	0.03 ± 0.02	0.01 ± 0.01	5	0.001 ± 0.001	0.001 ± 0.001

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

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

Location	Map Location[b]	pCi/g (dry weight)[a] 1984	1985	1986	1987	1988	1989
ON SITE							
1 Mile NE of 100-N Area	1	0.29 ± 0.017	0.28 ± 0.058	0.24 ± 0.01	—[c]	0.11 ± 0.01	0.18 ± 0.01
1 Mile E of 100-N Area	2	0.22 ± 0.010	0.44 ± 0.091	0.22 ± 0.01	0.31 ± 0.01	0.22 ± 0.01	0.17 ± 0.01
100 Area Fire Station	3	0.45 ± 0.020	0.57 ± 0.11	0.34 ± 0.01	0.33 ± 0.01	0.28 ± 0.02	0.31 ± 0.01
200-East N Central	4	0.20 ± 0.19	1.2 ± 0.23	0.61 ± 0.01	1.1 ± 0.1	0.77 ± 0.02	0.58 ± 0.01
E of 200-East	5	0.73 ± 0.48	0.90 ± 0.18	0.39 ± 0.01	0.34 ± 0.02	0.57 ± 0.02	0.41 ± 0.02
200-East SE	6	0.44 ± 0.060	0.20 ± 0.042	0.27 ± 0.01	0.24 ± 0.02	0.59 ± 0.02	0.13 ± 0.01
SW of BC Cribs	7	0.12 ± 0.050	0.39 ± 0.079	0.11 ± 0.01	0.02 ± 0.01	0.04 ± 0.01	0.12 ± 0.01
S of 200-East	8	0.50 ± 0.11	0.14 ± 0.030	0.54 ± 0.01	0.11 ± 0.01	0.23 ± 0.01	0.28 ± 0.01
E of 200-West	9	0.33 ± 0.020	0.61 ± 0.12	0.56 ± 0.01	0.38 ± 0.02	0.71 ± 0.27	0.50 ± 0.02
2 Miles S of 200-West	10	0.14 ± 0.020	0.37 ± 0.078	0.23 ± 0.02	—	0.14 ± 0.01	0.14 ± 0.01
NE of FFTF	11	0.18 ± 0.021	0.17 ± 0.039	—	0.09 ± 0.01	0.09 ± 0.01	0.05 ± 0.01
SE of FFTF	12	0.032 ± 0.054	0.20 ± 0.042	0.44 ± 0.01	—	0.07 ± 0.01	0.06 ± 0.01
N of 300 Area	13	0.58 ± 0.029	0.32 ± 0.068	0.18 ± 0.02	0.24 ± 0.01	0.13 ± 0.01	0.15 ± 0.01
Hanford Townsite	14	0.31 ± 0.029	0.25 ± 0.052	—	0.29 ± 0.01	0.13 ± 0.01	0.28 ± 0.01
Wye Barricade	15	0.31 ± 0.040	0.31 ± 0.062	—	0.18 ± 0.01	0.14 ± 0.01	0.11 ± 0.01
ONSITE AVERAGE		0.32 ± 0.10	0.42 ± 0.15	0.31 ± 0.11	0.31 ± 0.16	0.31 ± 0.13	0.23 ± 0.08
OFF SITE							
Riverview	16	0.039 ± 0.012	0.074 ± 0.019	0.06 ± 0.01	0.19 ± 0.01	0.23 ± 0.01	0.07 ± 0.01
Byers Landing	17	0.064 ± 0.008	0.18 ± 0.016	0.17 ± 0.01	0.08 ± 0.01	0.10 ± 0.01	0.13 ± 0.01
Sagemoor	18	0.25 ± 0.046	0.081 ± 0.019	0.11 ± 0.02	0.04 ± 0.01	0.20 ± 0.01	0.03 ± 0.01
Taylor Flats No. 2	19	0.042 ± 0.008	0.046 ± 0.013	0.36 ± 0.02	0.10 ± 0.01	0.06 ± 0.01	0.16 ± 0.01
W End Fir Road	20	0.14 ± 0.015	0.091 ± 0.022	0.12 ± 0.02	0.05 ± 0.01	0.08 ± 0.01	0.20 ± 0.01
Ringold	21	0.24 ± 0.014	0.20 ± 0.042	0.26 ± 0.02	0.21 ± 0.01	0.26 ± 0.01	0.15 ± 0.01
Berg Ranch	22	0.20 ± 0.019	0.15 ± 0.033	0.20 ± 0.01	0.20 ± 0.01	0.10 ± 0.01	0.09 ± 0.01
Wahluke Slope No. 2[d]	23	0.16 ± 0.017	0.21 ± 0.046	0.10 ± 0.01	0.07 ± 0.01	0.09 ± 0.01	0.07 ± 0.01
Vernita Bridge[d]	24	0.17 ± 0.015	0.31 ± 0.064	0.09 ± 0.01	—	0.07 ± 0.01	0.12 ± 0.01
Yakima Barricade[d]	25	0.13 ± 0.017	0.54 ± 0.109	—	0.06 ± 0.01	0.07 ± 0.01	0.13 ± 0.01
Rattlesnake Springs[d]	26	0.075 ± 0.009	0.33 ± 0.069	0.18 ± 0.01	0.12 ± 0.01	0.04 ± 0.01	0.09 ± 0.01
ALE[d]	27	0.36 ± 0.039	0.61 ± 0.12	—	0.40 ± 0.03	0.34 ± 0.01	0.26 ± 0.01
Prosser Barricade[d]	28	0.36 ± 0.020	0.45 ± 0.092	0.17 ± 0.01	—	0.11 ± 0.01	0.24 ± 0.01
S of 300 Area[d]	29	0.35 ± 0.015	0.51 ± 0.10	0.31 ± 0.01	—	0.27 ± 0.01	0.30 ± 0.01

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

Location	Map Location[b]	pCi/g (dry weight)[a] 1984	1985	1986	1987	1988	1989
Benton City	30	0.36 ± 0.031	0.12 ± 0.027	0.25 ± 0.01	0.24 ± 0.01	0.43 ± 0.02	0.17 ± 0.01
Sunnyside	31	0.31 ± 0.029	0.26 ± 0.055	0.05 ± 0.01	0.25 ± 0.02	0.26 ± 0.06	0.13 ± 0.01
Walla Walla	32		0.31 ± 0.015	0.14 ± 0.08	0.02 ± 0.01	0.04 ± 0.01	0.01 ± 0.01
McNary Dam	33		0.29 ± 0.019	0.18 ± 0.08	0.07 ± 0.06	0.13 ± 0.01	0.09 ± 0.01
Moses Lake	34			0.08 ± 0.01	0.06 ± 0.02	0.08 ± 0.01	0.05 ± 0.01
Washtucna	35			0.40 ± 0.02	0.12 ± 0.12	0.25 ± 0.01	0.12 ± 0.01
Connell	36			0.32 ± 0.02	0.12 ± 0.11	0.09 ± 0.01	0.14 ± 0.01
Othello	37			0.27 ± 0.02	0.15 ± 0.08	0.04 ± 0.01	0.08 ± 0.01
Yakima	38			0.04 ± 0.01	0.06 ± 0.04	0.09 ± 0.01	0.10 ± 0.01
OFFSITE AVERAGE		0.20 ± 0.059	0.26 ± 0.080	0.18 ± 0.05	0.12 ± 0.03	0.16 ± 0.04	0.13 ± 0.03

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

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

Location	Map Location[b]	pCi/g (dry weight)[a] 1984	1985	1986	1987	1988	1989
ON SITE							
1 Mile NE of 100-N Area	1	0.70 ± 0.05	0.76 ± 0.065	0.81 ± 0.05	—[c]	0.80 ± 0.05	0.96 ± 0.05
1 Mile E of 100-N Area	2	0.67 ± 0.04	0.62 ± 0.057	0.55 ± 0.04	1.1 ± 0.1	0.74 ± 0.05	0.63 ± 0.05
100 Area Fire Station	3	0.98 ± 0.06	1.2 ± 0.082	1.6 ± 0.1	1.3 ± 0.1	1.2 ± 0.1	1.1 ± 0.1
200-East N Central	4	21 ± 0.23	23 ± 1.4	9.6 ± 0.2	16 ± 0.1	26 ± 0.1	18 ± 0.2
E of 200-East	5	1.4 ± 0.06	3.0 ± 0.20	1.4 ± 0.1	0.69 ± 0.04	1.8 ± 0.1	2.1 ± 0.1
200-East SE	6	0.54 ± 0.04	0.55 ± 0.048	0.37 ± 0.03	0.61 ± 0.04	1.6 ± 0.1	0.59 ± 0.04
SW of BC Cribs	7	0.06 ± 0.02	0.14 ± 0.022	0.12 ± 0.02	0.01 ± 0.02	0.04 ± 0.02	0.52 ± 0.04
S of 200-East	8	0.14 ± 0.02	0.56 ± 0.053	0.71 ± 0.04	0.13 ± 0.03	0.58 ± 0.04	0.80 ± 0.04
E of 200-West	9	0.59 ± 0.04	2.0 ± 0.069	3.1 ± 0.1	1.3 ± 0.1	5.4 ± 1.7	3.0 ± 0.1
2 Miles S of 200-West	10	0.17 ± 0.03	0.30 ± 0.030	0.50 ± 0.04	—	0.49 ± 0.04	0.63 ± 0.04
NE of FFTF	11	0.12 ± 0.02	0.080 ± 0.028	—	0.33 ± 0.03	0.24 ± 0.03	0.19 ± 0.02
SE of FFTF	12	0.08 ± 0.02	0.083 ± 0.022	0.04 ± 0.02	—	0.12 ± 0.02	0.22 ± 0.03
N of 300 Area	13	0.43 ± 0.04	0.46 ± 0.052	0.54 ± 0.45	1.2 ± 0.1	0.51 ± 0.04	1.2 ± 0.1
Hanford Townsite	14	0.91 ± 0.05	1.1 ± 0.086	—	1.1 ± 0.1	0.88 ± 0.06	1.2 ± 0.1
Wye Barricade	15	0.68 ± 0.04	1.3 ± 0.098	—	0.59 ± 0.04	0.56 ± 0.04	0.39 ± 0.04
ONSITE AVERAGE		1.9 ± 2.8	2.3 ± 3.0	1.5 ± 1.4	2.0 ± 2.6	2.9 ± 3.2	2.1 ± 2.3
OFF SITE							
Riverview	16	0.077 ± 0.021	0.21 ± 0.026	0.17 ± 0.04	0.86 ± 0.05	1.3 ± 0.1	0.45 ± 0.04
Byers Landing	17	0.20 ± 0.03	0.19 ± 0.035	0.50 ± 0.04	0.23 ± 0.03	0.52 ± 0.03	0.68 ± 0.04
Sagemoor	18	1.0 ± 0.06	0.10 ± 0.023	0.32 ± 0.04	0.12 ± 0.02	1.0 ± 0.1	0.12 ± 0.02
Taylor Flats No. 2	19	0.084 ± 0.031	0.085 ± 0.028	1.2 ± 0.1	0.60 ± 0.06	0.39 ± 0.04	0.79 ± 0.06
W End Fir Road	20	0.12 ± 0.03	0.14 ± 0.025	0.25 ± 0.03	0.23 ± 0.04	0.28 ± 0.03	1.3 ± 0.1
Ringold	21	0.44 ± 0.044	1.1 ± 0.046	0.40 ± 0.04	1.0 ± 0.1	1.8 ± 0.06	1.7 ± 0.1
Berg Ranch	22	0.49 ± 0.046	0.58 ± 0.052	0.60 ± 0.05	0.31 ± 0.04	0.35 ± 0.03	0.53 ± 0.04
Wahluke Slope No. 2[d]	23	0.29 ± 0.03	0.47 ± 0.047	0.30 ± 0.03	0.16 ± 0.03	0.22 ± 0.03	0.25 ± 0.03
Vernita Bridge[d]	24	0.46 ± 0.037	0.20 ± 0.03	—	—	0.19 ± 0.04	0.66 ± 0.05
Yakima Barricade[d]	25	0.10 ± 0.028	1.1 ± 0.066	—	0.08 ± 0.02	0.08 ± 0.02	0.54 ± 0.04
Rattlesnake Springs[d]	26	0.14 ± 0.03	0.46 ± 0.037	0.37 ± 0.04	0.32 ± 0.04	0.08 ± 0.02	0.46 ± 0.03
ALE[d]	27	0.55 ± 0.04	1.6 ± 0.069	—	1.1 ± 0.1	1.0 ± 0.1	0.96 ± 0.06
Prosser Barricade[d]	28	0.15 ± 0.03	0.73 ± 0.045	0.32 ± 0.03	—	0.33 ± 0.03	0.86 ± 0.05
S of 300 Area[d]	29	1.1 ± 0.06	0.88 ± 0.072	0.68 ± 0.04	—	0.77 ± 0.04	1.1 ± 0.1
Benton City	30	0.53 ± 0.04	0.87 ± 0.064	0.79 ± 0.05	0.65 ± 0.04	0.91 ± 0.06	0.76 ± 0.05
Sunnyside	31	1.5 ± 0.071	0.29 ± 0.036	0.09 ± 0.03	0.29 ± 0.04	1.0 ± 0.3	0.48 ± 0.04

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

Location	Map Location[b]	pCi/g (dry weight)[a] 1984	1985	1986	1987	1988	1989
Walla Walla	32		0.29 ± 0.024	0.25 ± 0.03	0.07 ± 0.02	0.23 ± 0.03	0.07 ± 0.03
McNary Dam	33		0.52 ± 0.040	0.28 ± 0.03	0.30 ± 0.47	0.48 ± 0.04	0.54 ± 0.04
Moses Lake	34			0.24 ± 0.03	0.16 ± 0.09	0.38 ± 0.04	0.18 ± 0.03
Washtucna	35			1.2 ± 0.1	0.38 ± 0.17	0.97 ± 0.06	0.91 ± 0.05
Connell	36			1.7 ± 0.1	0.35 ± 0.61	0.46 ± 0.04	0.67 ± 0.05
Othello	37			0.26 ± 0.2	0.76 ± 0.42	0.22 ± 0.03	0.54 ± 0.04
Yakima	38			0.11 ± 0.1	0.16 ± 0.06	0.11 ± 0.02	0.56 ± 0.04
OFFSITE AVERAGE		0.44 ± 0.21	0.56 ± 0.19	0.80 ± 0.68	0.38 ± 0.12	0.59 ± 0.18	0.74 ± 0.27

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

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

Location	Map Location[b]	pCi/g (dry weight)[a] 1984	1985	1986	1987	1988	1989
ON SITE							
1 Mile NE of 100-N Area	1	0.015 ± 0.0020	0.016 ± 0.0016	0.015 ± 0.001	—[c]	0.011 ± 0.001	0.017 ± 0.002
1 Mile E of 100-N Area	2	0.016 ± 0.0027	0.013 ± 0.0011	0.012 ± 0.001	0.023 ± 0.002	0.019 ± 0.002	0.013 ± 0.001
100 Area Fire Station	3	0.021 ± 0.0017	0.024 ± 0.0016	0.030 ± 0.002	0.017 ± 0.001	0.027 ± 0.002	0.026 ± 0.003
200-East N Central	4	0.033 ± 0.0040	0.030 ± 0.0019	0.015 ± 0.002	0.031 ± 0.002	0.066 ± 0.003	0.031 ± 0.003
E of 200-East	5	0.012 ± 0.0015	0.026 ± 0.0017	0.011 ± 0.001	0.009 ± 0.001	0.017 ± 0.001	0.018 ± 0.002
200-East SE	6	0.0091 ± 0.0017	0.022 ± 0.0016	0.008 ± 0.001	0.012 ± 0.001	0.036 ± 0.002	0.011 ± 0.001
SW of BC Cribs	7	0.0034 ± 0.0019	0.024 ± 0.0022	0.004 ± 0.001	0.001 ± 0.001	0.001 ± 0.001	0.014 ± 0.001
S of 200-East	8	0.0056 ± 0.0031	0.0041 ± 0.0014	0.007 ± 0.001	0.003 ± 0.001	0.013 ± 0.001	0.015 ± 0.002
E of 200-West	9	0.074 ± 0.0040	0.33 ± 0.0069	0.34 ± 0.001	0.17 ± 0.01	0.67 ± 0.12	0.53 ± 0.01
2 Miles S of 200-West	10	0.0036 ± 0.0019	0.0094 ± 0.0011	0.013 ± 0.001	—	0.015 ± 0.001	0.022 ± 0.002
NE of FFTF	11	0.0021 ± 0.0007	0.0025 ± 0.0005	—	0.006 ± 0.001	0.005 ± 0.001	0.004 ± 0.001
SE of FFTF	12	0.0087 ± 0.0011	0.0021 ± 0.0005	0.001 ± 0.001	—	0.003 ± 0.001	0.006 ± 0.001
N of 300 Area	13	0.0064 ± 0.0029	0.010 ± 0.0011	0.008 ± 0.001	0.014 ± 0.001	0.011 ± 0.001	0.024 ± 0.002
Hanford Townsite	14	0.016 ± 0.0030	0.0059 ± 0.0009	—	0.019 ± 0.002	0.021 ± 0.002	0.027 ± 0.003
Wye Barricade	15	0.014 ± 0.0020	0.017 ± 0.0015	—	0.011 ± 0.001	0.008 ± 0.001	0.007 ± 0.001
ONSITE AVERAGE		0.016 ± 0.0090	0.035 ± 0.042	0.038 ± 0.005	0.026 ± 0.027	0.10 ± 0.11	0.051 ± 0.069
OFF SITE							
Riverview	16	0.0018 ± 0.0018	0.0052 ± 0.0098	0.003 ± 0.001	0.015 ± 0.001	0.022 ± 0.002	0.008 ± 0.001
Byers Landing	17	0.0066 ± 0.0040	0.0027 ± 0.0006	0.008 ± 0.001	0.003 ± 0.001	0.009 ± 0.001	0.014 ± 0.002
Sagemoor	18	0.019 ± 0.0021	0.0018 ± 0.0005	0.006 ± 0.001	0.002 ± 0.001	0.020 ± 0.002	0.019 ± 0.001
Taylor Flats No. 2	19	0.0014 ± 0.0005	0.0008 ± 0.0003	0.021 ± 0.003	0.019 ± 0.002	0.004 ± 0.001	0.015 ± 0.001
W End Fir Road	20	0.0022 ± 0.0015	0.0017 ± 0.0005	0.004 ± 0.001	0.003 ± 0.001	0.004 ± 0.001	0.028 ± 0.002
Ringold	21	0.0075 ± 0.0012	0.017 ± 0.0016	0.006 ± 0.001	0.017 ± 0.002	0.033 ± 0.002	0.029 ± 0.003
Berg Ranch	22	0.0097 ± 0.0015	0.011 ± 0.0011	0.012 ± 0.002	0.006 ± 0.001	0.008 ± 0.001	0.009 ± 0.002
Wahluke Slope No. 2[d]	23	0.0061 ± 0.0029	0.0087 ± 0.0015	0.006 ± 0.001	0.003 ± 0.001	0.007 ± 0.001	0.005 ± 0.001
Vernita Bridge[d]	24	0.0060 ± 0.0024	0.0095 ± 0.0010	0.003 ± 0.001	—	0.003 ± 0.001	0.013 ± 0.002
Yakima Barricade[d]	25	0.0016 ± 0.0011	0.022 ± 0.0015	—	0.002 ± 0.001	0.003 ± 0.001	0.011 ± 0.001
Rattlesnake Springs[d]	26	0.0032 ± 0.0016	0.0085 ± 0.0009	0.006 ± 0.001	0.006 ± 0.001	0.003 ± 0.001	0.011 ± 0.001
ALE[d]	27	0.0091 ± 0.0014	0.034 ± 0.0021	—	0.024 ± 0.002	0.026 ± 0.002	0.021 ± 0.002
Prosser Barricade[d]	28	0.0039 ± 0.0016	0.019 ± 0.0019	0.008 ± 0.001	—	0.006 ± 0.001	0.018 ± 0.002
S of 300 Area[d]	29	0.022 ± 0.0023	0.018 ± 0.0015	0.015 ± 0.001	—	0.017 ± 0.001	0.025 ± 0.002
Benton City	30	0.0099 ± 0.0015	0.019 ± 0.0020	0.016 ± 0.001	0.014 ± 0.001	0.014 ± 0.002	0.015 ± 0.001
Sunnyside	31	0.025 ± 0.0026	0.015 ± 0.0016	0.002 ± 0.001	0.006 ± 0.001	0.023 ± 0.006	0.011 ± 0.002

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

Location	Map Location[b]	pCi/g (dry weight)[a] 1984	19[illegible]	1986	1987	1988	1989
Walla Walla	32		0.013 ± 0.0012	0.005 ± 0.001	0.002 ± 0.002	0.003 ± 0.001	0.001 ± 0.001
McNary Dam	33		0.015 ± 0.0023	0.007 ± 0.001	0.006 ± 0.008	0.009 ± 0.001	0.009 ± 0.002
Moses Lake	34			0.016 ± 0.001	0.002 ± 0.001	0.008 ± 0.001	0.002 ± 0.001
Washtucna	35			0.024 ± 0.002	0.006 ± 0.003	0.016 ± 0.001	0.017 ± 0.002
Connell	36			0.027 ± 0.002	0.007 ± 0.011	0.008 ± 0.001	0.010 ± 0.002
Othello	37			0.004 ± 0.001	0.013 ± 0.011	0.004 ± 0.001	0.008 ± 0.002
Yakima	38			0.002 ± 0.001	0.003 ± 0.003	0.003 ± 0.001	0.010 ± 0.001
OFFSITE AVERAGE		0.0084 ± 0.0037	0.012 ± 0.0046	0.009 ± 0.003	0.007 ± 0.002	0.011 ± 0.004	0.013 ± 0.003

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

TABLE C.29. Uranium Concentrations in Soil

Location	Map Location[d]	Total Uranium,[a] pCi/g (dry weight)[b] 1984	1985	1986	1987	^{238}U,[c] pCi/g (dry weight)[b] 1988	1989
ON SITE							
1 Mile NE of 100-N	1	0.42 ± 0.11	0.49 ± 0.16	0.19 ± 0.06	—[e]	0.78 ± 0.45	0.35 ± 0.20
1 Mile E of 100-N	2	0.32 ± 0.088	0.40 ± 0.13	0.45 ± 0.13	0.34 ± 0.10	0.71 ± 0.44	0.67 ± 0.22
100 Area Fire Station	3	0.45 ± 0.12	0.44 ± 0.15	0.53 ± 0.15	0.35 ± 0.10	0.88 ± 0.30	0.97 ± 0.29
200-East N Central	4	0.36 ± 0.098	0.39 ± 0.13	0.28 ± 0.08	0.23 ± 0.06	0.64 ± 0.50	0.44 ± 0.26
E of 200-East	5	0.32 ± 0.08	0.46 ± 0.15	0.47 ± 0.13	0.31 ± 0.09	1.2 ± 0.3	0.40 ± 0.23
200-East SE	6	0.37 ± 0.070	0.39 ± 0.13	0.03 ± 0.08	0.25 ± 0.07	1.2 ± 0.3	0.91 ± 0.28
SW of BC Cribs	7	1.0 ± 0.15	0.33 ± 0.11	0.32 ± 0.09	0.19 ± 0.05	0.61 ± 0.48	0.85 ± 0.26
S of 200-East	8	0.46 ± 0.22	0.34 ± 0.11	0.32 ± 0.09	0.22 ± 0.06	0.66 ± 0.33	0.39 ± 0.23
E of 200-West	9	0.53 ± 0.29	0.43 ± 0.14	0.48 ± 0.13	0.39 ± 0.11	0.77 ± 0.31	0.97 ± 0.29
2 Miles S of 200-West	10	0.34 ± 0.092	0.47 ± 0.16	0.49 ± 0.14	—	0.65 ± 0.33	0.39 ± 0.22
NE of FFTF	11	0.30 ± 0.082	0.39 ± 0.13	—	0.24 ± 0.07	0.54 ± 0.45	0.72 ± 0.29
SE of FFTF	12	0.27 ± 0.073	0.40 ± 0.13	0.37 ± 0.11	—	0.76 ± 0.32	0.56 ± 0.17
N of 300 Area	13	0.76 ± 0.20	3.9 ± 1.1	0.66 ± 0.19	3.8 ± 1.1	0.90 ± 0.47	0.34 ± 0.19
Hanford Townsite	14	0.34 ± 0.093	0.35 ± 0.12	—	0.42 ± 0.12	0.44 ± 0.46	0.42 ± 0.28
Wye Barricade	15	0.65 ± 0.10	0.29 ± 0.097	—	0.19 ± 0.05	0.45 ± 0.45	0.66 ± 0.20
ONSITE AVERAGE		0.46 ± 0.11	0.82 ± 0.66	0.40 ± 0.08	0.58 ± 0.59	0.74 ± 0.15	0.60 ± 0.12
OFF SITE							
Riverview	16	0.32 ± 0.085	0.44 ± 0.14	0.26 ± 0.07	0.30 ± 0.08	0.90 ± 0.46	0.58 ± 0.20
Byers Landing	17	0.43 ± 0.11	0.39 ± 0.13	0.26 ± 0.07	0.10 ± 0.03	0.90 ± 0.48	0.42 ± 0.23
Sagemoor	18	0.50 ± 0.13	0.58 ± 0.18	0.31 ± 0.08	0.24 ± 0.07	0.63 ± 0.31	0.75 ± 0.29
Taylor Flats No. 2	19	1.0 ± 0.26	1.3 ± 0.36	0.44 ± 0.12	0.97 ± 0.27	0.93 ± 0.55	0.87 ± 0.24
W End Fir Road	20	0.54 ± 0.14	0.73 ± 0.22	0.32 ± 0.09	0.55 ± 0.15	0.86 ± 0.34	0.56 ± 0.21
Ringold	21	0.78 ± 0.21	0.84 ± 0.26	1.1 ± 0.3	0.67 ± 0.19	0.83 ± 0.35	0.50 ± 0.19
Berg Ranch	22	0.41 ± 0.11	0.43 ± 0.14	0.28 ± 0.08	0.38 ± 0.11	0.55 ± 0.46	0.80 ± 0.24
Wahluke Slope No. 2[f]	23	0.43 ± 0.12	0.35 ± 0.12	0.21 ± 0.06	0.17 ± 0.05	0.68 ± 0.49	1.1 ± 0.3
Vernita Bridge[f]	24	0.92 ± 0.26	0.73 ± 0.22	0.34 ± 0.09	—	0.58 ± 0.32	0.58 ± 0.20
Yakima Barricade[f]	25	0.21 ± 0.056	0.35 ± 0.12	—	0.27 ± 0.08	1.0 ± 0.5	0.40 ± 0.19
Rattlesnake Springs[f]	26	0.26 ± 0.069	0.44 ± 0.14	0.26 ± 0.07	0.28 ± 0.08	0.78 ± 0.45	0.84 ± 0.25
ALE[f]	27	0.25 ± 0.067	0.46 ± 0.15	—	0.45 ± 0.13	0.68 ± 0.36	1.5 ± 0.3
Prosser Barricade[f]	28	0.36 ± 0.06	0.80 ± 0.24	0.25 ± 0.07	—	0.81 ± 0.43	0.61 ± 0.22
S of 300 Area[f]	29	1.0 ± 0.29	0.66 ± 0.21	0.56 ± 0.16	—	0.94 ± 0.33	1.1 ± 0.3
Benton City	30	0.91 ± 0.24	0.64 ± 0.20	0.45 ± 0.12	0.39 ± 0.11	1.1 ± 0.4	0.45 ± 0.19
Sunnyside	31	0.26 ± 0.071	0.26 ± 0.090	0.31 ± 0.09	0.29 ± 0.08	0.70 ± 0.39	1.0 ± 0.3

TABLE C.29. Uranium Concentrations in Soil (contd)

Location	Map Location[d]	Total Uranium,[a] pCi/g (dry weight)[b]												^{238}U,[c] pCi/g (dry weight)[b]					
		1984			1985			1986			1987			1988			1989		
Walla Walla	32				0.20	±	0.071	0.35	±	0.10	0.62	±	0.17	0.66	±	0.34	1.3	±	0.3
McNary Dam	33				0.15	±	0.055	0.41	±	0.12	0.32	±	0.09	0.59	±	0.33	0.56	±	0.21
Moses Lake	34							0.11	±	0.03	0.19	±	0.05	0.42	±	0.29	0.37	±	0.19
Washtucna	35							0.20	±	0.06	0.24	±	0.07	0.73	±	0.39	0.72	±	0.24
Connell	36							0.25	±	0.07	0.32	±	0.09	0.53	±	0.30	0.69	±	0.29
Othello	37							0.21	±	0.06	0.24	±	0.06	0.58	±	0.30	0.64	±	0.18
Yakima	38							0.48	±	0.14	0.41	±	0.11	1.0	±	0.5	0.45	±	0.22
OFFSITE AVERAGE		0.54	±	0.15	0.54	±	0.14	0.35	±	0.09	0.36	±	0.07	0.75	±	0.11	0.73	±	0.13

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

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

Location	Map Location[b]	pCi/g (dry weight)[a] 1984	1985	1986	1987	1988	1989
ON SITE							
1 Mile NE of 100-N Area	1	0.069 ± 0.007	0.078 ± 0.072	NS	—[c]	0.050 ± 0.007	0.071 ± 0.007
1 Mile E of 100-N Area	2	0.12 ± 0.012	0.012 ± 0.0012	0.14 ± 0.01	0.038 ± 0.008	0.049 ± 0.005	0.10 ± 0.01
100 Area Fire Station	3	0.11 ± 0.011	0.17 ± 0.017	0.14 ± 0.01	0.010 ± 0.005	0.041 ± 0.005	0.060 ± 0.005
200-East N Central	4	0.39 ± 0.020	0.41 ± 0.018	0.38 ± 0.01	0.13 ± 0.01	0.096 ± 0.007	0.26 ± 0.01
E of 200-East	5	0.20 ± 0.030	0.25 ± 0.019	0.18 ± 0.01	0.24 ± 0.02	0.12 ± 0.01	0.16 ± 0.01
200-East SE	6	0.20 ± 0.013	0.53 ± 0.018	8.2 ± 0.1	0.086 ± 0.010	0.066 ± 0.006	0.13 ± 0.01
SW of BC Cribs	7	0.11 ± 0.030	0.41 ± 0.016	NS	0.071 ± 0.009	0.092 ± 0.007	0.28 ± 0.01
S of 200-East	8	1.1 ± 0.066	0.44 ± 0.022	0.14 ± 0.01	0.089 ± 0.010	0.14 ± 0.01	0.26 ± 0.01
E of 200-West	9	0.13 ± 0.020	1.1 ± 0.026	0.13 ± 0.01	0.10 ± 0.01	0.078 ± 0.008	0.20 ± 0.01
2 Miles S of 200-West	10	0.19 ± 0.007	0.89 ± 0.035	0.14 ± 0.01	—	0.046 ± 0.006	0.069 ± 0.007
NE of FFTF	11	0.022 ± 0.006	0.28 ± 0.015	—	0.025 ± 0.005	0.014 ± 0.004	0.026 ± 0.007
SE of FFTF	12	0.088 ± 0.009	0.28 ± 0.019	NS	—	0.016 ± 0.005	0.044 ± 0.005
N of 300 Area	13	0.023 ± 0.004	0.13 ± 0.016	0.26 ± 0.01	0.021 ± 0.004	0.008 ± 0.003	0.027 ± 0.004
Hanford Townsite	14	0.044 ± 0.006	0.18 ± 0.013	—	0.087 ± 0.009	0.081 ± 0.006	0.039 ± 0.004
Wye Barricade	15	0.016 ± 0.007	0.15 ± 0.012	—	0.012 ± 0.004	0.034 ± 0.005	0.027 ± 0.004
ONSITE AVERAGE		0.19 ± 0.14	0.36 ± 0.16	1.1 ± 1.8	0.075 ± 0.004	0.062 ± 0.020	0.012 ± 0.05
OFF SITE							
Riverview	16	0.015 ± 0.010	0.069 ± 0.085	0.039 ± 0.004	0.018 ± 0.005	0.014 ± 0.005	0.065 ± 0.007
Byers Landing	17	0.018 ± 0.008	0.057 ± 0.089	0.074 ± 0.006	0.007 ± 0.005	0.052 ± 0.006	0.067 ± 0.006
Sagemoor	18	0.067 ± 0.012	0.097 ± 0.011	NS	0.046 ± 0.008	0.010 ± 0.005	0.042 ± 0.005
Taylor Flats No. 2	19	0.063 ± 0.010	0.10 ± 0.010	0.054 ± 0.006	0.064 ± 0.010	0.047 ± 0.006	0.080 ± 0.006
W End Fir Road	20	0.047 ± 0.016	0.076 ± 0.088	0.062 ± 0.005	0.040 ± 0.007	0.013 ± 0.005	0.053 ± 0.005
Ringold	21	0.051 ± 0.010	0.066 ± 0.0081	0.059 ± 0.005	0.012 ± 0.005	0.048 ± 0.007	0.024 ± 0.004
Berg Ranch	22	0.092 ± 0.026	0.050 ± 0.079	NS	0.036 ± 0.009	0.043 ± 0.006	0.089 ± 0.008
Wahluke Slope No. 2[d]	23	0.046 ± 0.013	0.15 ± 0.012	NS	0.038 ± 0.008	0.046 ± 0.005	0.15 ± 0.02
Vernita Bridge[d]	24	0.073 ± 0.011	0.21 ± 0.011	NS	—	0.034 ± 0.005	0.027 ± 0.005
Yakima Barricade[d]	25	0.022 ± 0.003	0.21 ± 0.011	—	0.034 ± 0.007	0.021 ± 0.003	0.069 ± 0.006
Rattlesnake Springs[d]	26	0.087 ± 0.011	1.7 ± 0.033	0.14 ± 0.01	0.073 ± 0.009	0.016 ± 0.004	0.043 ± 0.005
ALE[d]	27	0.082 ± 0.007	0.095 ± 0.090	—	0.036 ± 0.006	0.017 ± 0.005	0.060 ± 0.006
Prosser Barricade[d]	28	0.12 ± 0.009	NS	0.084 ± 0.07	—	0.067 ± 0.006	0.020 ± 0.005
S of 300 Area[d]	29	0.047 ± 0.005	0.091 ± 0.014	0.10 ± 0.01	—	0.036 ± 0.005	0.079 ± 0.006
Benton City	30	0.055 ± 0.016	0.30 ± 0.013	0.14 ± 0.01	0.045 ± 0.009	0.025 ± 0.004	0.058 ± 0.006
Sunnyside	31	0.037 ± 0.008	0.061 ± 0.075	0.044 ± 0.00	0.061 ± 0.008	0.067 ± 0.006	0.053 ± 0.006

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

Location	Map Location[b]	pCi/g (dry weight)[a] 1984	1985	1986	1987	1988	1989
Walla Walla	32				0.039 ± 0.008	0.031 ± 0.005	0.011 ± 0.003
McNary Dam	33				0.007 ± 0.003	0.065 ± 0.006	0.026 ± 0.004
Moses Lake	34				0.023 ± 0.008	0.020 ± 0.005	0.013 ± 0.003
Washtucna	35				0.091 ± 0.011	0.052 ± 0.006	0.030 ± 0.005
Cornell	36				0.024 ± 0.005	0.018 ± 0.004	0.055 ± 0.006
Othello	37				0.053 ± 0.007	0.046 ± 0.006	0.049 ± 0.005
Yakima	38				0.024 ± 0.006	0.019 ± 0.005	0.029 ± 0.005
OFFSITE AVERAGE		0.057 ± 0.015	0.22 ± 0.21	0.080 ± 0.023	0.038 ± 0.010	0.035 ± 0.008	0.052 ± 0.013

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

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

Location	Map Location[b]	pCi/g (dry weight)[a] 1984	1985	1986	1987	1988	1989
ON SITE							
1 Mile NE of 100-N Area	1	0.0097 ± 0.014	0.015 ± 0.011	0.027 ± 0.017	---[c]	0.009 ± 0.14	0.014 ± 0.016
1 Mile E of 100-N Area	2	0.0032 ± 0.013	0.003 ± 0.025	0.007 ± 0.022	0.21 ± 0.03	0.024 ± 0.015	0.013 ± 0.018
100 Area Fire Station	3	0.015 ± 0.012	0.016 ± 0.014	0.034 ± 0.0177	0.11 ± 0.02	0.018 ± 0.014	0.020 ± 0.017
200-East N Central	4	0.24 ± 0.020	0.36 ± 0.042	0.20 ± 0.03	0.32 ± 0.03	0.25 ± 0.02	0.030 ± 0.032
E of 200-East	5	0.069 ± 0.013	0.12 ± 0.030	0.11 ± 0.03	0.11 ± 0.02	0.057 ± 0.016	0.070 ± 0.014
200-East SE	6	0.079 ± 0.017	0.078 ± 0.020	0.10 ± 0.02	0.11 ± 0.02	0.022 ± 0.014	0.030 ± 0.015
SW of BC Cribs	7	0.018 ± 0.013	0.038 ± 0.016	0.011 ± 0.017	0.052 ± 0.018	-0.005 ± 0.015	0.004 ± 0.016
S of 200-East	8	0.022 ± 0.011	0.068 ± 0.015	0.029 ± 0.017	0.035 ± 0.020	0.004 ± 0.020	0.026 ± 0.015
E of 200-West	9	0.055 ± 0.016	0.052 ± 0.017	0.032 ± 0.020	0.054 ± 0.019	0.034 ± 0.016	0.038 ± 0.022
2 Miles S of 200-West	10	0.011 ± 0.012	0.019 ± 0.023	0.029 ± 0.020	---	0.011 ± 0.018	0.021 ± 0.016
NE of FFTF	11	0.0064 ± 0.11	0.048 ± 0.020	---	0.056 ± 0.023	0.001 ± 0.016	0.004 ± 0.017
SE of FFTF	12	-0.0095 ± 0.015	0.032 ± 0.018	0.017 ± 0.012	---	0.011 ± 0.016	0.018 ± 0.015
N of 300 Area	13	0.011 ± 0.009	0.024 ± 0.016	0.17 ± 0.51	0.053 ± 0.016	0.003 ± 0.013	0.013 ± 0.014
Hanford Townsite	14	0.010 ± 0.020	0.038 ± 0.022	---	0.097 ± 0.022	0.024 ± 0.013	0.046 ± 0.018
Wye Barricade	15	0.0037 ± 0.011	0.035 ± 0.015	---	0.053 ± 0.020	0.022 ± 0.012	0.009 ± 0.017
ONSITE AVERAGE		0.034 ± 0.033	0.062 ± 0.045	0.071 ± 0.051	0.10 ± 0.05	0.033 ± 0.033	0.041 ± 0.037
OFF SITE							
Riverview	16	-0.0001 ± 0.014	-0.0054 ± 0.011	1.1 ± 0.1	0.049 ± 0.016	0.003 ± 0.011	0.012 ± 0.017
Byers Landing	17	0.024 ± 0.012	0.017 ± 0.011	1.9 ± 0.1	0.049 ± 0.023	0.015 ± 0.015	0.009 ± 0.017
Sagemoor	18	0.003 ± 0.012	0.013 ± 0.014	1.2 ± 0.1	0.035 ± 0.017	0.007 ± 0.017	0.004 ± 0.022
Taylor Flats No. 2	19	0.016 ± 0.013	0.011 ± 0.022	1.7 ± 0.1	0.030 ± 0.015	0.017 ± 0.013	0.012 ± 0.017
W End Fir Road	20	0.095 ± 0.021	0.022 ± 0.021	1.2 ± 0.1	0.012 ± 0.013	0.013 ± 0.017	0.005 ± 0.019
Ringold	21	-0.0008 ± 0.013	0.0083 ± 0.013	1.5 ± 0.1	0.031 ± 0.014	0.025 ± 0.014	0.012 ± 0.018
Berg Ranch	22	0.027 ± 0.011	0.0073 ± 0.014	0.009 ± 0.013	0.11 ± 0.03	0.008 ± 0.016	0.005 ± 0.018
Wahluke Slope No. 2[d]	23	-0.0012 ± 0.012	0.023 ± 0.013	0.026 ± 0.024	0.075 ± 0.025	0.026 ± 0.017	0.001 ± 0.001
Vernita Bridge[d]	24	0.005 ± 0.010	0.0061 ± 0.015	0.009 ± 0.022	---	0.021 ± 0.014	0.008 ± 0.022
Yakima Barricade[d]	25	0.00 ± 0.013	0.0027 ± 0.015	---	0.018 ± 0.013	-0.006 ± 0.020	0.018 ± 0.017
Rattlesnake Springs[d]	26	0.0054 ± 0.013	0.016 ± 0.014	0.81 ± 0.05	0.047 ± 0.017	0.009 ± 0.013	0.002 ± 0.017
ALE[d]	27	-0.0006 ± 0.012	0.022 ± 0.013	---	0.049 ± 0.020	-0.006 ± 0.015	0.003 ± 0.016
Prosser Barricade[d]	28	0.012 ± 0.012	NS	0.004 ± 0.025	---	0.031 ± 0.018	0.009 ± 0.021
S of 300 Area[d]	29	0.0032 ± 0.013	0.013 ± 0.020	0.018 ± 0.023	---	0.014 ± 0.017	0.010 ± 0.015
Benton City	30	0.0041 ± 0.011	0.093 ± 0.021	1.4 ± 0.1	0.002 ± 0.016	0.008 ± 0.020	0.021 ± 0.019

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

Location	Map Location[b]	pCi/g (dry weight)[a] 1984	1985	1986	1987	1988	1989
Sunnyside	31	0.018 ± 0.012	0.018 ± 0.015	0.34 ± 0.03	0.004 ± 0.023	0.026 ± 0.012	0.016 ± 0.022
Walla Walla	32			0.006 ± 0.020	0.029 ± 0.015	0.016 ± 0.020	0.004 ± 0.016
McNary Dam	33			0.014 ± 0.019	0.042 ± 0.020	0.011 ± 0.014	0.004 ± 0.016
Moses Lake	34			0.85 ± 0.05	0.079 ± 0.023	-0.001 ± 0.016	0.007 ± 0.018
Washtucna	35			0.98 ± 0.05	0.023 ± 0.018	0.002 ± 0.016	0.005 ± 0.018
Connell	36			0.027 ± 0.017	0.029 ± 0.014	0.007 ± 0.018	0.006 ± 0.017
Othello	37			0.002 ± 0.019	0.012 ± 0.017	-0.001 ± 0.017	0.017 ± 0.019
Yakima	38			0.21 ± 0.03	0.011 ± 0.015	0.012 ± 0.017	0.019 ± 0.016
OFFSITE AVERAGE		0.0078 ± 0.0055	0.018 ± 0.012	0.64 ± 0.29	0.039 ± 0.012	0.011 ± 0.005	0.007 ± 0.003

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

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

Location	Map Location[b]	pCi/g (dry weight)[a] 1984	1985	1986	1987	1988	1989
ON SITE							
1 Mile NE of 100-N	1	0.0005 ± 0.00015	0.00013 ± 0.00015	NS	—[c]	0.00030 ± 0.00025	0.00033 ± 0.00030
1 Mile E of 100-N	2	0.00012 ± 0.00030	0.00036 ± 0.00020	0.00048 ± 0.00026	0.00061 ± 0.00027	0.0014 ± 0.0005	0.00037 ± 0.00031
100 Area Fire Station	3	0.00012 ± 0.00025	0.00032 ± 0.00018	0.00041 ± 0.00029	0.00064 ± 0.00032	0.00024 ± 0.00022	0.00038 ± 0.00024
200-East N Central	4	0.00042 ± 0.00022	0.00067 ± 0.00026	0.00070 ± 0.00042	0.0021 ± 0.0005	0.00053 ± 0.00038	0.0017 ± 0.0005
E of 200-East	5	0.00074 ± 0.00066	0.0075 ± 0.0011	0.0010 ± 0.0003	0.0010 ± 0.0003	0.00054 ± 0.00037	0.00071 ± 0.00041
200-East SE	6	0.00093 ± 0.00066	0.0018 ± 0.00043	0.0021 ± 0.0005	0.0012 ± 0.0004	0.00040 ± 0.00037	0.00048 ± 0.00028
SW of BC Cribs	7	0.00054 ± 0.00061	0.00096 ± 0.00032	NS	0.00077 ± 0.00033	0.0011 ± 0.0005	0.0010 ± 0.0004
S of 200-East	8	0.00044 ± 0.00037	0.0025 ± 0.00051	0.0017 ± 0.0004	0.00062 ± 0.00032	0.0017 ± 0.0006	0.00019 ± 0.00020
E of 200-West	9	0.0065 ± 0.0018	0.0060 ± 0.00083	0.0044 ± 0.0012	0.0082 ± 0.0015	0.0032 ± 0.0010	0.0082 ± 0.0008
2 Miles S of 200-West	10	0.0001 ± 0.00020	0.00059 ± 0.00028	0.00094 ± 0.00036	—	0.00039 ± 0.00025	0.00053 ± 0.00025
NE of FFTF	11	0.00036 ± 0.00039	0.00047 ± 0.00023	—	0.00012 ± 0.00012	0.00006 ± 0.00015	0.00009 ± 0.00019
SE of FFTF	12	0.00083 ± 0.00063	0.00049 ± 0.00030	NS	—	0.00016 ± 0.00024	0.00020 ± 0.00013
N of 300 Area	13	0.0022 ± 0.0011	0.00026 ± 0.00014	0.00053 ± 0.00025	0.00021 ± 0.00019	0.00012 ± 0.00016	0.00029 ± 0.00018
Hanford Townsite	14	0.00055 ± 0.00035	0.00042 ± 0.00022	—	0.00016 ± 0.00013	0.00040 ± 0.00023	0.00050 ± 0.00028
Wye Barricade	15	0.00078 ± 0.00088	0.0012 ± 0.00038	—	0.00018 ± 0.00014	0.00009 ± 0.00014	0.00013 ± 0.00014
ONSITE AVERAGE		0.0010 ± 0.00085	0.0016 ± 0.0012	0.0014 ± 0.0009	0.0013 ± 0.0013	0.00071 ± 0.00045	0.0010 ± 0.0010
OFF SITE							
Riverview	16	-0.00013 ± 0.00017	0.00075 ± 0.00039	0.00029 ± 0.00028	0.00010 ± 0.00011	0.00023 ± 0.00020	0.00022 ± 0.00016
Byers Landing	17	0.00010 ± 0.00010	0.00015 ± 0.00013	0.00029 ± 0.00024	0.00037 ± 0.00023	0.00022 ± 0.00019	0.00010 ± 0.00015
Sagemoor	18	0.00012 ± 0.00014	0.00022 ± 0.00017	NS	0.00005 ± 0.00008	0.00027 ± 0.00028	0.00004 ± 0.00010
Taylor Flats No. 2	19	-0.00010 ± 0.00010	0.00036 ± 0.00028	0.00015 ± 0.00015	0.00028 ± 0.00018	0.00026 ± 0.00021	0.00014 ± 0.00019
W End Fir Road	20	0.00039 ± 0.00048	0.00019 ± 0.00015	0.00007 ± 0.00015	0.00004 ± 0.00018	0.00009 ± 0.00011	0.00003 ± 0.00009
Ringold	21	-0.00007 ± 0.00030	0.00019 ± 0.00017	0.00033 ± 0.00031	0.00001 ± 0.00001	0.00017 ± 0.00027	0.00005 ± 0.00009
Berg Ranch	22	0.00080 ± 0.00059	0.00058 ± 0.00031	NS	0.00023 ± 0.00018	0.00012 ± 0.00016	0.00009 ± 0.00024
Wahluke Slope No. 2[d]	23	0.00017 ± 0.00028	0.00026 ± 0.00021	NS	0.00020 ± 0.00016	0.00019 ± 0.00017	0.00012 ± 0.00012
Vernita Bridge[d]	24	0.00035 ± 0.00025	0.00017 ± 0.00028	NS	—	0.00021 ± 0.00019	0.00014 ± 0.00018
Yakima Barricade[d]	25	0.00027 ± 0.00044	0.00056 ± 0.00022	—	0.00017 ± 0.00018	0.00043 ± 0.00026	0.00030 ± 0.00025
Rattlesnake Springs[d]	26	0.00022 ± 0.00022	0.00040 ± 0.00021	0.00013 ± 0.00012	0.00037 ± 0.00022	0.00047 ± 0.00034	0.00022 ± 0.00017
ALE[d]	27	0.00074 ± 0.00063	0.00054 ± 0.00025	—	0.00020 ± 0.00014	0.00031 ± 0.00024	0.00009 ± 0.00012
Prosser Barricade[d]	28	0.00017 ± 0.00031	NS	0.00071 ± 0.00027	—	0.00043 ± 0.00036	0.00004 ± 0.00009
S of 300 Area[d]	29	0.00036 ± 0.00067	0.00045 ± 0.00021	0.0026 ± 0.00027	—	0.00007 ± 0.00017	0.00005 ± 0.00013
Benton City	30	-0.00015 ± 0.00025	0.0019 ± 0.00048	0.0013 ± 0.00016	0.00005 ± 0.00011	0.00014 ± 0.00015	0.00017 ± 0.00018
Sunnyside	31	0.00031 ± 0.00025	0.00017 ± 0.00014	0.0006 ± 0.00011	0.00015 ± 0.00017	0.00083 ± 0.00034	0.00017 ± 0.00015

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

Location	Map Location[b]	pCi/g (dry weight)[a] 1984	1985	1986	1987	1988	1989
Walla Walla	32				0.00008 ± 0.00002	0.00030 ± 0.00022	0.00012 ± 0.00012
McNary Dam	33				0.00011 ± 0.00014	0.00048 ± 0.00031	0.00014 ± 0.00012
Moses Lake	34				0.00024 ± 0.00020	0.00027 ± 0.00030	0.00015 ± 0.00015
Washtucna	35				0.00005 ± 0.00008	0.00020 ± 0.00021	0.00003 ± 0.00020
Connell	36				0.00007 ± 0.00009	0.00027 ± 0.00025	0.00001 ± 0.00000
Othello	37				0.00015 ± 0.00016	-0.00001 ± 0.00000	0.00004 ± 0.00009
Yakima	38				0.00010 ± 0.00013	0.00005 ± 0.00013	0.00002 ± 0.00005
OFFSITE AVERAGE		0.00022 ± 0.00017	0.00046 ± 0.00023	0.00047 ± 0.00049	0.00015 ± 0.00006	0.00026 ± 0.00009	0.00010 ± 0.00004

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

TABLE C.33. Uranium Concentrations in Vegetation

Location	Map Location[b]	pCi/g (dry weight)[a] 1984	1985	1986	1987	1988	1989
ON SITE							
1 Mile NE of 100-N Area	1	0.007 ± 0.0034	0.0076 ± 0.0056	NS	—[c]	0.005 ± 0.002	0.009 ± 0.003
1 Mile E of 100-N Area	2	0.0061 ± 0.0030	0.013 ± 0.0074	0.0060 ± 0.0017	0.014 ± 0.004	0.004 ± 0.001	0.014 ± 0.004
100 Area Fire Station	3	0.0067 ± 0.0033	0.016 ± 0.0078	0.0054 ± 0.0016	0.008 ± 0.002	0.001 ± 0.001	0.004 ± 0.001
200-East N Central	4	0.0092 ± 0.0037	0.015 ± 0.0076	0.011 ± 0.003	0.014 ± 0.004	0.007 ± 0.002	0.026 ± 0.008
E of 200-East	5	0.0066 ± 0.0042	0.011 ± 0.0064	0.0046 ± 0.0013	0.029 ± 0.08	-0.001 ± 0.001	0.010 ± 0.003
200-East SE	6	0.0052 ± 0.0040	0.016 ± 0.0080	0.013 ± 0.004	0.016 ± 0.04	0.003 ± 0.001	0.015 ± 0.005
SW of BC Cribs	7	0.017 ± 0.0077	0.014 ± 0.0077	NS	0.007 ± 0.002	0.003 ± 0.001	0.009 ± 0.003
S of 200-East	8	0.011 ± 0.0054	0.035 ± 0.014	0.0072 ± 0.0021	0.025 ± 0.007	0.001 ± 0.001	0.014 ± 0.004
E of 200-West	9	0.016 ± 0.0065	0.022 ± 0.0096	0.016 ± 0.005	—	0.001 ± 0.001	0.017 ± 0.005
2 Miles S of 200-West	10	0.015 ± 0.0058	0.0096 ± 0.0063	0.0060 ± 0.0017	0.025 ± 0.007	0.007 ± 0.002	0.015 ± 0.004
NE of FFTF	11	0.014 ± 0.005	0.0081 ± 0.0054	—	0.015 ± 0.004	0.006 ± 0.002	0.015 ± 0.004
SE of FFTF	12	0.0050 ± 0.0027	0.022 ± 0.0098	NS	—	0.002 ± 0.001	0.018 ± 0.005
N of 300 Area	13	0.012 ± 0.0046	0.082 ± 0.027	0.018 ± 0.005	0.016 ± 0.004	0.019 ± 0.006	0.012 ± 0.004
Hanford Townsite	14	0.0032 ± 0.0022	0.015 ± 0.0080	—	0.010 ± 0.003	0.004 ± 0.001	0.026 ± 0.008
Wye Barricade	15	0.0045 ± 0.0036	0.021 ± 0.0095	—	0.007 ± 0.002	0.005 ± 0.002	0.009 ± 0.003
ONSITE AVERAGE		0.0093 ± 0.0026	0.021 ± 0.0099	0.0097 ± 0.0030	0.002 ± 0.004	0.005 ± 0.002	0.014 ± 0.003
OFF SITE							
Riverview	16	0.021 ± 0.0076	0.0099 ± 0.0060	0.015 ± 0.004	0.018 ± 0.005	0.009 ± 0.003	0.008 ± 0.003
Byers Landing	17	0.022 ± 0.0078	0.19 ± 0.058	0.021 ± 0.006	0.020 ± 0.006	0.020 ± 0.006	0.012 ± 0.004
Sagemoor	18	0.012 ± 0.0050	0.019 ± 0.0086	NS	0.012 ± 0.003	0.006 ± 0.002	0.009 ± 0.003
Taylor Flats No. 2	19	0.011 ± 0.0044	0.022 ± 0.0096	0.016 ± 0.005	0.031 ± 0.009	0.012 ± 0.004	0.012 ± 0.004
W End Fir Road	20	0.036 ± 0.012	0.038 ± 0.014	0.0092 ± 0.0027	0.023 ± 0.006	0.022 ± 0.007	0.016 ± 0.005
Ringold	21	0.025 ± 0.0085	0.041 ± 0.015	0.011 ± 0.003	0.049 ± 0.014	0.021 ± 0.006	0.021 ± 0.006
Berg Ranch	22	0.017 ± 0.0066	0.0097 ± 0.0063	NS	0.014 ± 0.004	0.006 ± 0.002	0.006 ± 0.002
Wahluke Slope No. 2[d]	23	0.0088 ± 0.0039	0.015 ± 0.0079	NS	0.018 ± 0.005	0.011 ± 0.003	0.010 ± 0.003
Vernita Bridge[d]	24	0.011 ± 0.0045	0.020 ± 0.0090	NS	—	0.004 ± 0.001	0.042 ± 0.013
Yakima Barricade[d]	25	0.0037 ± 0.0020	0.020 ± 0.0090	—	0.009 ± 0.001	0.005 ± 0.002	0.013 ± 0.004
Rattlesnake Springs[d]	26	0.0042 ± 0.0022	0.013 ± 0.0068	0.0097 ± 0.0028	0.012 ± 0.003	0.001 ± 0.001	0.016 ± 0.005
ALE[d]	27	0.0057 ± 0.0025	0.0075 ± 0.0054	—	0.016 ± 0.004	0.001 ± 0.001	0.008 ± 0.002
Prosser Barricade[d]	28	0.0042 ± 0.0023	NS	0.0097 ± 0.0028	—	0.008 ± 0.003	0.013 ± 0.004
S of 300 Area[d]	29	0.014 ± 0.0053	0.036 ± 0.014	0.014 ± 0.004	—	0.011 ± 0.003	0.035 ± 0.010
Benton City	30	0.014 ± 0.0056	0.013 ± 0.0074	0.021 ± 0.006	0.018 ± 0.005	0.007 ± 0.002	0.006 ± 0.002

TABLE C.33. Uranium Concentrations in Vegetation (contd)

Location	Map Location[b]	pCi/g (dry weight)[a] 1984	1985	1986	1987	1988	1989
Sunnyside	31	0.0013 ± 0.0014	0.0086 ± 0.0057	0.0060 ± 0.0017	0.014 ± 0.004	0.005 ± 0.002	0.018 ± 0.005
Walla Walla	32				0.016 ± 0.004	0.016 ± 0.005	0.011 ± 0.003
McNary Dam	33				0.014 ± 0.004	0.010 ± 0.003	0.014 ± 0.004
Moses Lake	34				0.016 ± 0.004	0.007 ± 0.002	0.003 ± 0.001
Washtucna	35				0.015 ± 0.004	0.004 ± 0.001	0.017 ± 0.005
Connell	36				0.014 ± 0.004	0.007 ± 0.002	0.017 ± 0.005
Othello	37				0.013 ± 0.004	0.001 ± 0.001	0.010 ± 0.003
Yakima	38				0.011 ± 0.003	0.007 ± 0.002	0.023 ± 0.007
OFFSITE AVERAGE		0.013 ± 0.0049	0.041 ± 0.041	0.013 ± 0.003	0.018 ± 0.004	0.009 ± 0.003	0.015 ± 0.004

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

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

Location	Map Location[b]	No. of Samples	Dose Rate, mrem/yr[a] Maximum	Minimum	Average[c,d]
PERIMETER STATIONS					
Prosser Barricade	1	8	107	68	87 ± 10
ALE	2	8	111	70	91 ± 10
Rattlesnake Springs	3	8	119	75	92 ± 10
Yakima Barricade	4	8	121	77	94 ± 10
Vernita Bridge	5	8	103	73	86 ± 8
Wahluke Slope No. 2	6	8	105	73	89 ± 9
Berg Ranch	7	8	121	74	91 ± 11
Sagehill	8	8	119	68	87 ± 11
Ringold	9	8	117	70	92 ± 11
Fir Road	10	8	115	69	86 ± 12
Pettett	11	8	112	73	86 ± 11
Sagemoor	12	8	108	73	86 ± 9
Byers Landing	13	8	119	78	95 ± 11
RRC No. 64	14	8	99	67	80 ± 8
Horn Rapids Rd., Mi. 12	15	8	103	70	85 ± 8
Horn Rapids, Substation	16	8	99	65	85 ± 9
Perimeter Average					88 ± 2
NEARBY COMMUNITIES					
Benton City	17	8	101	63	74 ± 11
Othello	18	8	105	59	76 ± 10
Connell	19	8	103	59	81 ± 10
Pasco	20	8	99	64	80 ± 10
Richland	21	8	98	62	77 ± 10
Eltopia	22	8	92	51	66 ± 10
Prosser	23	8	106	62	77 ± 11
Mattawa	24	8	100	58	83 ± 11
Kennewick	25	8	103	67	84 ± 10
Nearby Average					78 ± 4
DISTANT COMMUNITIES					
Walla Walla	26	8	106	63	82 ± 10
McNary	27	8	108	68	88 ± 10
Sunnyside	28	8	106	64	78 ± 10
Moses Lake	29	7	101	59	72 ± 13
Washtucna	30	7	116	70	86 ± 13
Yakima	31	8	100	58	74 ± 10
Distant Average					80 ± 5

(a) Monthly integrated readings in mR were converted to annual dose equivalent rates.
(b) Locations are identified in Figure 4.42.
(c) Averages ±2 times the standard error of the calculated mean (SEM).
(d) The grand averages and 2 SEM were computed using station averages rather than the individual measurements.

TABLE C.35. Immersion Dose Rates Measured in the Columbia River in 1989

Location[b]	Number of Measurements	Dose Rate, mrem/h[a] Maximum	Minimum	Average[c]
Richland Pumphouse	5	0.007	0.004	0.006 ± 0.001
Coyote Rapids	5	0.010	0.005	0.007 ± 0.002

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

TABLE C.36. Environmental Dosimeter Measurements at Onsite Locations in 1989[a]

Location	Map Location[c]	No. of Measurements	Dose Rate, mrem/h[b] Maximum	Minimum	Average[d]
100-N Area Shoreline					
100-N Trench Springs	1	11	0.037	0.024	0.030 ± 0.0028
Below 100-N Main Stack	2	11	0.027	0.012	0.018 ± 0.0027
Upstream Tip 100-N Berm	3	11	0.023	0.013	0.018 ± 0.0021
Downstream 100-N Outfall	4	11	0.030	0.017	0.024 ± 0.0030
3705 West Fence	5	11	0.012	0.008	0.010 ± 0.0010
400 East Fence	6	11	0.012	0.008	0.010 ± 0.0011

(a) These locations are onsite where access is controlled but where the public could have access for a short period of time.
(b) Monthly integrated readings in mR were converted to hourly dose equivalent rates.
(c) Locations are identified in Figure 4.45.
(d) Averages ±2 times the standard error of the calculated mean.

TABLE C.37. Environmental Dosimeter Measurements Along the Hanford Reach of the Columbia River in 1989

Location	Map Location[b]	No. of Measurements	Dose Rate, mrem/h[a] Maximum	Minimum	Average[c]
Upriver 100-B Area	1	4	0.014	0.009	0.010 ± 0.0024
Below 100-B Retention Basin	2	5	0.019	0.013	0.016 ± 0.0021
Above 100-K Boat Ramp	3	5	0.014	0.009	0.011 ± 0.0021
Downriver from 100-D Area	4	5	0.016	0.010	0.012 ± 0.0017
Downriver Opposite 100-D Area	5	5	0.013	0.009	0.010 ± 0.0017
Lower End Locke Island	6	5	0.014	0.009	0.011 ± 0.0016
White Bluffs Slough	7	5	0.019	0.012	0.015 ± 0.0023
White Bluffs Ferry Landing	8	5	0.014	0.009	0.011 ± 0.0018
Below 100-F Area	9	5	0.013	0.008	0.010 ± 0.0020
100-F Floodplain	10	5	0.018	0.013	0.015 ± 0.0015
Hanford Powerline Crossing	11	5	0.014	0.009	0.011 ± 0.0020
Hanford Ferry Landing	12	4	0.013	0.008	0.010 ± 0.0021
Hanford Peninsula	13	5	0.018	0.011	0.014 ± 0.0022
Hanford Railroad Track	14	5	0.017	0.011	0.013 ± 0.0019
Savage Island Slough	15	5	0.016	0.010	0.013 ± 0.0019
Ringold Island	16	5	0.013	0.009	0.011 ± 0.0015
Powerline Crossing	17	5	0.014	0.010	0.011 ± 0.0014
North End Wooded Island	18	4	0.013	0.007	0.010 ± 0.0018
South End Wooded Island	19	5	0.014	0.010	0.012 ± 0.0015
Island Near 300 Area	20	5	0.016	0.009	0.012 ± 0.0022
Below Bateman Island	21	5	0.015	0.011	0.012 ± 0.0017

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

TABLE C.38. Onsite External Penetrating Dose Measurements in 1989

Location	Map Location[b]	No. of Measurements	Dose Rate, mrem/h[a] Maximum	Minimum	Average[c]
100 Areas					
100-K	1	11	0.012	0.007	0.009 ± 0.0011
100-N	2	11	0.013	0.008	0.011 ± 0.0013
100-D	3	11	0.012	0.008	0.010 ± 0.0008
100 Area Fire Station	4	11	0.012	0.008	0.009 ± 0.0010
200 Areas					
N of 200-East	5	11	0.013	0.008	0.010 ± 0.0010
E of 200-East	6	11	0.013	0.009	0.010 ± 0.0011
200-E SE	7	11	0.010	0.008	0.010 ± 0.0009
GTE Building	8	11	0.012	0.008	0.010 ± 0.0010
SW of BC Cribs	9	11	0.013	0.009	0.011 ± 0.0011
S of 200-East	10	11	0.013	0.009	0.011 ± 0.0010
200-W SE	11	4	0.012	0.008	0.010 ± 0.0019
B Pond	12	4	0.014	0.009	0.011 ± 0.0027
300 Area					
300 NE	13	4	0.013	0.008	0.010 ± 0.0024
300 Pond	14	11	0.013	0.008	0.011 ± 0.0011
3614 A Building	15	11	0.012	0.007	0.010 ± 0.0010
300 S Gate	16	11	0.012	0.008	0.010 ± 0.0010
300 SW Gate	17	11	0.013	0.008	0.010 ± 0.0011
3705 West Fence	18	11	0.012	0.008	0.010 ± 0.0010
400 Area					
400 East	19	11	0.012	0.008	0.010 ± 0.0011
400 West	20	11	0.012	0.008	0.010 ± 0.0009
400 South	21	11	0.012	0.008	0.010 ± 0.0011
400 North	22	11	0.012	0.008	0.010 ± 0.0010
FFTF North	23	11	0.012	0.008	0.010 ± 0.0009
FFTF Southeast	24	11	0.012	0.007	0.010 ± 0.0011
600 Area					
Rt. 11A, Mi. 9	25	11	0.013	0.008	0.010 ± 0.0011
Hanford Townsite	26	11	0.012	0.008	0.009 ± 0.0011
Wye Barricade	27	11	0.011	0.007	0.009 ± 0.0009
Army Loop Camp	28	11	0.013	0.009	0.010 ± 0.0013

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

TABLE C.39. Maximum, Minimum, and Average Tritium (^3H) Concentrations in Ground-Water Samples in 1989

Well Name[a]	No. of Samples	Concentration, pCi/L[b] (10^{-9} µCi/mL) Maximum			Minimum			Average		
1-B3-1	2	4,450	±	255	4,090	±	243	4,270	±	180
1-B4-1	2	42,900	±	705	16,100	±	453	29,500	±	13,400
1-B4-2	2	4,290	±	248	3,480	±	231	3,890	±	405
1-B4-3	2	21,600	±	515	11,500	±	393	16,600	±	5,050
1-B4-4	2	2,850	±	216	2,390	±	200	2,620	±	230
1-B5-1	2	2,360	±	205	1,980	±	190	2,170	±	190
1-B9-1	2	2,220	±	196	2,120	±	195	2,170	±	50
1-D2-5	2	28,200	±	458	27,800	±	561	28,000	±	200
1-D5-12	2	53,300	±	628	35,200	±	621	44,300	±	9,050
1-D8-3	2	4,230	±	199	3,690	±	236	3,960	±	270
1-F5-1	1	56	±	95	---	±	---	56	±	---
1-F5-3	2	486	±	145	189	±	99	338	±	149
1-F5-4	2	9,550	±	281	7,970	±	317	8,760	±	790
1-F5-6	2	1,440	±	178	1,110	±	130	1,280	±	165
1-F7-1	2	1,210	±	171	486	±	111	848	±	362
1-F8-1	2	5,290	±	302	4,810	±	286	5,050	±	240
1-F8-2	2	3,640	±	232	2,140	±	159	2,890	±	750
1-H3-1	2	3,890	±	239	1,670	±	181	2,780	±	1,110
1-H4-3	2	3,610	±	236	1,730	±	181	2,670	±	940
1-H4-4	2	1,800	±	188	498	±	140	1,150	±	651
1-H4-5	1	1,960	±	191	---	±	---	1,960	±	---
1-H4-6	2	5,280	±	267	5,060	±	264	5,170	±	110
1-H4-7	2	4,680	±	254	3,100	±	218	3,890	±	790
1-H4-8	2	4,580	±	249	2,120	±	195	3,350	±	1,230
1-H4-9	2	2,970	±	221	1,360	±	137	2,170	±	805
1-H4-10	2	3,630	±	232	429	±	137	2,030	±	1,600
1-H4-11	2	1,700	±	184	989	±	158	1,340	±	356
1-H4-14	2	1,550	±	177	1,050	±	161	1,300	±	250
1-H4-16	2	641	±	147	583	±	148	612	±	29
1-H4-17	2	4,170	±	248	3,610	±	232	3,890	±	280
1-H4-18	2	1,580	±	180	1,400	±	174	1,490	±	90
1-K-11	2	3,660	±	235	1,680	±	182	2,670	±	990
1-K-22	1	491	±	145	---	±	---	491	±	---
1-K-27	3	172,000	±	1,390	52,600	±	775	92,800	±	39,600
1-K-28	3	2,290	±	204	2,200	±	197	2,260	±	30
1-K-29	3	11,200	±	375	8,530	±	327	10,200	±	859
1-K-30	3	882,000	±	3,070	570,000	±	2,480	680,000	±	101,00
1-N-2	3	95,600	±	1,040	54,200	±	753	72,000	±	12,300
1-N-3	4	47,100	±	738	22,600	±	501	31,700	±	5,770
1-N-4	4	88,900	±	998	22,100	±	536	45,500	±	14,800
1-N-5	1	51,200	±	772	---	±	---	51,200	±	---
1-N-6	1	8,910	±	342	---	±	---	8,910	±	---
1-N-14	5	93,100	±	1,020	34,600	±	653	48,500	±	11,300
1-N-16	2	3,010	±	219	1,130	±	168	2,070	±	940
1-N-17	1	19,400	±	463	---	±	---	19,400	±	---
1-N-18	1	8,660	±	337	---	±	---	8,660	±	---
1-N-20	1	1,020	±	193	---	±	---	1,020	±	---

TABLE C.39. Tritium (contd)

Well Name[a]	No. of Samples	Concentration, pCi/L[b] (10^{-9} µCi/mL) Maximum			Minimum			Average		
1-N-21	1	13,600	±	396	---	±	---	13,600	±	---
1-N-22	1	2,750	±	215	---	±	---	2,750	±	---
1-N-23	2	15,700	±	424	15,000	±	424	15,400	±	350
1-N-24	2	368	±	143	174	±	131	271	±	97
1-N-25	2	200	±	138	166	±	132	183	±	17
1-N-26	1	585	±	149	---	±	---	585	±	---
1-N-27	3	189,000	±	1,450	7,880	±	310	79,000	±	55,800
1-N-28	1	8,530	±	327	---	±	---	8,530	±	---
1-N-29	3	67,200	±	837	4,890	±	257	37,000	±	18,000
1-N-31	5	218,000	±	1,520	10,500	±	258	85,800	±	36,500
1-N-32	4	164,000	±	1,300	7,800	±	309	67,600	±	34,400
1-N-33	5	170,000	±	1,340	11,300	±	362	82,600	±	35,300
1-N-36	4	209,000	±	1,520	6,440	±	286	79,900	±	44,500
1-N-37	1	8,460	±	352	---	±	---	8,460	±	---
1-N-39	1	51,300	±	738	---	±	---	51,300	±	---
1-N-41	4	66,600	±	881	7,280	±	302	23,700	±	14,400
1-N-42	4	71,900	±	912	8,880	±	329	29,100	±	14,800
1-N-47	1	15,800	±	431	---	±	---	15,800	±	---
1-N-50	1	92,600	±	1,020	---	±	---	92,600	±	---
1-N-51	1	95,800	±	1,030	---	±	---	95,800	±	---
1-N-52	4	80,800	±	960	16,000	±	428	34,600	±	15,500
1-N-54	1	19,700	±	470	---	±	---	19,700	±	---
1-N-55	1	19,700	±	477	---	±	---	19,700	±	---
1-N-56	1	31,100	±	599	---	±	---	31,100	±	---
1-N-57	1	21,800	±	507	---	±	---	21,800	±	---
1-N-58	4	118	±	146	-147	±	153	9	±	56
1-N-59	4	247	±	153	-26	±	158	125	±	57
1-N-60	5	100	±	130	31	±	158	57	±	12
1-N-61	5	157	±	132	27	±	151	69	±	23
1-N-66	4	52,400	±	758	12,200	±	284	36,200	±	9,890
1-N-67	4	77,300	±	938	42,600	±	670	59,300	±	8,920
1-N-69	4	92,700	±	745	75,100	±	925	82,800	±	3,890
1-N-70	4	120,000	±	1,160	32,500	±	587	59,400	±	20,500
2-E13-5	1	10	±	147	---	±	---	10	±	---
2-E13-8	1	-26	±	93	---	±	---	-26	±	---
2-E16-2	5	6,640	±	305	155	±	161	1,890	±	1,210
2-E17-1	4	5,360,000	±	7,500	3,300,000	±	6,000	3,860,000	±	501,000
2-E17-2	5	43,200	±	722	26,700	±	569	32,200	±	3,060
2-E17-5	7	1,260,000	±	3,750	118,000	±	1,140	457,000	±	204,000
2-E17-6	2	309	±	180	182	±	162	246	±	64
2-E17-8	1	3,420,000	±	6,020	---	±	---	3,420,000	±	---
2-E17-9	8	5,200,000	±	7,360	3,550,000	±	6,300	4,310,000	±	208,000
2-E17-12	3	1,500,000	±	4,060	982,000	±	3,210	1,190,000	±	157,000
2-E17-13	5	3,340,000	±	6,070	866,000	±	2,970	1,730,000	±	497,000
2-E17-14	4	2,700,000	±	5,430	264,000	±	1,690	1,860,000	±	560,000
2-E17-15	2	1,300,000	±	3,710	236,000	±	1,150	768,000	±	532,000
2-E17-16	3	54,500	±	629	27,400	±	553	41,400	±	7,840
2-E17-17	3	334,000	±	1,550	201,000	±	1,470	250,000	±	42,200

TABLE C.39. Tritium (contd)

Well Name[a]	No. of Samples	Concentration, pCi/L[b] (10^{-9} µCi/mL) Maximum			Minimum			Average		
2-E17-18	4	41,100	±	682	35,600	±	637	37,900	±	1,230
2-E17-19	3	2,620,000	±	3,830	261,000	±	1,710	1,810,000	±	777,000
2-E17-20	3	4,600,000	±	7,120	4,210,000	±	6,550	4,470,000	±	128,000
2-E18-1	3	86	±	128	-56	±	113	10	±	41
2-E18-2	1	35	±	91	---	±	---	35	±	---
2-E18-3	1	-57	±	89	---	±	---	-57	±	---
2-E18-4	1	-48	±	90	---	±	---	-48	±	---
2-E24-1	5	2,880,000	±	5,660	1,930,000	±	4,490	2,300,000	±	208,000
2-E24-2	5	2,560,000	±	3,810	1,370,000	±	3,730	1,910,000	±	200,000
2-E24-4	1	8,710	±	341	---	±	---	8,710	±	---
2-E24-7	1	1,320,000	±	3,780	---	±	---	1,320,000	±	---
2-E24-8	1	14,300	±	416	---	±	---	14,300	±	---
2-E24-11	3	4,310,000	±	6,740	2,680,000	±	5,460	3,320,000	±	503,000
2-E24-12	3	50,700	±	746	45,000	±	727	48,000	±	1,660
2-E24-13	1	6,310	±	292	---	±	---	6,310	±	---
2-E24-16	3	3,050,000	±	5,630	2,580,000	±	5,290	2,760,000	±	145,000
2-E24-17	3	2,990,000	±	5,550	2,350,000	±	4,850	2,610,000	±	194,000
2-E24-18	3	1,430,000	±	3,800	1,370,000	±	3,830	1,410,000	±	20,000
2-E25-2	1	9,650	±	366	---	±	---	9,650	±	---
2-E25-3	1	3,940	±	194	---	±	---	3,940	±	---
2-E25-6	4	8,620	±	355	5,060	±	294	6,400	±	810
2-E25-9	2	2,840	±	236	2,600	±	208	2,720	±	120
2-E25-11	6	657,000	±	2,620	344,000	±	1,840	501,000	±	51,200
2-E25-17	4	555,000	±	2,480	397,000	±	2,050	477,000	±	40,500
2-E25-18	1	254,000	±	1,640	---	±	---	254,000	±	---
2-E25-19	1	966,000	±	3,200	---	±	---	966,000	±	---
2-E25-20	1	1,380,000	±	3,810	---	±	---	1,380,000	±	---
2-E25-21	1	2,940	±	235	---	±	---	2,940	±	---
2-E25-22	2	10,100	±	355	5,240	±	280	7,670	±	2,430
2-E25-23	1	200	±	155	---	±	---	200	±	---
2-E25-24	2	453	±	139	211	±	155	332	±	121
2-E25-25	1	442	±	167	---	±	---	442	±	---
2-E25-26	2	3,590	±	169	2,730	±	211	3,160	±	430
2-E25-28	1	1,350	±	173	---	±	---	1,350	±	---
2-E25-29P	2	85,700	±	944	36,700	±	637	61,200	±	24,500
2-E25-31	3	19,100	±	462	16,600	±	440	18,100	±	764
2-E25-32P	2	1,040	±	164	670	±	175	855	±	185
2-E25-33	1	19,800	±	478	---	±	---	19,800	±	---
2-E25-34	5	1,570	±	178	922	±	154	1,280	±	136
2-E25-35	5	69,900	±	893	51,500	±	733	61,000	±	2,930
2-E25-36	3	5,360	±	270	4,720	±	257	5,110	±	199
2-E26-1	1	12,700	±	397	---	±	---	12,700	±	---
2-E26-2	3	3,370	±	239	1,600	±	180	2,390	±	520
2-E26-4	3	30,900	±	606	16,400	±	446	22,900	±	4,250
2-E26-6	1	1,300	±	188	---	±	---	1,300	±	---
2-E26-8[c]	2	-29	±	116	-48	±	125	-39	±	9
2-E27-8	3	12,300	±	376	11,500	±	381	12,000	±	252
2-E27-9	3	14,200	±	297	12,800	±	399	13,500	±	404

TABLE C.39. Tritium (contd)

Well Name[a]	No. of Samples	Concentration, pCi/L[b] (10^{-9} µCi/mL) Maximum			Minimum			Average		
2-E27-10	3	7,960	±	323	7,220	±	297	7,630	±	217
2-E28-7	1	6,920	±	303	---	±	---	6,920	±	---
2-E28-12	5	134,000	±	1,190	70,400	±	835	104,000	±	11,400
2-E28-13	1	5,880	±	292	---	±	---	5,880	±	---
2-E28-18	2	300,000	±	1,830	285,000	±	1,740	293,000	±	7,500
2-E28-21	3	209,000	±	1,520	175,000	±	1,360	191,000	±	9,870
2-E28-23	1	7,170	±	315	---	±	---	7,170	±	---
2-E28-26	3	169,000	±	1,370	122,000	±	1,130	142,000	±	14,100
2-E28-27	4	417,000	±	2,050	212,000	±	1,580	356,000	±	48,300
2-E32-1	1	22,800	±	518	---	±	---	22,800	±	---
2-E32-2	3	220,000	±	1,500	95,900	±	1,050	177,000	±	40,700
2-E32-3	1	652,000	±	2,550	---	±	---	652,000	±	---
2-E32-4	6	41,700	±	667	-94	±	114	13,000	±	6,840
2-E33-3	1	4,660	±	256	---	±	---	4,660	±	---
2-E33-7	1	6,710	±	296	---	±	---	6,710	±	---
2-E33-9	3	3,060	±	223	24	±	133	1,820	±	920
2-E33-10	1	4,740	±	260	---	±	---	4,740	±	---
2-E33-12[c]	2	390	±	138	353	±	134	372	±	19
2-E33-20	1	4,380	±	253	---	±	---	4,380	±	---
2-E33-28	3	3,440	±	168	2,610	±	209	3,110	±	255
2-E33-29	3	7,140	±	219	6,390	±	290	6,800	±	220
2-E33-30	3	6,790	±	217	5,860	±	281	6,460	±	302
2-E34-1	2	3,480	±	228	2,280	±	217	2,880	±	600
2-E34-2	4	3,470	±	166	2,340	±	198	3,090	±	262
2-E34-3	3	9,480	±	347	8,270	±	315	8,690	±	397
2-E34-5	3	207	±	128	99	±	95	157	±	32
2-E34-6	3	431	±	137	225	±	136	342	±	61
2-W6-2	5	14,500	±	405	10,500	±	363	13,400	±	735
2-W7-1	3	167	±	120	-39	±	126	70	±	60
2-W7-2	3	57	±	144	-61	±	126	12	±	37
2-W7-3	3	135	±	132	-61	±	89	46	±	57
2-W7-4	3	451	±	144	283	±	132	373	±	49
2-W7-5	3	371	±	154	113	±	122	254	±	75
2-W7-6	3	918	±	171	842	±	153	891	±	25
2-W8-1	3	112	±	131	57	±	116	78	±	17
2-W9-1	3	265	±	137	36	±	94	140	±	67
2-W10-13	4	421	±	156	13	±	152	215	±	88
2-W10-14	4	173	±	133	-83	±	114	32	±	53
2-W14-6	1	7,600	±	335	---	±	---	7,600	±	---
2-W15-15	3	476	±	160	267	±	136	353	±	63
2-W15-16	3	33,700	±	612	100	±	120	11,400	±	11,200
2-W15-17	2	261	±	137	32	±	94	147	±	115
2-W15-18	3	472	±	161	18	±	125	204	±	137
2-W18-15	1	67	±	123	---	±	---	67	±	---
2-W18-17	3	3,300	±	223	132	±	161	1,410	±	966
2-W18-20	2	131	±	163	106	±	127	119	±	13
2-W18-21	3	734	±	119	-4	±	119	346	±	214
2-W18-22	3	1,150	±	163	-61	±	90	726	±	394

TABLE C.39. Tritium (contd)

Well Name[a]	No. of Samples	Concentration, pCi/L[b] (10^{-9} µCi/mL) Maximum			Minimum			Average		
2-W18-23	4	615	±	148	-78	±	151	207	±	146
2-W18-24	4	219	±	135	17	±	153	107	±	44
2-W19-2	2	77,400	±	911	24,700	±	551	51,100	±	26,400
2-W19-3	1	404	±	169	---	±	---	404	±	---
2-W19-9	1	430	±	167	---	±	---	430	±	---
2-W19-13	1	-46	±	153	---	±	---	-46	±	---
2-W19-14	1	5	±	153	---	±	---	5	±	---
2-W19-15	1	2,770	±	229	---	±	---	2,770	±	---
2-W19-16	1	2,180	±	216	---	±	---	2,180	±	---
2-W19-17	1	263	±	159	---	±	---	263	±	---
2-W19-18	2	4,960	±	275	841	±	199	2,900	±	2,060
2-W19-19	5	3,190	±	240	1,520	±	177	1,950	±	314
2-W19-20	5	3,760	±	249	1,850	±	209	2,550	±	340
2-W19-21	2	118	±	132	-103	±	150	8	±	111
2-W19-23	5	1,990	±	212	606	±	173	1,120	±	283
2-W19-24	5	2,820	±	227	1,260	±	171	1,730	±	279
2-W19-25	4	3,010	±	252	1,780	±	206	2,370	±	252
2-W19-26	2	2,090	±	231	1,090	±	178	1,590	±	500
2-W19-27	2	162	±	153	114	±	132	138	±	24
2-W22-1	1	2,960	±	233	---	±	---	2,960	±	---
2-W22-2	1	67,300	±	856	---	±	---	67,300	±	---
2-W22-22	1	1,400	±	191	---	±	---	1,400	±	---
2-W23-4	5	206,000	±	1,480	23,500	±	514	132,000	±	31,900
2-W23-9	5	1,520,000	±	4,110	1,050,000	±	3,370	1,210,000	±	80,800
2-W23-10	2	555,000	±	2,410	553,000	±	2,420	554,000	±	1,000
2-W23-11	1	820	±	179	---	±	---	820	±	---
2-W27-1	1	5,050	±	278	---	±	---	5,050	±	---
3-1-3	1	211	±	156	---	±	---	211	±	---
3-1-7	5	246	±	138	146	±	128	192	±	16
3-1-12	1	66	±	121	---	±	---	66	±	---
3-1-17A	3	326	±	135	124	±	97	198	±	64
3-1-17B	2	-3	±	126	-54	±	116	-29	±	26
3-1-17C	1	58	±	120	---	±	---	58	±	---
3-1-18A	1	6,450	±	287	---	±	---	6,450	±	---
3-2-1	1	367	±	141	---	±	---	367	±	---
3-3-7	1	1,450	±	180	---	±	---	1,450	±	---
3-3-9	1	433	±	147	---	±	---	433	±	---
3-3-10	2	471	±	146	137	±	125	304	±	167
3-4-1	1	380	±	143	---	±	---	380	±	---
3-4-7	1	2,050	±	195	---	±	---	2,050	±	---
3-4-11	1	429	±	144	---	±	---	429	±	---
3-8-1	2	223	±	129	18	±	128	120	±	103
3-8-3	1	1,050	±	163	---	±	---	1,050	±	---
6-S43-E12	3	204	±	135	68	±	123	124	±	41
6-S41-E13A	3	84	±	131	58	±	122	74	±	8
6-S41-E13B	3	137	±	132	-39	±	153	57	±	51
6-S40-E14	3	101	±	129	66	±	120	87	±	11
6-S37-E14	4	239	±	137	-18	±	119	111	±	70

TABLE C.39. Tritium (contd)

Well Name[a]	No. of Samples	Concentration, pCi/L[b] (10^{-9} µCi/mL) Maximum			Minimum			Average		
6-S31-1P[c]	1	-95	±	155	---	±	---	-95	±	---
6-S30-E15A	2	39	±	131	-93	±	117	-27	±	66
6-S29-E12	2	20	±	128	-119	±	116	-50	±	69
6-S28-E0	3	-88	±	111	-263	±	148	-148	±	58
6-S27-E14	3	-109	±	150	-159	±	113	-132	±	15
6-S24-19	1	-134	±	114	---	±	---	-134	±	---
6-S19-E13	2	8,410	±	323	7,670	±	317	8,040	±	370
6-S19-11	3	-2	±	129	-90	±	115	-34	±	28
6-S18-51	1	-60	±	117	---	±	---	-60	±	---
6-S14-20A	1	-30	±	146	---	±	---	-30	±	---
6-S12-3	2	84	±	129	-38	±	120	23	±	61
6-S12-29	1	-162	±	111	---	±	---	-162	±	---
6-S11-E12A	1	4,460	±	252	---	±	---	4,460	±	---
6-S11-E12AP[c]	1	188	±	123	---	±	---	188	±	---
6-S8-19	2	9	±	117	-137	±	123	-64	±	73
6-S7-34	1	-55	±	117	---	±	---	-55	±	---
6-S6-E14A	1	46	±	155	---	±	---	46	±	---
6-S6-E4B	2	29,000	±	584	27,400	±	571	28,200	±	800
6-S6-E4D	2	39,800	±	680	39,500	±	677	39,700	±	150
6-S3-E12	2	7,630	±	310	6,110	±	282	6,870	±	760
6-S3-25	1	92	±	163	---	±	---	92	±	---
6-1-18	2	42,300	±	698	39,300	±	679	40,800	±	1,500
6-2-3	2	104,000	±	1,030	104,000	±	1,070	104,000	±	0
6-2-7	1	12,300	±	388	---	±	---	12,300	±	---
6-2-33A	2	72	±	114	-305	±	115	-117	±	188
6-3-45	1	-158	±	113	---	±	---	-158	±	---
6-8-17	2	144,000	±	1,250	136,000	±	1,240	140,000	±	4,000
6-8-25	2	46,000	±	707	39,600	±	676	42,800	±	3,200
6-8-32	2	-12	±	116	143	±	123	77	±	66
6-10-E12	2	23,400	±	535	22,600	±	521	23,000	±	400
6-10-54A	1	-68	±	107	---	±	---	-68	±	---
6-13-64	1	-142	±	113	---	±	---	-142	±	---
6-14-38	2	125	±	128	29	±	113	77	±	48
6-14-47	1	-96	±	116	---	±	---	-96	±	---
6-15-15B	1	-119	±	114	---	±	---	-119	±	---
6-17-5	3	127	±	117	-95	±	150	25	±	65
6-17-47	1	197	±	117	---	±	---	197	±	---
6-17-70	1	-121	±	115	---	±	---	-121	±	---
6-19-43	1	18	±	118	---	±	---	18	±	---
6-19-88	1	-24	±	111	---	±	---	-24	±	---
6-20-E12	2	3,610	±	232	2,360	±	199	2,990	±	625
6-20-E12P	1	-127	±	114	---	±	---	-127	±	---
6-20-E5A	2	77,200	±	914	70,600	±	893	73,900	±	3,300
6-20-E5P	1	-70	±	115	---	±	---	-70	±	---
6-20-E5Q	1	20	±	122	---	±	---	20	±	---
6-20-E5R[c]	1	-15	±	119	---	±	---	-15	±	---
6-20-20	2	137,000	±	1,230	133,000	±	1 220	135,000	±	2,000
6-20-39	1	23	±	122	---	±	---	23	±	---

TABLE C.39. Tritium (contd)

Well Name[a]	No. of Samples	Concentration, pCi/L[b] (10^{-9} µCi/mL) Maximum			Minimum			Average		
6-20-82	1	-107	±	115	---	±	---	-107	±	---
6-21-6	2	31,100	±	597	26,900	±	547	29,000	±	2,100
6-22-70	2	162	±	128	-16	±	109	73	±	89
6-23-34	3	143,000	±	913	127,000	±	1,160	133,000	±	5,170
6-24-1P[c]	1	-113	±	114	---	±	---	-113	±	---
6-24-1Q[c]	1	-16	±	118	---	±	---	-16	±	---
6-24-1R[c]	1	127	±	121	---	±	---	127	±	---
6-24-1S	1	23	±	115	---	±	---	23	±	---
6-24-1T	1	12,800	±	394	---	±	---	12,800	±	---
6-24-33	2	316,000	±	1,360	315,000	±	1,840	316,000	±	500
6-24-34A	1	202,000	±	1,080	---	±	---	202,000	±	---
6-24-34B	2	298,000	±	1,320	272,000	±	1,700	285,000	±	13,000
6-24-34C	2	326,000	±	1,380	279,000	±	1,710	303,000	±	23,500
6-24-35	3	143,000	±	909	136,000	±	1,220	140,000	±	2,080
6-24-46	1	-100	±	114	---	±	---	-100	±	---
6-25-33A	3	1,000	±	162	888	±	112	942	±	32
6-25-34A	2	267,000	±	1,240	241,000	±	1,600	254,000	±	13,000
6-25-34C	2	285,000	±	1,280	268,000	±	1,700	277,000	±	8,500
6-25-55	2	133	±	128	-35	±	107	49	±	84
6-25-70	2	831	±	155	692	±	148	762	±	70
6-26-15A	2	242,000	±	1,620	235,000	±	1,630	239,000	±	3,500
6-26-33	2	258,000	±	1,220	246,000	±	1,670	252,000	±	6,000
6-26-34	2	264,000	±	1,240	248,000	±	1,630	256,000	±	8,000
6-26-35A	2	281,000	±	1,290	275,000	±	1,730	278,000	±	3,000
6-26-35C	2	57,300	±	583	51,800	±	753	54,600	±	2,750
6-27-8	2	219,000	±	1,560	208,000	±	1,520	214,000	±	5,500
6-28-40	2	98,800	±	1,050	83,700	±	965	91,300	±	7,550
6-28-40P[c]	1	150	±	122	---	±	---	150	±	---
6-28-52A	1	-101	±	114	---	±	---	-101	±	---
6-29-4	2	115,000	±	1,140	103,000	±	1,060	109,000	±	6,000
6-29-78	2	498	±	142	228	±	130	363	±	135
6-31-31	1	19,600	±	477	---	±	---	19,600	±	---
6-31-31P[c]	1	77	±	118	---	±	---	77	±	---
6-32-22	2	172,000	±	1,380	147,000	±	1,230	160,000	±	12,500
6-32-43	2	279,000	±	1,780	212,000	±	1,530	246,000	±	33,500
6-32-62	1	2,240	±	195	---	±	---	2,240	±	---
6-32-70B	2	249,000	±	1,660	231,000	±	1,590	240,000	±	9,000
6-32-72	1	140,000	±	1,230	---	±	---	140,000	±	---
6-32-77	1	64	±	123	---	±	---	64	±	---
6-33-42	2	232,000	±	1,620	189,000	±	1,440	211,000	±	21,500
6-33-56	2	-69	±	117	-84	±	119	-76	±	7
6-34-39A	1	2,030	±	210	---	±	---	2,030	±	---
6-34-41B	1	15,900	±	436	---	±	---	15,900	±	---
6-34-42	2	51,500	±	755	31,300	±	593	41,400	±	10,100
6-34-51	2	436	±	183	35	±	172	236	±	200
6-35-9	2	201,000	±	1,480	199,000	±	1,480	200,000	±	1,000
6-35-66	1	1,160,000	±	3,550	---	±	---	1,160,000	±	---
6-35-70	2	926,000	±	3,160	849,000	±	2,950	888,000	±	38,500

TABLE C.39. Tritium (contd)

Well Name[a]	No. of Samples	Concentration, pCi/L[b] (10^{-9} µCi/mL) Maximum			Minimum			Average		
6-35-78A	2	12	±	154	-61	±	116	-25	±	37
6-36-46P[c]	1	76	±	118	----	±	---	76	±	---
6-36-46Q[c]	3	130	±	121	-42	±	112	68	±	55
6-36-61B	1	32,200	±	612	---	±	---	32,200	±	---
6-36-93	1	-165	±	151	---	±	---	-165	±	---
6-37-E4	1	66,900	±	869	---	±	---	66,900	±	---
6-37-43	1	38,500	±	667	---	±	---	38,500	±	---
6-37-82A	1	-46	±	118	---	±	---	-46	±	---
6-38-15	2	394,000	±	2,070	365,000	±	1,960	380,000	±	14,500
6-38-65	2	452,000	±	2,160	440,000	±	2,190	446,000	±	6,000
6-38-70	1	1,010	±	152	---	±	---	1,010	±	---
6-39-0	1	242,000	±	1,630	---	±	---	242,000	±	---
6-39-39	2	190	±	158	7	±	114	98	±	92
6-40-1	2	235,000	±	1,620	226,000	±	1,560	231,000	±	4,500
6-40-33A	2	-47	±	121	-69	±	152	-58	±	11
6-40-39	1	57,700	±	770	---	±	---	57,700	±	---
6-40-62	2	88,100	±	994	82,300	±	924	85,200	±	2,900
6-41-1	2	244,000	±	1,640	233,000	±	1,600	239,000	±	5,500
6-41-23	2	88,700	±	1,000	73,100	±	868	80,900	±	7,800
6-41-40	1	232,000	±	1,530	---	±	---	232,000	±	---
6-42-2	1	229,000	±	1,560	---	±	---	229,000	±	---
6-42-12A	2	286,000	±	1,770	265,000	±	1,720	276,000	±	10,500
6-42-40A	5	237	±	161	-94	±	115	64	±	62
6-42-40B	7	4,510	±	265	-87	±	154	1,050	±	652
6-42-40C[c]	2	3,830	±	228	2,970	±	217	3,400	±	430
6-42-42B	4	79,500	±	678	72,800	±	908	74,800	±	1,580
6-43-3	2	234,000	±	1,600	231,000	±	1,600	233,000	±	1,500
6-43-41E	1	95,400	±	1,000	---	±	---	95,400	±	---
6-43-41F	1	32	±	128	---	±	---	32	±	---
6-43-42J	4	2,620	±	206	1,080	±	117	1,660	±	356
6-43-43	4	432	±	135	283	±	131	335	±	35
6-43-45	1	342	±	140	---	±	---	342	±	---
6-43-88	1	-159	±	113	---	±	---	-159	±	---
6-44-4	1	146,000	±	1,250	---	±	---	146,000	±	---
6-44-42	3	1,140	±	161	346	±	135	641	±	251
6-44-43B	2	41,400	±	662	40,100	±	650	40,800	±	650
6-44-64	1	652	±	147	---	±	---	652	±	---
6-45-2	2	218,000	±	1,540	211,000	±	1,530	215,000	±	3,500
6-45-42	4	44,500	±	701	39,100	±	656	41,900	±	1,130
6-45-69A	1	-32	±	119	---	±	---	-32	±	---
6-46-4	2	153,000	±	1,250	151,000	±	1,290	152,000	±	1,000
6-46-21B	2	49,000	±	764	48,100	±	737	48,600	±	450
6-47-5	3	232,000	±	1,590	167,000	±	1,340	200,000	±	18,800
6-47-35A	1	-43	±	118	---	±	---	-43	±	---
6-47-46A	2	53	±	124	-23	±	120	15	±	38
6-47-50[c]	1	288	±	129	---	±	---	288	±	---
6-47-60	1	-176	±	114	---	±	---	-176	±	---
6-48-7	2	140	±	125	84	±	128	112	±	28

TABLE C.39. Tritium (contd)

Well Name[a]	No. of Samples	Concentration, pCi/L[b] (10^{-9} µCi/mL) Maximum			Minimum			Average		
6-48-18	2	92	±	129	-10	±	117	41	±	51
6-48-71	2	-90	±	122	-102	±	115	-96	±	6
6-49-13E	2	7	±	114	-167	±	115	-80	±	87
6-49-28	2	2,000	±	195	1,650	±	178	1,830	±	175
6-49-55A	2	3,620	±	233	2,910	±	216	3,270	±	355
6-49-55B	2	53	±	121	14	±	117	34	±	20
6-49-57	2	5,330	±	271	5,130	±	266	5,230	±	100
6-49-79	2	38	±	127	-97	±	115	-29	±	68
6-49-100C	3	-79	±	154	-144	±	113	-116	±	19
6-50-30	2	221	±	136	186	±	127	204	±	18
6-50-42	2	4,540	±	253	4,010	±	248	4,280	±	265
6-50-45[c]	2	99	±	121	54	±	121	77	±	22
6-50-48B[c]	2	50	±	119	-24	±	118	13	±	37
6-50-53	1	4,350	±	248	---	±	---	4,350	±	---
6-50-85	2	43	±	125	-122	±	114	-40	±	83
6-51-46	2	10	±	126	-65	±	113	-28	±	38
6-51-63	2	-41	±	126	-171	±	112	-106	±	65
6-51-75	2	26	±	130	-23	±	118	1	±	25
6-52-19	2	56	±	132	-184	±	111	-64	±	120
6-52-46A[c]	2	187	±	133	-47	±	114	70	±	117
6-52-48[c]	2	7	±	116	-133	±	121	-63	±	70
6-53-50[c]	1	48	±	158	---	±	---	48	±	---
6-53-103[c]	1	-10	±	122	---	±	---	-10	±	---
6-54-34	1	14	±	112	---	±	---	14	±	---
6-54-45A	2	117	±	117	-67	±	125	25	±	92
6-54-57[c]	2	247	±	128	-73	±	123	87	±	160
6-55-40	1	6	±	114	---	±	---	6	±	---
6-55-44	1	98	±	118	---	±	---	98	±	---
6-55-50A	2	-58	±	127	-95	±	113	-77	±	19
6-55-50C	1	-23	±	120	---	±	---	-23	±	---
6-55-50D	1	291	±	131	---	±	---	291	±	---
6-55-70	1	66	±	118	---	±	---	66	±	---
6-55-89	1	25	±	115	---	±	---	25	±	---
6-56-43	2	114	±	120	-46	±	127	34	±	80
6-56-53	2	86	±	131	-21	±	156	33	±	53
6-57-29A	1	579	±	141	---	±	---	579	±	---
6-59-58	1	894	±	156	---	±	---	894	±	---
6-60-57	1	483	±	136	---	±	---	483	±	---
6-60-60	1	6,510	±	306	---	±	---	6,510	±	---
6-61-37	1	518	±	136	---	±	---	518	±	---
6-61-41	1	239	±	125	---	±	---	239	±	---
6-61-62	1	8,540	±	328	---	±	---	8,540	±	---
6-61-66	1	121	±	123	---	±	---	121	±	---
6-63-25A	2	96	±	119	20	±	130	58	±	38
6-63-55	2	930	±	152	917	±	159	924	±	7
6-63-58	2	1,940	±	191	1,790	±	186	1,870	±	75
6-63-90	1	81	±	115	---	±	---	81	±	---
6-64-27	1	296	±	169	---	±	---	296	±	---

TABLE C.39. Tritium (contd)

Well Name[a]	No. of Samples	Concentration, pCi/L[b] (10^{-9} µCi/mL) Maximum			Minimum			Average		
6-64-62	1	8,270	±	326	---	±	---	8,270	±	----
6-65-23	1	94	±	162	---	±	---	94	±	---
6-65-50	2	701	±	153	685	±	147	693	±	8
6-65-59A	1	1,300	±	169	---	±	---	1,300	±	---
6-65-72	2	2,650	±	207	2,320	±	203	2,490	±	165
6-65-83	2	923	±	161	634	±	145	779	±	145
6-66-58	2	797	±	145	778	±	158	788	±	10
6-66-64	2	6,220	±	290	6,070	±	277	6,150	±	75
6-66-103	1	194	±	121	---	±	---	194	±	---
6-67-51	2	545	±	147	360	±	128	453	±	93
6-67-86	2	875	±	161	736	±	141	806	±	70
6-67-98	2	178	±	120	-330	±	114	-76	±	254
6-68-105	1	95	±	124	---	±	---	95	±	---
6-69-38	2	-8	±	128	-154	±	112	-81	±	73
6-70-68	2	1,860	±	192	1,610	±	173	1,740	±	125
6-71-30	2	90	±	116	9	±	124	50	±	41
6-71-52	2	808	±	159	769	±	151	789	±	20
6-71-77	2	3,220	±	228	2,530	±	203	2,880	±	345
6-72-73	1	1,280	±	194	---	±	---	1,280	±	---
6-72-88	2	4,220	±	247	2,440	±	197	3,330	±	890
6-72-92	1	1,550	±	205	---	±	---	1,550	±	---
6-73-61	1	185	±	131	---	±	---	185	±	---
6-74-44	2	61	±	131	-180	±	113	-60	±	121
6-77-36	1	84	±	152	---	±	---	84	±	---
6-77-54	2	41	±	128	-22	±	120	9	±	32
6-80-43P	1	-14	±	113	---	±	---	-14	±	---
6-80-43Q	1	150	±	122	---	±	---	150	±	---
6-80-43R	1	101	±	118	---	±	---	101	±	---
6-80-43S	1	286	±	127	---	±	---	286	±	---
6-81-58	3	270	±	165	88	±	129	172	±	53
6-83-47	1	710	±	148	---	±	---	710	±	---
6-84-35AO	1	260	±	157	---	±	---	260	±	---
6-87-55	2	80,800	±	911	74,100	±	912	77,500	±	3,350
6-89-35	2	564	±	136	543	±	146	554	±	11
6-90-45	2	2,150	±	198	2,060	±	193	2,110	±	45
6-96-49	2	11,900	±	400	11,900	±	398	11,900	±	0
6-97-43	1	10,300	±	376	---	±	---	10,300	±	---
6-97-51A	2	14,000	±	423	13,400	±	421	13,700	±	300
6-101-48B	2	143	±	129	-6	±	119	69	±	74

(a) See Figures 5.1, 5.2, and 5.3 for well locations.
(b) Maximum and minimum concentrations ±2 sigma counting errors. Average concentrations ±2 times the standard error of the calculated mean (no estimate of standard error for one sample).
(c) Wells that sample a confined aquifer.

TABLE C.40. Maximum, Minimum, and Average Uranium Concentrations in Ground-Water Samples in 1989

Well Name[a]	No. of Samples	Concentration, pCi/L[b] (10^{-9} µCi/mL) Maximum			Minimum			Average		
1-B3-1	2	2.42	±	0.73	2.21	±	0.72	2.32	±	0.11
1-B4-1	2	1.45	±	0.47	1.40	±	0.47	1.43	±	0.03
1-B4-2	2	14.40	±	5.00	0.93	±	0.33	7.67	±	6.73
1-B4-3	2	1.19	±	0.41	1.01	±	0.36	1.10	±	0.09
1-B4-4	2	1.28	±	0.45	0.77	±	0.28	1.03	±	0.25
1-B5-1	2	1.07	±	0.38	0.88	±	0.31	0.97	±	0.10
1-B9-1	3	3.14	±	0.97	0.86	±	0.31	1.71	±	0.72
1-D2-5	2	1.43	±	0.49	1.40	±	0.46	1.42	±	0.02
1-D5-12	2	2.39	±	0.79	1.69	±	0.56	2.04	±	0.35
1-D8-3	2	1.82	±	0.63	0.57	±	0.23	1.19	±	0.63
1-F5-1	1	1.05	±	0.39	---	±	---	1.05	±	---
1-F5-3	2	0.47	±	0.20	0.16	±	0.10	0.31	±	0.16
1-F5-4	2	7.11	±	2.08	6.68	±	1.90	6.90	±	0.22
1-F5-6	2	0.52	±	0.20	0.44	±	0.18	0.48	±	0.04
1-F7-1	2	4.27	±	1.25	4.23	±	1.27	4.25	±	0.02
1-F8-1	2	143.00	±	39.80	91.00	±	25.60	117.00	±	26.00
1-F8-2	2	51.50	±	15.10	42.20	±	11.50	46.90	±	4.65
1-H3-1	1	2.39	±	0.74	---	±	---	2.39	±	---
1-H3-2A	4	3.68	±	1.11	2.08	±	0.67	2.83	±	0.35
1-H3-2B	1	3.11	±	0.96	---	±	---	3.11	±	---
1-H3-2C	1	0.74	±	0.26	---	±	---	0.74	±	---
1-H4-3	5	145.00	±	41.80	40.40	±	11.80	72.50	±	18.80
1-H4-4	4	88.80	±	26.20	1.67	±	0.94	39.50	±	21.90
1-H4-5	3	3.62	±	1.10	2.79	±	0.87	3.11	±	0.26
1-H4-6	5	5.91	±	1.80	2.98	±	0.91	4.28	±	0.48
1-H4-7	2	4.95	±	1.46	3.26	±	0.99	4.11	±	0.84
1-H4-8	1	3.97	±	1.20	---	±	---	3.97	±	---
1-H4-9	2	6.18	±	1.80	4.85	±	1.44	5.52	±	0.67
1-H4-10	1	0.41	±	0.17	---	±	---	0.41	±	---
1-H4-11	1	5.26	±	1.56	---	±	---	5.26	±	---
1-H4-12A	4	20.80	±	5.90	1.68	±	0.57	8.51	±	4.24
1-H4-12B	3	5.60	±	1.63	2.48	±	0.77	4.13	±	0.91
1-H4-12C	4	2.19	±	0.70	0.89	±	0.32	1.31	±	0.30
1-H4-13	1	1.43	±	0.50	---	±	---	1.43	±	---
1-H4-14	2	1.72	±	0.56	1.12	±	0.39	1.42	±	0.30
1-H4-15A	1	1.22	±	0.41	---	±	---	1.22	±	---
1-H4-15B	1	1.34	±	0.45	---	±	---	1.34	±	---
1-H4-16	1	1.04	±	0.38	---	±	---	1.04	±	---
1-H4-17	1	4.17	±	1.26	---	±	---	4.17	±	---
1-H4-18	4	3.65	±	1.14	1.57	±	0.52	2.65	±	0.49
1-K-11	2	3.43	±	1.02	2.75	±	0.84	3.09	±	0.34
1-K-22	1	1.14	±	0.39	---	±	---	1.14	±	---
1-K-27	2	5.89	±	1.72	3.16	±	0.97	4.53	±	1.37
1-K-28	2	4.41	±	1.32	4.29	±	1.27	4.35	±	0.06
1-K-29	2	2.22	±	0.70	1.84	±	0.59	2.03	±	0.19
1-K-30	2	1.98	±	0.62	1.73	±	0.56	1.86	±	0.13
1-N-2	3	0.30	±	0.17	0.15	±	0.11	0.22	±	0.04

TABLE C.40. Uranium (contd)

Well Name[a]	No. of Samples	Concentration, pCi/L[b] (10^{-9} µCi/mL) Maximum			Minimum			Average		
1-N-3	4	0.82	±	0.32	0.28	±	0.16	0.55	±	0.15
1-N-4	4	0.76	±	0.30	0.28	±	0.14	0.43	±	0.11
1-N-5	1	0.45	±	0.20	---	±	---	0.45	±	---
1-N-6	1	0.56	±	0.22	---	±	---	0.56	±	---
1-N-14	6	0.83	±	0.30	0.17	±	0.13	0.42	±	0.13
1-N-16	2	3.96	±	1.27	1.77	±	0.63	2.87	±	1.10
1-N-17	1	0.78	±	0.30	---	±	---	0.78	±	---
1-N-18	1	0.53	±	0.26	---	±	---	0.53	±	---
1-N-20	1	1.07	±	0.38	---	±	---	1.07	±	---
1-N-21	1	1.50	±	0.51	---	±	---	1.50	±	---
1-N-22	1	4.59	±	1.42	---	±	---	4.59	±	---
1-N-23	2	6.41	±	1.87	0.00	±	0.07	3.21	±	3.20
1-N-24	2	4.23	±	1.25	1.02	±	0.35	2.63	±	1.61
1-N-25	2	3.84	±	1.21	1.71	±	0.56	2.78	±	1.07
1-N-26	1	1.39	±	0.46	---	±	---	1.39	±	---
1-N-27	3	0.59	±	0.23	0.56	±	0.21	0.57	±	0.01
1-N-28	1	1.22	±	0.42	---	±	---	1.22	±	---
1-N-29	3	0.60	±	0.24	0.47	±	0.20	0.56	±	0.04
1-N-31	5	0.76	±	0.28	0.31	±	0.15	0.46	±	0.08
1-N-32	4	0.71	±	0.28	0.35	±	0.16	0.51	±	0.08
1-N-33	5	0.88	±	0.33	0.51	±	0.20	0.70	±	0.06
1-N-36	5	0.78	±	0.29	0.36	±	0.18	0.51	±	0.08
1-N-37	1	0.56	±	0.22	---	±	---	0.56	±	---
1-N-39	2	0.52	±	0.21	0.49	±	0.20	0.51	±	0.01
1-N-41	4	0.48	±	0.20	0.38	±	0.18	0.42	±	0.02
1-N-42	4	0.72	±	0.28	0.38	±	0.17	0.58	±	0.08
1-N-47	1	4.56	±	1.34	---	±	---	4.56	±	---
1-N-50	1	0.38	±	0.17	---	±	---	0.38	±	---
1-N-51	1	0.45	±	0.19	---	±	---	0.45	±	---
1-N-52	4	0.86	±	0.30	0.53	±	0.22	0.71	±	0.07
1-N-54	1	0.45	±	0.19	---	±	---	0.45	±	---
1-N-55	1	0.73	±	0.27	---	±	---	0.73	±	---
1-N-56	1	0.53	±	0.22	---	±	---	0.53	±	---
1-N-57	1	0.91	±	0.33	---	±	---	0.91	±	---
1-N-58	4	2.40	±	1.24	1.37	±	0.51	1.90	±	0.24
1-N-59	5	1.68	±	0.62	0.82	±	0.35	1.23	±	0.18
1-N-60	5	3.01	±	1.45	0.83	±	0.30	1.76	±	0.45
1-N-61	5	2.92	±	1.50	0.62	±	0.29	1.46	±	0.42
1-N-66	4	0.80	±	0.31	0.39	±	0.19	0.61	±	0.08
1-N-67	4	0.37	±	0.19	0.21	±	0.12	0.29	±	0.04
1-N-69	4	0.44	±	0.20	0.19	±	0.12	0.29	±	0.06
1-N-70	4	0.50	±	0.22	0.32	±	0.16	0.41	±	0.05
2-E13-8	1	2.51	±	0.79	---	±	---	2.51	±	---
2-E16-2	1	1.05	±	0.38	---	±	---	1.05	±	---
2-E17-1	2	2.15	±	0.68	2.05	±	0.66	2.10	±	0.05
2-E17-2	3	9.45	±	2.53	7.28	±	2.00	8.19	±	0.65
2-E17-5	4	5.93	±	1.64	4.30	±	1.20	5.05	±	0.33
2-E17-12	3	3.76	±	1.07	3.14	±	0.90	3.36	±	0.20

TABLE C.40. Uranium (contd)

Well Name[a]	No. of Samples	Concentration, pCi/L[b] (10^{-9} µCi/mL) Maximum			Minimum			Average		
2-E17-13	5	4.35	±	1.22	2.90	±	0.90	3.52	±	0.25
2-E17-19	4	4.55	±	1.35	3.04	±	0.94	3.72	±	0.33
2-E17-20	4	3.76	±	1.13	3.38	±	1.03	3.64	±	0.09
2-E18-1	1	4.56	±	1.35	---	±	---	4.56	±	---
2-E24-2	4	3.17	±	0.98	2.36	±	0.76	2.75	±	0.21
2-E24-16	4	3.50	±	1.07	3.00	±	0.93	3.36	±	0.12
2-E24-17	3	2.96	±	0.91	2.67	±	0.83	2.78	±	0.09
2-E24-18	3	3.37	±	1.06	3.28	±	1.00	3.33	±	0.03
2-E25-9	2	2.63	±	0.82	1.59	±	0.52	2.11	±	0.52
2-E25-11	1	0.95	±	0.35	---	±	---	0.95	±	---
2-E25-22	1	0.83	±	0.31	---	±	---	0.83	±	---
2-E25-24	1	0.71	±	0.26	---	±	---	0.71	±	---
2-E25-26	2	1.04	±	0.37	0.98	±	0.36	1.01	±	0.03
2-E25-28	1	0.93	±	0.33	---	±	---	0.93	±	---
2-E25-32P	1	0.68	±	0.27	---	±	---	0.68	±	---
2-E25-34	1	0.83	±	0.31	---	±	---	0.83	±	---
2-E25-35	1	2.56	±	0.80	---	±	---	2.56	±	---
2-E25-36	3	1.40	±	0.47	0.93	±	0.35	1.10	±	0.15
2-E27-8	3	2.52	±	0.76	1.89	±	0.62	2.22	±	0.18
2-E27-9	3	2.79	±	0.89	1.74	±	0.54	2.14	±	0.33
2-E27-10	3	2.31	±	0.75	1.90	±	0.63	2.07	±	0.12
2-E28-7	3	3.40	±	1.00	1.85	±	0.58	2.72	±	0.46
2-E28-9	2	10.92	±	3.00	9.94	±	2.54	10.40	±	0.49
2-E28-16	1	7.91	±	2.15	---	±	---	7.91	±	---
2-E28-17	2	15.47	±	3.88	9.03	±	3.32	12.30	±	3.22
2-E28-18	2	32.48	±	9.38	15.47	±	4.01	24.00	±	8.51
2-E28-19	1	10.50	±	3.75	---	±	---	10.50	±	---
2-E28-21	3	31.99	±	9.38	20.09	±	6.22	25.10	±	3.57
2-E28-23	1	10.15	±	3.52	---	±	---	10.20	±	---
2-E28-24	3	1.20	±	0.76	0.29	±	0.20	0.85	±	0.28
2-E28-25	3	21.42	±	5.89	11.80	±	3.36	15.20	±	3.13
2-E28-26	3	25.00	±	7.02	17.10	±	4.57	22.20	±	2.57
2-E28-27	4	3.66	±	1.08	3.31	±	1.05	3.45	±	0.08
2-E32-2	3	2.91	±	0.90	2.11	±	0.68	2.46	±	0.24
2-E32-3	1	11.40	±	3.21	---	±	---	11.40	±	---
2-E32-4	4	9.32	±	2.65	2.19	±	0.71	4.98	±	1.52
2-E33-7	1	2.46	±	0.79	---	±	---	2.46	±	---
2-E33-9	1	1.42	±	0.47	---	±	---	1.42	±	---
2-E33-20	1	1.24	±	0.42	---	±	---	1.24	±	---
2-E33-28	4	1.75	±	0.62	1.45	±	0.49	1.61	±	0.06
2-E33-29	3	1.84	±	0.61	1.36	±	0.48	1.56	±	0.14
2-E33-30	3	1.54	±	0.53	1.54	±	0.54	1.54	±	0.00
2-E34-1	1	1.30	±	0.44	---	±	---	1.30	±	---
2-E34-2	4	3.00	±	0.95	1.57	±	0.51	2.07	±	0.32
2-E34-3	3	2.43	±	0.80	1.82	±	0.61	2.04	±	0.20
2-E34-5	3	4.26	±	1.30	3.18	±	0.98	3.61	±	0.33
2-E34-6	3	3.71	±	1.13	2.65	±	0.84	3.10	±	0.32

TABLE C.40. Uranium (contd)

Well Name[a]	No. of Samples	Concentration, pCi/L[b] (10^{-9} µCi/mL) Maximum			Minimum			Average		
2-W6-2	5	1.50	±	0.52	0.83	±	0.30	1.16	±	0.13
2-W7-1	3	0.62	±	0.24	0.48	±	0.21	0.54	±	0.04
2-W7-2	3	0.90	±	0.35	0.56	±	0.23	0.72	±	0.10
2-W7-3	3	1.52	±	0.51	0.95	±	0.37	1.16	±	0.18
2-W7-4	3	1.40	±	0.49	1.17	±	0.42	1.28	±	0.07
2-W7-5	3	1.19	±	0.42	0.98	±	0.37	1.12	±	0.07
2-W7-6	3	7.57	±	2.18	1.86	±	0.63	4.43	±	1.67
2-W8-1	3	0.85	±	0.31	0.58	±	0.25	0.71	±	0.08
2-W9-1	3	1.08	±	0.38	0.84	±	0.31	0.94	±	0.07
2-W10-13	5	0.70	±	0.31	0.49	±	0.23	0.65	±	0.04
2-W10-14	4	0.79	±	0.32	0.60	±	0.25	0.72	±	0.05
2-W15-15	3	3.64	±	1.09	2.33	±	0.71	3.05	±	0.38
2-W15-16	3	3.52	±	1.11	1.41	±	0.49	2.31	±	0.63
2-W15-17	2	0.69	±	0.28	0.55	±	0.25	0.62	±	0.07
2-W15-18	3	0.75	±	0.28	0.57	±	0.26	0.67	±	0.05
2-W18-15	1	32.76	±	9.87	---	±	---	32.80	±	---
2-W18-21	3	24.00	±	6.73	20.80	±	5.73	22.70	±	0.96
2-W18-22	3	0.88	±	0.33	0.51	±	0.20	0.68	±	0.11
2-W18-23	4	1.41	±	0.51	0.98	±	0.38	1.12	±	0.10
2-W18-24	4	1.10	±	0.39	0.71	±	0.28	0.86	±	0.09
2-W19-2	4	104.30	±	27.44	16.31	±	4.16	59.70	±	21.10
2-W19-3	3	1,680.00	±	464.10	1,155.00	±	320.60	1,410.00	±	152.00
2-W19-9	1	980.00	±	284.20	---	±	---	980.00	±	---
2-W19-13	1	6.56	±	1.78	---	±	---	6.56	±	---
2-W19-14	1	3.19	±	0.92	---	±	---	3.19	±	---
2-W19-15	1	32.06	±	12.04	---	±	---	32.10	±	---
2-W19-16	1	448.70	±	139.30	---	±	---	449.00	±	---
2-W19-17	1	12.60	±	4.21	---	±	---	12.60	±	---
2-W19-18	4	2,191.00	±	610.40	1,316.00	±	371.00	1,920.00	±	204.00
2-W19-19	5	2,030.00	±	567.70	428.40	±	120.40	796.00	±	309.00
2-W19-20	5	421.40	±	118.30	2.04	±	0.65	272.00	±	71.50
2-W19-21	2	15.33	±	4.96	15.10	±	4.14	15.20	±	0.12
2-W19-23	5	173.60	±	49.14	115.50	±	34.65	136.00	±	10.00
2-W19-24	5	397.00	±	110.00	299.60	±	88.20	346.00	±	16.60
2-W19-25	4	233.10	±	70.00	182.00	±	58.66	199.00	±	11.50
2-W19-26	2	340.00	±	96.40	335.30	±	89.60	338.00	±	2.35
2-W19-27	2	9.17	±	3.21	8.57	±	2.43	8.87	±	0.30
2-W22-22	1	1.36	±	0.46	---	±	---	1.36	±	---
2-W23-4	5	260.40	±	67.27	47.88	±	12.46	105.00	±	39.30
2-W23-9	5	51.31	±	14.35	31.43	±	8.26	41.50	±	3.48
2-W23-10	2	31.36	±	9.31	30.94	±	8.96	31.20	±	0.21
2-W23-11	1	17.57	±	4.59	---	±	---	17.60	±	---
2-W27-1	1	7.98	±	2.13	---	±	---	7.98	±	---
3-1-3	1	66.40	±	18.80	---	±	---	66.40	±	---
3-1-7	4	68.60	±	19.40	51.80	±	14.20	59.50	±	3.63
3-1-10	2	27.70	±	7.73	11.50	±	3.24	19.60	±	8.10
3-1-11	13	63.20	±	18.20	10.50	±	3.53	32.90	±	5.91
3-1-12	2	39.10	±	11.00	34.90	±	9.66	37.00	±	2.10

TABLE C.40. Uranium (contd)

Well Name[a]	No. of Samples	Concentration, pCi/L[b] (10^{-9} µCi/mL) Maximum			Minimum			Average		
3-1-13	2	8.20	±	2.34	6.68	±	1.93	7.44	±	0.76
3-1-14	2	12.40	±	3.46	10.70	±	3.06	11.60	±	0.85
3-1-15	3	9.09	±	2.58	5.32	±	1.56	7.82	±	1.25
3-1-16A	3	12.20	±	3.37	6.96	±	2.00	10.40	±	1.71
3-1-16B	3	2.11	±	0.68	1.23	±	0.41	1.65	±	0.26
3-1-16C	2	3.63	±	1.09	2.08	±	0.67	2.86	±	0.78
3-1-17A	26	201.00	±	55.50	40.10	±	11.80	104.00	±	8.73
3-1-17B	2	0.03	±	0.06	-0.03	±	0.08	-0.00	±	0.03
3-1-17C	1	0.18	±	0.13	---	±	---	0.18	±	---
3-1-18A	13	4.05	±	1.21	2.58	±	1.40	3.41	±	0.12
3-1-18B	1	-0.01	±	0.05	---	±	---	-0.01	±	---
3-1-19	6	370.00	±	105.00	125.00	±	34.80	241.00	±	39.90
3-2-1	2	13.50	±	3.78	6.95	±	1.96	10.20	±	3.28
3-2-2	1	39.50	±	10.80	---	±	---	39.50	±	---
3-3-7	3	10.20	±	2.90	5.55	±	1.59	8.03	±	1.35
3-3-9	2	17.90	±	4.97	11.60	±	3.22	14.80	±	3.15
3-3-10	2	17.60	±	4.80	8.58	±	2.47	13.10	±	4.51
3-4-1	2	16.10	±	4.53	8.75	±	2.43	12.40	±	3.68
3-4-7	2	20.80	±	5.56	12.50	±	3.45	16.70	±	4.15
3-4-11	2	8.75	±	2.49	7.04	±	1.98	7.90	±	0.85
3-8-1	2	4.06	±	1.23	2.82	±	0.86	3.44	±	0.62
3-8-2	1	2.32	±	0.73	---	±	---	2.32	±	---
3-8-3	1	3.78	±	1.14	---	±	---	3.78	±	---
6-S30-E15A	2	1.46	±	0.50	1.38	±	0.47	1.42	±	0.04
6-S29-E12	2	2.07	±	0.68	1.23	±	0.42	1.65	±	0.42
6-S28-E0	2	1.39	±	0.47	1.38	±	0.47	1.39	±	0.00
6-S27-E14	3	4.78	±	1.45	3.20	±	0.98	3.80	±	0.50
6-S24-19	1	0.46	±	0.23	---	±	---	0.46	±	---
6-S19-E13	2	4.38	±	1.32	2.70	±	0.83	3.54	±	0.84
6-S14-20A	1	0.26	±	0.15	---	±	---	0.26	±	---
6-S12-3	1	0.53	±	0.22	---	±	---	0.53	±	---
6-S6-E4B	2	3.17	±	0.97	2.40	±	0.75	2.79	±	0.39
6-S6-E4D	2	3.07	±	0.95	2.83	±	0.88	2.95	±	0.12
6-3-45	1	2.52	±	0.89	---	±	---	2.52	±	---
6-20-E12	2	1.39	±	0.48	1.19	±	0.44	1.29	±	0.10
6-20-20	2	3.38	±	1.04	2.70	±	0.82	3.04	±	0.34
6-32-70B	2	3.25	±	1.06	1.22	±	0.41	2.24	±	1.02
6-32-72	1	0.26	±	0.15	---	±	---	0.26	±	---
6-35-66	1	1.98	±	0.66	---	±	---	1.98	±	---
6-35-70	2	3.95	±	1.20	2.39	±	0.76	3.17	±	0.78
6-35-78A	2	19.67	±	5.17	17.57	±	4.52	18.60	±	1.05
6-38-70	5	65.73	±	18.06	29.19	±	8.26	46.00	±	5.87
6-40-39	1	1.92	±	0.62	---	±	---	1.92	±	---
6-41-1	2	3.16	±	0.98	2.75	±	0.83	2.96	±	0.21
6-41-40	1	2.51	±	0.78	---	±	---	2.51	±	---
6-42-12A	2	2.19	±	0.71	1.13	±	0.38	1.66	±	0.53
6-42-40A	3	0.71	±	0.27	0.68	±	0.26	0.70	±	0.01
6-42-40B	1	1.73	±	0.57	---	±	---	1.73	±	---

TABLE C.40. Uranium (contd)

Well Name[a]	No. of Samples	Concentration, pCi/L[b] (10^{-9} µCi/mL) Maximum			Minimum			Average		
6-42-42B	1	1.36	±	0.46	---	±	---	1.36	±	---
6-43-41E	1	1.84	±	0.59	---	±	---	1.84	±	---
6-43-41F	1	2.39	±	0.75	---	±	---	2.39	±	---
6-43-42J	1	1.51	±	0.51	---	±	---	1.51	±	---
6-43-45	1	1.21	±	0.41	---	±	---	1.21	±	---
6-44-43B	2	1.89	±	0.60	1.51	±	0.48	1.70	±	0.19
6-45-42	4	1.88	±	0.58	1.50	±	0.49	1.72	±	0.08
6-47-5	2	2.37	±	0.77	2.33	±	0.72	2.35	±	0.02
6-47-46A	2	2.34	±	0.74	2.14	±	0.67	2.24	±	0.10
6-47-60	1	1.88	±	0.61	---	±	---	1.88	±	---
6-49-55A	2	3.69	±	1.10	2.50	±	0.79	3.10	±	0.59
6-49-57	2	1.93	±	0.65	1.52	±	0.51	1.73	±	0.21
6-51-63	2	5.90	±	1.76	1.81	±	0.60	3.86	±	2.05
6-55-50A	2	0.05	±	0.11	0.01	±	0.08	0.03	±	0.02
6-55-50C	1	0.76	±	0.32	---	±	---	0.76	±	---
6-55-50D	1	2.56	±	0.85	---	±	---	2.56	±	---
6-55-70	1	1.59	±	0.73	---	±	---	1.59	±	---
6-55-89	1	0.83	±	0.36	---	±	---	0.83	±	---
6-59-58	1	0.57	±	0.28	---	±	---	0.57	±	---
6-60-57	1	0.14	±	0.11	---	±	---	0.14	±	---
6-60-60	1	0.74	±	0.30	---	±	---	0.74	±	---
6-61-62	1	1.22	±	0.42	---	±	---	1.22	±	---
6-61-66	1	1.61	±	0.55	---	±	---	1.61	±	---
6-63-55	2	1.16	±	0.44	0.76	±	0.28	0.96	±	0.20
6-63-58	2	1.09	±	0.39	1.06	±	0.37	1.08	±	0.02
6-64-62	1	1.84	±	0.61	---	±	---	1.84	±	---
6-65-50	2	1.44	±	0.49	0.76	±	0.29	1.10	±	0.34
6-65-59A	1	0.84	±	0.31	---	±	---	0.84	±	---
6-65-72	2	1.85	±	0.62	1.65	±	0.54	1.75	±	0.10
6-66-58	2	0.81	±	0.32	0.69	±	0.27	0.75	±	0.06
6-66-64	2	1.27	±	0.46	1.00	±	0.36	1.14	±	0.14
6-67-51	2	2.31	±	0.78	0.87	±	0.33	1.59	±	0.72
6-70-68	2	1.17	±	0.41	0.77	±	0.31	0.97	±	0.20
6-71-52	2	1.72	±	0.57	1.62	±	0.55	1.67	±	0.05
6-71-77	2	1.54	±	0.54	1.22	±	0.41	1.38	±	0.16
6-73-61	1	1.73	±	0.59	---	±	---	1.73	±	---
6-81-58	3	1.27	±	0.45	0.73	±	0.27	1.07	±	0.17
6-96-49	2	0.93	±	0.34	0.47	±	0.20	0.70	±	0.23
6-97-51A	2	1.39	±	0.48	1.22	±	0.44	1.31	±	0.09

(a) See Figures 5.1, 5.2, and 5.3 for well locations.
(b) Maximum and minimum concentrations ±2 sigma analytical errors. Average concentrations ±2 times the standard error of the calculated mean (no estimate of standard error for one sample).

TABLE C.41. Maximum, Minimum, and Average Strontium-90 (^{90}Sr) Concentrations in Ground-Water Samples in 1989

Well Name[a]	No. of Samples	Concentration, pCi/L[b] (10^{-9} µCi/mL)								
		Maximum			Minimum			Average		
1-B3-1	2	52.60	±	3.89	48.30	±	3.56	50.50	±	2.15
1-B4-1	2	24.50	±	2.64	21.60	±	2.61	23.10	±	1.45
1-B4-2	2	53.50	±	3.77	19.90	±	2.44	36.70	±	16.80
1-B4-3	2	20.00	±	2.28	16.70	±	2.21	18.40	±	1.65
1-B4-4	2	29.10	±	3.02	25.40	±	2.66	27.30	±	1.85
1-B5-1	2	1.55	±	0.85	0.45	±	0.84	1.00	±	0.55
1-B9-1	2	1.91	±	1.13	1.67	±	1.11	1.79	±	0.12
1-D2-5	2	0.42	±	0.72	-0.06	±	0.60	0.18	±	0.24
1-D5-12	2	45.20	±	3.41	44.60	±	3.51	44.90	±	0.30
1-D8-3	2	3.78	±	1.13	2.63	±	0.99	3.21	±	0.58
1-F5-1	1	41.40	±	3.18	---	±	---	41.40	±	---
1-F5-3	2	244.00	±	8.31	118.00	±	5.41	181.00	±	63.00
1-F5-4	2	0.14	±	0.70	-0.01	±	0.69	0.06	±	0.08
1-F5-6	2	2.23	±	0.98	1.69	±	0.92	1.96	±	0.27
1-F7-1	2	0.31	±	0.76	0.28	±	0.73	0.29	±	0.02
1-F8-1	2	-0.16	±	0.71	-0.22	±	0.62	-0.19	±	0.03
1-F8-2	2	0.15	±	0.68	0.12	±	0.64	0.13	±	0.02
1-K-11	2	0.28	±	0.67	-0.24	±	0.56	0.02	±	0.26
1-K-22	1	3.39	±	1.19	---	±	---	3.39	±	---
1-K-27	2	-0.12	±	0.71	-0.46	±	0.55	-0.29	±	0.17
1-K-28	2	-0.09	±	0.61	-0.44	±	0.53	-0.27	±	0.17
1-K-29	2	0.16	±	0.62	-0.45	±	0.81	-0.14	±	0.30
1-K-30	2	0.26	±	0.65	0.26	±	0.70	0.26	±	0.00
1-N-2	3	3,610.00	±	153.00	1,840.00	±	97.50	2,670.00	±	514.00
1-N-3	4	2,640.00	±	120.00	541.00	±	56.60	1,230.00	±	487.00
1-N-4	4	9.25	±	1.74	6.92	±	1.57	7.84	±	0.52
1-N-5	1	492.00	±	49.90	---	±	---	492.00	±	---
1-N-6	1	40.80	±	3.34	---	±	---	40.80	±	---
1-N-14	5	1,110.00	±	56.30	1,010.00	±	57.10	1,070.00	±	20.10
1-N-16	2	0.39	±	0.75	-0.25	±	0.62	0.07	±	0.32
1-N-17	1	111.00	±	5.32	---	±	---	111.00	±	---
1-N-18	1	415.00	±	46.20	---	±	---	415.00	±	---
1-N-20	1	13.10	±	2.03	---	±	---	13.10	±	---
1-N-21	1	3.21	±	1.12	---	±	---	3.21	±	---
1-N-22	1	-0.39	±	0.69	---	±	---	-0.39	±	---
1-N-23	2	1.96	±	1.02	1.15	±	0.85	1.56	±	0.41
1-N-24	2	11.70	±	1.84	4.55	±	1.21	8.13	±	3.58
1-N-25	2	8.04	±	1.59	-0.12	±	0.58	3.96	±	4.08
1-N-26	1	-0.48	±	0.60	---	±	---	-0.48	±	---
1-N-27	3	325.00	±	13.40	38.40	±	4.60	205.00	±	86.10
1-N-28	1	26.90	±	2.72	---	±	---	26.90	±	---
1-N-29	3	1,750.00	±	65.30	591.00	±	40.50	1,340.00	±	374.00
1-N-31	5	60.90	±	4.18	36.60	±	3.11	52.80	±	4.42
1-N-32	4	195.00	±	6.89	11.20	±	1.86	64.50	±	43.60
1-N-33	4	285.00	±	19.50	209.00	±	16.30	237.00	±	16.80
1-N-36	4	224.00	±	11.10	65.50	±	5.75	161.00	±	33.80
1-N-37	1	58.10	±	3.88	---	±	---	58.10	±	---
1-N-39	2	526.00	±	37.30	454.00	±	10.70	490.00	±	36.00

TABLE C.41. Strontium-90 (contd)

Well Name[a]	No. of Samples	Concentration, pCi/L[b] (10^{-9} µCi/mL) Maximum			Minimum			Average		
1-N-41	4	0.06	±	0.61	-0.42	±	0.57	-0.13	±	0.11
1-N-42	4	0.22	±	0.72	-0.27	±	0.67	0.04	±	0.11
1-N-47	1	-0.26	±	0.59	---	±	---	-0.26	±	---
1-N-50	1	0.17	±	0.76	---	±	---	0.17	±	---
1-N-51	1	0.13	±	0.69	---	±	---	0.13	±	---
1-N-52	4	0.18	±	0.67	-0.18	±	0.60	0.04	±	0.08
1-N-54	1	171.00	±	6.66	---	±	---	171.00	±	---
1-N-55	1	44.10	±	3.43	---	±	---	44.10	±	---
1-N-56	1	364.00	±	9.67	---	±	---	364.00	±	---
1-N-57	1	18.50	±	2.39	---	±	---	18.50	±	---
1-N-58	4	1.35	±	1.22	0.30	±	0.85	0.89	±	0.23
1-N-59	4	0.69	±	0.93	-0.29	±	0.64	0.23	±	0.22
1-N-60	5	0.43	±	0.79	0.08	±	0.64	0.28	±	0.06
1-N-61	5	0.78	±	0.82	-0.09	±	0.69	0.37	±	0.15
1-N-66	4	2.18	±	0.96	0.57	±	0.85	1.27	±	0.40
1-N-67	4	23,400.00	±	1150.00	11,600.00	±	766.00	15,500.00	±	2670.00
1-N-69	4	0.84	±	0.79	0.06	±	0.67	0.43	±	0.19
1-N-70	4	0.09	±	0.82	-0.48	±	0.56	-0.18	±	0.14
2-E13-8	1	0.38	±	0.75	---	±	---	0.38	±	---
2-E16-2	3	0.13	±	0.64	-0.13	±	0.70	-0.03	±	0.08
2-E17-1	2	3.39	±	1.13	3.18	±	1.12	3.29	±	0.11
2-E17-2	3	2.43	±	1.06	2.05	±	0.97	2.18	±	0.13
2-E17-5	3	4.21	±	3.22	2.61	±	1.06	3.39	±	0.46
2-E17-8	1	2.92	±	1.13	---	±	---	2.92	±	---
2-E17-9	3	4.02	±	1.29	2.37	±	1.05	3.24	±	0.48
2-E17-12	3	0.68	±	0.88	-0.14	±	0.67	0.20	±	0.25
2-E17-13	5	0.70	±	0.85	-0.33	±	0.66	0.27	±	0.19
2-E17-14	1	28.10	±	2.88	---	±	---	28.10	±	---
2-E17-16	1	3.62	±	1.20	---	±	---	3.62	±	---
2-E17-17	1	-0.16	±	0.65	---	±	---	-0.16	±	---
2-E17-18	1	0.28	±	0.68	---	±	---	0.28	±	---
2-E18-1	1	0.43	±	0.78	---	±	---	0.43	±	---
2-E24-1	2	9.15	±	1.57	5.36	±	1.36	7.26	±	1.90
2-E24-2	2	3.01	±	1.06	2.93	±	1.10	2.97	±	0.04
2-E24-4	1	-0.10	±	0.65	---	±	---	-0.10	±	---
2-E24-11	3	1.27	±	0.95	0.95	±	0.67	1.07	±	0.10
2-E24-12	1	18.50	±	2.12	---	±	---	18.50	±	---
2-E24-13	1	0.62	±	0.83	---	±	---	0.62	±	---
2-E25-2	1	0.07	±	0.62	---	±	---	0.07	±	-
2-E25-3	1	0.42	±	0.74	---	±	---	0.42	±	---
2-E25-6	2	0.28	±	0.74	0.21	±	0.76	0.25	±	0.04
2-E25-9	2	0.18	±	0.65	-0.06	±	0.68	0.06	±	0.12
2-E25-11	4	0.08	±	0.63	-0.34	±	0.66	-0.10	±	0.09
2-E25-17	2	0.26	±	0.76	-0.07	±	0.66	0.10	±	0.16
2-E25-18	1	-0.20	±	0.66	---	±	---	-0.20	±	---
2-E25-19	1	-0.56	±	0.59	---	±	---	-0.56	±	---
2-E25-20	1	-0.60	±	0.55	---	±	---	-0.60	±	---
2-E25-21	1	-0.16	±	0.76	---	±	---	-0.16	±	---

TABLE C.41. Strontium-90 (contd)

Well Name[a]	No. of Samples	Concentration, pCi/L[b] (10^{-9} µCi/mL) Maximum			Minimum			Average		
2-E25-22	2	0.05	±	0.66	-0.14	±	0.69	-0.05	±	0.09
2-E25-23	1	0.33	±	0.82	---	±	---	0.33	±	---
2-E25-24	2	-0.15	±	0.70	-0.44	±	0.54	-0.30	±	0.15
2-E25-26	1	-0.25	±	0.53	---	±	---	-0.25	±	---
2-E25-28	1	-0.14	±	0.67	---	±	---	-0.14	±	---
2-E25-32P	1	-0.19	±	0.63	---	±	---	-0.19	±	---
2-E25-34	1	-0.53	±	0.54	---	±	---	-0.53	±	---
2-E25-35	1	0.00	±	0.70	---	±	---	0.00	±	---
2-E26-2	1	0.33	±	0.69	---	±	---	0.33	±	---
2-E26-4	1	0.28	±	0.86	---	±	---	0.28	±	---
2-E26-6	1	-0.11	±	0.66	---	±	---	-0.11	±	---
2-E26-8[c]	1	-0.14	±	0.60	---	±	---	-0.14	±	---
2-E27-8	3	0.22	±	0.73	-0.29	±	0.64	-0.01	±	0.15
2-E27-9	3	0.14	±	0.65	-0.08	±	0.67	0.02	±	0.07
2-E27-10	3	0.51	±	0.81	-0.18	±	0.79	0.16	±	0.20
2-E28-7	3	113.00	±	5.51	61.00	±	4.18	91.10	±	15.60
2-E28-21	1	-0.02	±	0.68	---	±	---	-0.02	±	---
2-E28-23	1	3,960.00	±	145.00	---	±	---	3,960.00	±	---
2-E28-24	1	175.00	±	6.94	---	±	---	175.00	±	---
2-E28-25	1	5,740.00	±	173.00	---	±	---	5,740.00	±	---
2-E28-26	3	1.11	±	0.86	-0.32	±	0.56	0.22	±	0.45
2-E28-27	4	0.28	±	0.77	-0.25	±	0.63	0.02	±	0.13
2-E32-2	3	0.32	±	0.70	-0.45	±	0.59	-0.16	±	0.24
2-E32-3	1	0.25	±	0.70	---	±	---	0.25	±	---
2-E32-4	3	-0.17	±	0.66	-0.35	±	0.57	-0.29	±	0.06
2-E33-1	1	-0.10	±	0.66	---	±	---	-0.10	±	---
2-E33-3	1	-0.21	±	0.66	---	±	---	-0.21	±	---
2-E33-5	1	-0.33	±	0.68	---	±	---	-0.33	±	---
2-E33-7	3	0.82	±	0.81	0.24	±	0.59	0.51	±	0.17
2-E33-8	1	-0.19	±	0.64	---	±	---	-0.19	±	---
2-E33-9	3	0.98	±	0.95	0.02	±	0.66	0.60	±	0.29
2-E33-10	1	-0.36	±	0.69	---	±	---	-0.36	±	---
2-E33-18	1	-0.09	±	0.72	---	±	---	-0.09	±	---
2-E33-20	2	3.63	±	1.12	0.80	±	0.61	2.21	±	1.42
2-E33-24	1	-0.2[illegible]	±	0.66	---	±	---	-0.25	±	---
2-E33-26	1	-0.18	±	0.66	---	±	---	-0.18	±	---
2-E33-28	3	0.15	±	0.69	-0.36	±	0.56	-0.14	±	0.15
2-E33-29	3	0.41	±	0.73	0.16	±	0.71	0.28	±	0.07
2-E33-30	3	0.17	±	0.68	-0.54	±	0.54	-0.20	±	0.21
2-E34-1	1	-0.23	±	0.53	---	±	---	-0.23	±	---
2-E34-2	4	0.35	±	0.63	-0.26	±	0.60	0.01	±	0.15
2-E34-3	3	0.12	±	0.69	-0.04	±	0.66	0.06	±	0.05
2-E34-5	3	-0.20	±	0.61	-0.32	±	0.64	-0.28	±	0.04
2-E34-6	3	0.44	±	0.81	-0.21	±	0.63	0.02	±	0.21
2-W6-2	4	0.32	±	0.87	-0.41	±	0.54	-0.06	±	0.17
2-W7-1	2	-0.32	±	0.58	-0.38	±	0.67	-0.35	±	0.03
2-W7-2	2	-0.14	±	0.63	-0.30	±	0.58	-0.22	±	0.08
2-W7-3	2	0.15	±	0.73	-0.13	±	0.64	0.01	±	0.14

TABLE C.41. Strontium-90 (contd)

Well Name[a]	No. of Samples	Concentration, pCi/L[b] (10^{-9} µCi/mL) Maximum			Minimum			Average		
2-W7-4	2	0.04	±	0.70	-0.25	±	0.76	-0.11	±	0.15
2-W7-5	2	0.05	±	0.82	-0.35	±	0.65	-0.15	±	0.20
2-W7-6	2	0.60	±	1.06	0.04	±	0.68	0.32	±	0.28
2-W8-1	2	0.13	±	0.74	-0.01	±	0.70	0.06	±	0.07
2-W9-1	2	0.03	±	0.70	-0.00	±	0.71	0.01	±	0.02
2-W10-1	2	0.04	±	0.63	0.02	±	0.72	0.03	±	0.01
2-W10-3	2	0.51	±	1.14	0.04	±	0.76	0.27	±	0.24
2-W10-13	3	-0.01	±	0.68	-0.79	±	0.59	-0.33	±	0.24
2-W10-14	3	0.19	±	0.69	-0.38	±	0.62	-0.11	±	0.17
2-W15-3	2	-0.05	±	0.72	-0.28	±	0.65	-0.17	±	0.11
2-W15-15	2	-0.21	±	0.78	-0.37	±	0.64	-0.29	±	0.08
2-W15-16	2	-0.01	±	0.80	-0.18	±	0.65	-0.10	±	0.08
2-W15-17	1	0.46	±	0.84	---	±	---	0.46	±	---
2-W15-18	2	0.58	±	0.80	0.24	±	0.72	0.41	±	0.18
2-W18-21	3	0.93	±	0.81	-0.07	±	0.67	0.30	±	0.32
2-W18-22	2	0.14	±	0.71	-0.26	±	0.62	-0.06	±	0.20
2-W18-23	3	0.11	±	0.67	-0.34	±	0.82	-0.18	±	0.14
2-W18-24	3	-0.00	±	0.63	-0.30	±	0.58	-0.13	±	0.09
2-W19-2	2	4.24	±	1.29	2.02	±	1.06	3.13	±	1.11
2-W19-3	1	0.16	±	0.77	---	±	---	0.16	±	---
2-W19-9	1	-0.20	±	1.02	---	±	---	-0.20	±	---
2-W19-13	1	0.05	±	0.78	---	±	---	0.05	±	---
2-W19-14	1	0.12	±	0.75	---	±	---	0.12	±	---
2-W19-15	1	-0.41	±	0.70	---	±	---	-0.41	±	---
2-W19-16	1	-0.20	±	0.65	---	±	---	-0.20	±	---
2-W19-17	1	-0.03	±	0.68	---	±	---	-0.03	±	---
2-W19-19	3	1.01	±	0.93	-0.06	±	0.69	0.40	±	0.32
2-W19-20	2	1.20	±	0.91	0.69	±	0.93	0.94	±	0.26
2-W19-21	2	-0.03	±	0.64	-0.47	±	0.62	-0.25	±	0.22
2-W19-23	3	0.45	±	0.72	-0.05	±	0.75	0.24	±	0.15
2-W19-24	2	4.31	±	1.54	1.81	±	1.01	3.06	±	1.25
2-W19-25	2	0.11	±	0.77	-0.07	±	0.77	0.02	±	0.09
2-W19-26	2	1.88	±	1.08	0.59	±	0.86	1.24	±	0.64
2-W19-27	2	0.11	±	0.64	0.04	±	0.67	0.08	±	0.03
2-W22-1	1	6.91	±	1.54	---	±	---	6.91	±	---
2-W22-2	1	1.10	±	0.88	---	±	---	1.10	±	---
2-W22-10	1	29.80	±	3.00	---	±	---	29.80	±	---
2-W22-18	1	0.31	±	1.01	---	±	---	0.31	±	---
2-W22-22	1	-0.20	±	0.71	---	±	---	-0.21	±	---
2-W23-1	1	0.17	±	0.73	---	±	---	0.17	±	---
2-W23-2	3	0.12	±	0.55	-0.06	±	0.67	0.04	±	0.05
2-W23-3	2	0.14	±	0.69	0.10	±	0.67	0.12	±	0.02
2-W23-9	2	0.16	±	0.73	0.13	±	0.74	0.14	±	0.01
2-W23-10	2	0.28	±	0.75	-0.66	±	0.59	-0.19	±	0.47
2-W27-1	1	-0.79	±	0.53	---	±	---	-0.79	±	---
3-1-3	1	0.48	±	0.68	---	±	---	0.48	±	---
3-1-7	1	-0.22	±	0.56	---	±	---	-0.22	±	---
3-1-17B	2	0.53	±	0.76	0.25	±	0.72	0.39	±	0.14

TABLE C.41. Strontium-90 (contd)

Well Name[a]	No. of Samples	Concentration, pCi/L[b] (10^{-9} µCi/mL) Maximum			Minimum			Average		
3-3-9	1	0.04	±	0.63	---	±	---	0.04	±	---
3-3-10	2	0.30	±	0.65	-0.28	±	0.56	0.01	±	0.29
6-S28-E0	3	0.19	±	0.69	-0.24	±	0.71	-0.08	±	0.14
6-S19-11	3	0.34	±	0.78	-0.28	±	0.59	-0.02	±	0.19
6-3-45	1	0.10	±	0.71	---	±	---	0.10	±	---
6-23-34	3	0.88	±	0.83	-0.31	±	0.63	0.20	±	0.35
6-24-33	3	0.51	±	0.80	-0.37	±	0.59	0.05	±	0.26
6-24-34A	3	0.00	±	0.73	-0.55	±	0.56	-0.22	±	0.17
6-24-34B	3	1.23	±	0.85	-0.28	±	0.66	0.34	±	0.46
6-24-34C	3	0.44	±	0.84	-0.39	±	0.60	0.10	±	0.25
6-24-35	3	0.53	±	0.79	-0.49	±	0.55	0.06	±	0.30
6-25-34C	3	0.44	±	0.72	-0.57	±	0.57	-0.13	±	0.30
6-32-70B	2	0.04	±	0.65	-0.17	±	0.64	-0.06	±	0.11
6-32-72	1	-0.08	±	0.61	---	±	---	-0.08	±	---
6-35-66	1	0.06	±	0.78	---	±	---	0.06	±	---
6-35-70	2	0.36	±	0.67	-0.06	±	0.65	0.15	±	0.21
6-36-93	1	-0.20	±	0.72	---	±	---	-0.20	±	---
6-38-70	1	-0.59	±	0.63	---	±	---	-0.59	±	---
6-40-1	2	0.29	±	0.70	-0.19	±	0.57	0.05	±	0.24
6-40-39	1	-0.05	±	0.58	---	±	---	-0.05	±	---
6-41-1	2	0.09	±	0.67	0.06	±	0.76	0.08	±	0.01
6-41-40	1	-0.03	±	0.60	---	±	---	-0.03	±	---
6-42-12A	2	0.27	±	0.74	0.15	±	0.66	0.21	±	0.06
6-42-40A	2	0.41	±	0.74	0.01	±	0.64	0.21	±	0.20
6-42-40B	4	1.13	±	1.65	-0.24	±	0.57	0.23	±	0.31
6-42-40C	1	-0.66	±	0.50	---	±	---	-0.66	±	---
6-43-41E	1	0.10	±	0.68	---	±	---	0.10	±	---
6-43-41F	1	-0.18	±	0.57	---	±	---	-0.18	±	---
6-43-45	1	-0.06	±	0.57	---	±	---	-0.06	±	---
6-44-43B	2	-0.23	±	0.61	-0.49	±	0.65	-0.36	±	0.13
6-45-42	4	0.35	±	0.73	-0.18	±	0.67	0.14	±	0.11
6-47-5	2	-0.11	±	0.64	-0.24	±	0.58	-0.17	±	0.07
6-49-55A	2	0.06	±	0.69	-0.17	±	0.62	-0.05	±	0.12
6-49-55B	2	0.34	±	0.70	-0.14	±	0.70	0.10	±	0.24
6-49-57	2	0.13	±	0.68	-0.13	±	0.59	0.00	±	0.13
6-49-100C	3	-0.01	±	0.71	-0.14	±	0.73	-0.07	±	0.04
6-50-30	2	0.12	±	0.72	0.00	±	0.62	0.06	±	0.06
6-50-42	3	0.11	±	0.64	-0.36	±	0.57	-0.14	±	0.14
6-50-45[c]	2	-0.04	±	0.66	-0.13	±	0.70	-0.08	±	0.05
6-50-48B[c]	2	0.53	±	0.82	0.14	±	0.63	0.33	±	0.20
6-50-53	1	-0.36	±	0.60	---	±	---	-0.36	±	---
6-51-46	2	0.58	±	0.76	0.01	±	0.66	0.30	±	0.28
6-52-46A[c]	2	0.03	±	0.70	-0.20	±	0.59	-0.09	±	0.11
6-52-48[c]	2	0.18	±	0.65	0.07	±	0.62	0.12	±	0.05
6-53-47A	4	69.40	±	4.46	57.70	±	3.94	62.30	±	2.71
6-53-47B	2	116.00	±	5.65	106.00	±	5.35	111.00	±	5.00
6-53-48A	2	124.00	±	5.81	108.00	±	5.59	116.00	±	8.00
6-53-48B	2	301.00	±	42.10	240.00	±	8.06	271.00	±	30.50

TABLE C.41. Strontium-90 (contd)

Well Name[a]	No. of Samples	Concentration, pCi/L[b] (10^{-9} µCi/mL) Maximum			Minimum			Average		
6-53-50[c]	1	0.23	±	0.79	---	±	---	0.23	±	---
6-53-55A	2	0.59	±	0.77	0.36	±	0.76	0.47	±	0.12
6-54-48	2	42.60	±	3.34	38.20	±	3.25	40.40	±	2.20
6-54-49	2	11.40	±	1.82	10.40	±	1.74	10.90	±	0.50
6-54-57[c]	2	0.20	±	0.67	-0.07	±	0.69	0.06	±	0.13
6-55-50A	2	0.21	±	0.68	0.04	±	0.64	0.13	±	0.08
6-55-50C	2	0.23	±	0.68	0.03	±	0.65	0.13	±	0.10
6-55-50D	3	-0.00	±	0.62	-0.10	±	0.67	-0.06	±	0.03
6-55-89	1	0.43	±	0.74	---	±	---	0.43	±	---
6-56-53	2	-0.26	±	0.63	-0.36	±	0.53	-0.31	±	0.05
6-59-58	2	0.10	±	0.73	0.09	±	0.62	0.09	±	0.00
6-60-60	1	0.19	±	0.73	---	±	---	0.19	±	---
6-61-62	1	-0.56	±	0.50	---	±	---	-0.56	±	---
6-61-66	1	-0.24	±	0.61	---	±	---	-0.24	±	---
6-63-58	1	0.14	±	0.72	---	±	---	0.14	±	---
6-64-62	1	0.05	±	0.69	---	±	---	0.05	±	---
6-65-59A	1	0.01	±	0.65	---	±	---	0.01	±	---
6-66-58	2	0.39	±	0.73	-0.31	±	0.60	0.04	±	0.35
6-66-64	2	0.16	±	0.69	-0.49	±	0.54	-0.16	±	0.33
6-70-68	2	-0.02	±	0.63	-0.13	±	0.65	-0.08	±	0.05
6-81-58	3	0.51	±	0.77	-0.14	±	0.57	0.17	±	0.19
6-83-47	1	0.76	±	0.95	---	±	---	0.76	±	---
6-101-48B	2	0.03	±	0.60	-0.16	±	0.62	-0.06	±	0.09

(a) See Figures 5.1, 5.2, and 5.3 for well locations.
(b) Maximum and minimum concentrations ±2 sigma counting errors. Average concentrations ±2 times the standard error of the calculated mean (no estimate of standard error for one sample).
(c) Wells that sample a confined aquifer.

TABLE C.42. Maximum, Minimum, and Average Iodine-129 (^{129}I) Concentrations in Ground-Water Samples in 1989

Well Name[a]	No. of Samples	Concentration, pCi/L[b] (10^{-9} µCi/mL) Maximum			Minimum			Average		
1-N-14	1	0.047	±	0.074	---	±	---	0.047	±	---
1-N-29	1	0.003	±	0.041	---	±	---	0.003	±	---
1-N-33	1	-0.051	±	0.087	---	±	---	-0.051	±	---
2-E13-8	1	0.008	±	0.037	---	±	---	0.008	±	---
2-E17-1	1	6.420	±	0.644	---	±	---	6.420	±	---
2-E17-2	2	0.996	±	0.152	0.730	±	0.121	0.863	±	0.133
2-E17-5	3	13.200	±	3.500	1.990	±	0.231	5.810	±	3.700
2-E17-6	1	-0.059	±	0.050	---	±	---	-0.059	±	---
2-E17-8	1	5.010	±	0.534	---	±	---	5.010	±	---
2-E17-9	1	16.000	±	3.690	---	±	---	16.000	±	---
2-E17-12	1	1.650	±	0.201	---	±	---	1.650	±	---
2-E17-13	3	2.040	±	0.245	1.330	±	0.164	1.650	±	0.207
2-E17-14	1	14.000	±	3.280	---	±	---	14.000	±	---
2-E17-16	1	2.030	±	1.620	---	±	-	2.030	±	---
2-E17-17	1	8.220	±	2.960	---	±	---	8.220	±	---
2-E17-18	1	3.600	±	2.140	---	±	---	3.600	±	---
2-E24-7	1	1.460	±	0.190	---	±	---	1.460	±	---
2-E24-13	1	2.220	±	0.256	---	±	---	2.220	±	---
2-E25-3	1	1.310	±	0.170	---	±	---	1.310	±	---
2-E26-1	1	0.399	±	0.074	---	±	---	0.399	±	---
2-E26-2	1	0.978	±	0.133	---	±	---	0.978	±	---
2-E26-4	1	1.160	±	0.162	---	±	---	1.160	±	---
2-E26-8[c]	1	-0.030	±	0.053	---	±	---	-0.030	±	---
2-E28-7	1	0.828	±	0.119	---	±	---	0.828	±	---
2-E33-7	1	0.504	±	0.083	---	±	---	0.504	±	---
2-E33-20	1	0.890	±	0.130	---	±	---	0.890	±	---
4-S1-7C	1	-0.009	±	0.082	---	±	---	-0.009	±	---
4-S1-8A	1	0.009	±	0.044	---	±	---	0.008	±	---
4-S1-8B	1	0.001	±	0.079	---	±	---	0.001	±	---
4-S1-8C	1	-0.008	±	0.051	---	±	---	-0.008	±	---
6-S8-19	1	-0.037	±	0.084	---	±	---	-0.037	±	---
6-S6-E4B	1	-0.037	±	0.074	---	±	---	-0.037	±	---
6-S6-E4D	1	0.010	±	0.047	---	±	---	0.010	±	---
6-S3-E12	1	0.073	±	0.053	---	±	---	0.073	±	---
6-S3-25	1	-0.006	±	0.047	---	±	---	-0.006	±	---
6-1-18	1	0.025	±	0.082	---	±	---	0.025	±	---
6-2-3	1	0.010	±	0.051	---	±	---	0.010	±	---
6-2-33A	1	0.019	±	0.045	---	±	---	0.019	±	---
6-3-45	1	0.014	±	0.084	---	±	---	0.014	±	---
6-8-17	1	0.041	±	0.079	---	±	---	0.041	±	---
6-8-25	1	0.090	±	0.052	---	±	---	0.090	±	---
6-8-32	1	-0.012	±	0.081	---	±	---	-0.012	±	---
6-10-E12	1	-0.004	±	0.087	---	±	---	-0.004	±	---
6-13-64	1	0.009	±	0.049	---	±	---	0.009	±	---
6-14-38	1	0.070	±	0.044	---	±	---	0.070	±	---
6-15-15B	1	-0.042	±	0.081	---	±	---	-0.042	±	---
6-15-26	1	0.337	±	0.074	---	±	---	0.337	±	---

TABLE C.42. Iodine-129 (contd)

Well Name[a]	No. of Samples	Concentration, pCi/L[b] (10^{-9} µCi/mL) Maximum			Minimum			Average		
6-17-47	1	-0.025	±	0.080	---	±	---	-0.025	±	---
6-20-E12	1	0.046	±	0.048	---	±	---	0.046	±	---
6-20-E5A	1	-0.048	±	0.147	---	±	---	-0.048	±	---
6-20-20	1	0.368	±	0.075	---	±	---	0.368	±	---
6-21-6	1	-0.008	±	0.047	---	±	---	-0.008	±	
6-24-33	1	0.743	±	0.145	---	±	---	0.743	±	---
6-24-46	1	0.017	±	0.076	---	±	---	0.017	±	---
6-25-70	1	-0.051	±	0.084	---	±	---	-0.051	±	---
6-26-15A	1	0.483	±	0.125	---	±	---	0.483	±	---
6-27-8	1	0.656	±	0.125	---	±	---	0.656	±	---
6-28-40	1	0.128	±	0.087	---	±	---	0.128	±	---
6-29-4	1	-0.002	±	0.055	---	±	---	-0.002	±	---
6-29-78	1	0.073	±	0.076	---	±	---	0.074	±	---
6-32-22	1	1.540	±	0.199	---	±	---	1.540	±	---
6-32-43	1	1.300	±	0.182	---	±	---	1.300	±	---
6-32-62	1	0.058	±	0.051	---	±	---	0.058	±	---
6-32-70B	1	0.856	±	0.133	---	±	---	0.856	±	---
6-32-72	1	0.029	±	0.043	---	±	---	0.029	±	---
6-32-77	1	-0.004	±	0.081	---	±	---	-0.004	±	---
6-34-51	1	-0.077	±	0.099	---	±	---	-0.076	±	---
6-35-9	1	0.056	±	0.049	---	±	---	0.056	±	---
6-35-66	1	1.490	±	0.192	---	±	---	1.490	±	---
6-35-70	2	11.100	±	1.140	10.300	±	1.060	10.700	±	0.400
6-36-61B	1	-0.013	±	0.079	---	±	---	-0.013	±	---
6-38-15	1	0.463	±	0.101	---	±	---	0.463	±	---
6-38-65	1	0.920	±	0.145	---	±	---	0.920	±	---
6-38-70	1	0.319	±	0.066	---	±	---	0.319	±	---
6-39-39	1	0.029	±	0.077	---	±	---	0.029	±	---
6-39-79	1	0.031	±	0.084	---	±	---	0.031	±	---
6-40-62	1	0.028	±	0.073	---	±	---	0.028	±	---
6-41-1	1	0.073	±	0.093	---	±	---	0.073	±	---
6-41-23	1	1.550	±	0.187	---	±	---	1.550	±	---
6-42-12A	1	0.246	±	0.060	---	±	---	0.246	±	---
6-42-40C[c]	1	0.045	±	0.075	---	±	---	0.045	±	---
6-43-3	1	0.033	±	0.032	---	±	---	0.033	±	---
6-44-64	1	-0.024	±	0.050	---	±	---	-0.024	±	---
6-45-2	1	0.069	±	0.077	---	±	---	0.069	±	---
6-45-69A	1	0.013	±	0.046	---	±	---	0.013	±	---
6-46-4	1	0.043	±	0.057	---	±	---	0.043	±	---
6-46-21B	1	-0.059	±	0.087	---	±	---	-0.059	±	---
6-47-35A	1	-0.040	±	0.077	---	±	---	-0.040	±	---
6-47-46A	1	-0.029	±	0.081	---	±	---	-0.029	±	---
6-47-60	1	0.022	±	0.073	---	±	---	0.022	±	---
6-48-7	1	-0.015	±	0.044	---	±	---	-0.015	±	---
6-48-71	1	0.067	±	0.270	---	±	---	0.067	±	---
6-49-13E	1	-0.057	±	0.079	---	±	---	-0.057	±	---
6-49-28	1	0.037	±	0.046	---	±	---	0.037	±	---
6-49-55A	1	0.060	±	0.083	---	±	---	0.060	±	---

TABLE C.42. Iodine-129 (contd)

Well Name[a]	No. of Samples	Concentration, pCi/L[b] (10^{-9} µCi/mL) Maximum	Minimum	Average
6-49-55B	1	0.025 ± 0.043	--- ± ---	0.025 ± ---
6-49-57	1	0.694 ± 0.112	--- ± ---	0.694 ± ---
6-50-42	1	0.030 ± 0.083	--- ± ---	0.030 ± ---
6-50-45[c]	1	-0.034 ± 0.047	--- ± ---	-0.034 ± ---
6-50-48B[c]	1	-0.007 ± 0.048	--- ± ---	-0.007 ± ---
6-50-53	1	0.023 ± 0.041	--- ± ---	0.023 ± ---
6-51-46	1	0.001 ± 0.086	--- ± ---	0.001 ± ---
6-51-63	1	0.063 ± 0.077	--- ± ---	0.063 ± ---
6-52-19	1	0.144 ± 0.081	--- ± ---	0.144 ± ---
6-52-46A[c]	1	-0.023 ± 0.094	--- ± ---	-0.023 ± ---
6-52-48[c]	1	0.033 ± 0.046	--- ± ---	0.033 ± ---
6-53-50[c]	1	0.076 ± 0.081	--- ± ---	0.076 ± ---
6-53-103[c]	1	0.008 ± 0.040	--- ± ---	0.008 ± ---
6-54-57[c]	1	-0.029 ± 0.046	--- ± ---	-0.029 ± ---
6-55-50A	1	-0.023 ± 0.047	--- ± ---	-0.023 ± ---
6-55-50C	1	-0.012 ± 0.050	--- ± ---	-0.012 ± ---
6-55-50D	1	-0.006 ± 0.047	--- ± ---	-0.006 ± ---
6-56-43	1	0.026 ± 0.044	--- ± ---	0.026 ± ---
6-56-53[c]	1	0.050 ± 0.046	--- ± ---	0.050 ± ---
6-59-58	1	0.056 ± 0.079	--- ± ---	0.056 ± ---
6-60-57	1	-0.029 ± 0.050	--- ± ---	-0.030 ± ---
6-60-60	1	-0.017 ± 0.083	--- ± ---	-0.017 ± ---
6-61-62	1	0.121 ± 0.052	--- ± ---	0.121 ± ---
6-61-66	1	0.026 ± 0.112	--- ± ---	0.026 ± ---
6-63-58	1	0.005 ± 0.082	--- ± ---	0.005 ± ---
6-64-62	1	0.031 ± 0.076	--- ± ---	0.031 ± ---
6-65-50	1	0.041 ± 0.051	--- ± ---	0.041 ± ---
6-65-59A	1	0.034 ± 0.053	--- ± ---	0.034 ± ---
6-65-72	1	0.012 ± 0.171	--- ± ---	0.012 ± ---
6-66-58	1	-0.007 ± 0.052	--- ± ---	-0.007 ± ---
6-66-64	1	-0.020 ± 0.051	--- ± ---	-0.020 ± ---
6-70-68	1	0.049 ± 0.076	--- ± ---	0.049 ± ---
6-71-52	1	-0.037 ± 0.053	--- ± ---	-0.037 ± ---
6-71-77	1	0.035 ± 0.045	--- ± ---	0.035 ± ---
6-72-73	1	-0.068 ± 0.085	--- ± ---	-0.068 ± ---
6-73-61	1	0.059 ± 0.077	--- ± ---	0.059 ± ---

(a) See Figures 5.1, 5.2, and 5.3 for well locations.
(b) Maximum and minimum concentrations ±2 sigma counting errors. Average concentrations ±2 times the standard error of the calculated mean (no estimate of standard error for one sample).
(c) Wells that sample a confined aquifer.

TABLE C.43. Maximum, Minimum, and Average Nitrate (NO_3^-) Concentrations in Ground-Water Samples in 1989

Well Name[a]	No. of Samples	Concentration (µg/L)[b,c] Maximum	Minimum	Average[d]		
1-B3-1	3	48,400	31,000	40,400	±	5,080
1-B4-1	3	15,300	13,900	14,700	±	426
1-B4-2	2	14,000	13,900	14,000	±	50
1-B4-3	2	15,000	14,600	14,800	±	200
1-B4-4	3	14,500	12,900	13,500	±	491
1-B5-1	2	14,000	13,900	14,000	±	50
1-B9-1	3	28,900	24,500	26,000	±	1,450
1-D2-5	3	72,000	57,000	64,900	±	4,350
1-D5-12	3	122,000	94,300	107,000	±	8,120
1-D8-3	3	98,500	69,500	83,400	±	8,390
1-F5-1	2	2,200	<2,500	<2,350	±	150
1-F5-3	2	<2,500	<2,500	<2,500	±	---
1-F5-4	3	78,500	64,300	72,000	±	4,150
1-F5-6	3	3,700	<500	<2,230	±	933
1-F7-1	2	92,000	89,500	90,800	±	1,250
1-F8-1	3	152,000	122,000	142,000	±	9,840
1-F8-2	2	167,000	150,000	159,000	±	8,500
1-H3-1	1	23,300	---	23,300	±	---
1-H3-2A	4	35,300	18,100	27,200	±	3,560
1-H3-2B	2	28,200	28,100	28,200	±	50
1-H3-2C	1	4,600	---	4,600	±	---
1-H4-3	8	524,000	127,000	258,000	±	54,000
1-H4-4	7	392,00	9,700	178,000	±	63,100
1-H4-5	4	44,800	39,000	41,000	±	1,320
1-H4-6	5	39,100	36,700	38,000	±	380
1-H4-7	3	56,800	35,300	42,700	±	7,050
1-H4-8	1	39,400	---	39,400	±	---
1-H4-9	3	69,300	58,000	65,300	±	3,640
1-H4-10	1	12,700	---	12,700	±	---
1-H4-11	1	32,000	---	32,000	±	---
1-H4-12A	4	82,000	29,100	50,100	±	12,700
1-H4-12B	3	49,000	27,400	38,500	±	6,240
1-H4-12C	4	6,800	6,300	6,480	±	111
1-H4-13	2	16,200	15,800	16,000	±	200
1-H4-14	2	21,700	18,600	20,200	±	1,550
1-H4-15A	1	41,400	---	41,400	±	---
1-H4-15B	1	22,500	---	22,500	±	---
1-H4-16	1	13,900	---	13,900	±	---
1-H4-17	1	51,200	---	51,200	±	---
1-H4-18	4	31,500	23,500	27,400	±	1,640
1-K-11	3	38,000	37,000	37,700	±	333
1-K-19	1	51,300	---	51,300	±	---
1-K-20	1	19,000	---	19,000	±	---
1-K-22	2	4,500	4,400	4,450	±	50
1-K-27	3	9,000	3,000	6,570	±	1,820
1-K-28	3	25,000	22,600	23,700	±	700
1-K-29	3	9,100	8,000	8,400	±	351

TABLE C.43. Nitrate (contd)

Well Name[a]	No. of Samples	Concentration (µg/L)[b,c] Maximum	Minimum	Average[d]		
1-K-30	3	66,000	42,900	50,800	±	7,620
1-N-2	4	30,700	9,300	20,500	±	4,400
1-N-3	5	23,400	7,100	12,400	±	2,990
1-N-4	7	18,600	2,800	7,000	±	2,100
1-N-5	1	16,900	---	16,900	±	---
1-N-6	1	<2,500	---	<2,500	±	---
1-N-14	9	30,900	8,000	13,400	±	2,560
1-N-16	5	<2,500	<500	<900	±	400
1-N-17	4	3,800	<500	<2,130	±	685
1-N-18	1	<500	---	<500	±	---
1-N-20	1	20,200	---	20,200	±	---
1-N-21	4	24,100	10,600	15,900	±	3,200
1-N-22	1	31,200	---	31,200	±	---
1-N-23	4	1,700	<500	<1,300	±	490
1-N-24	4	4,500	1,700	3,400	±	597
1-N-25	4	15,[illegible]00	5,200	9,630	±	2,580
1-N-26	3	28,100	11,600	21,700	±	5,100
1-N-27	3	9,100	500	5,230	±	2,520
1-N-28	1	<2,500	---	<2,500	±	---
1-N-29	4	6,700	<2,500	<4,200	±	1,100
1-N-31	5	4,900	1,500	2,760	±	568
1-N-32	5	7,100	<2,500	<2,980	±	1,140
1-N-33	5	6,300	1,960	4,020	±	811
1-N-36	6	4,900	1,300	3,550	±	609
1-N-37	1	<2,500	---	<2,500	±	---
1-N-39	2	6,500	6,500	6,500	±	0
1-N-41	4	22,700	1,000	7,380	±	5,190
1-N-42	4	16,000	1,100	8,730	±	3,810
1-N-47	3	6,900	3,300	4,800	±	1,080
1-N-50	1	38,800	---	38,800	±	---
1-N-51	1	35,400	---	35,400	±	---
1-N-52	5	17,200	7,700	10,500	±	1,700
1-N-54	4	22,600	9,500	14,800	±	2,850
1-N-55	5	93,000	8,700	50,900	±	15,700
1-N-56	4	63,600	8,100	22,300	±	13,800
1-N-57	4	24,700	8,100	13,000	±	3,930
1-N-58	5	5,200	2,400	3,440	±	480
1-N-59	6	4,000	3,000	3,230	±	156
1-N-60	7	3,600	1 900	2,700	±	261
1-N-61	6	4,300	1,600	2,880	±	476
1-N-66	5	8,600	1,600	3,740	±	1,240
1-N-67	5	87,900	10,300	30,600	±	14,500
1-N-69	5	30,300	22,900	27,000	±	1,420
1-N-70	5	28,800	9,100	14,600	±	3,620
2-E13-8	1	18,700	---	18,700	±	---
2-E16-2	4	1,200	<2,500	<2,180	±	325
2-E17-1	3	212,000	147,000	170,000	±	21,000
2-E17-2	5	115,000	39,700	81,900	±	14,100

TABLE C.43. Nitrate (contd)

Well Name[a]	No. of Samples	Concentration (µg/L)[b,c] Maximum	Minimum	Average[d]		
2-E17-5	7	126,000	74,000	91,900	±	6,730
2-E17-6	5	115,000	<2,500	<41,000	±	24,000
2-E17-8	1	134,000	---	134,000	±	---
2-E17-9	8	137,000	104,000	124,000	±	4,330
2-E17-12	3	30,400	28,000	28,800	±	784
2-E17-13	5	42,800	28,800	37,100	±	2,550
2-E17-14	4	300,000	165,000	252,000	±	30,200
2-E17-15	4	354,000	242,000	293,000	±	23,100
2-E17-16	3	56,700	24,500	37,700	±	9,730
2-E17-17	3	67,600	53,000	62,200	±	4,610
2-E17-18	4	11,100	4,900	8,230	±	1,570
2-E17-19	4	316,000	88,800	147,000	±	56,400
2-E17-20	4	228,000	217,000	225,000	±	2,600
2-E18-1	4	12,500	11,400	12,000	±	232
2-E18-2	3	600	<500	<567	±	33
2-E18-3	6	600	<500	<517	±	17
2-E18-4	5	1,000	<500	<674	±	98
2-E24-1	5	169,000	89,800	123,000	±	17,400
2-E24-2	5	111,000	69,800	93,700	±	9,010
2-E24-4	1	4,400	---	4,400	±	---
2-E24-7	1	24,900	---	24,900	±	---
2-E24-8	1	4,200	---	4,200	±	---
2-E24-11	3	127,000	98,500	117,000	±	9,340
2-E24-12	3	93,900	87,400	90,200	±	1,920
2-E24-13	1	4,300	---	4,300	±	---
2-E24-16	4	114,000	108,000	112,000	±	1,350
2-E24-17	3	107,000	97,300	103,000	±	2,870
2-E24-18	3	59,000	57,300	58,100	±	491
2-E25-2	1	<2,500	---	<2,500	±	---
2-E25-3	1	<2,500	---	<2,500	±	---
2-E25-6	2	3,500	<2,500	<3,000	±	500
2-E25-9	2	<2,500	<2,500	<2,500	±	0
2-E25-11	6	47,300	32,500	40,700	±	2,350
2-E25-13	1	237,000	---	237,000	±	---
2-E25-17	4	41,300	24,300	34,900	±	3,760
2-E25-18	4	88,700	28,700	58,500	±	16,900
2-E25-19	1	68,000	---	68,000	±	---
2-E25-20	4	235,000	186,000	210,000	±	11,600
2-E25-21	1	6,270	---	6,270	±	---
2-E25-22	5	4,800	3,100	3,760	±	294
2-E25-23	1	<2,500	---	<2,500	±	---
2-E25-24	5	1,600	<2,500	<1,540	±	254
2-E25-25	5	900	700	800	±	45
2-E25-26	5	1,600	1,100	1,400	±	84
2-E25-27	3	2,270	2,200	2,220	±	23
2-E25-28	5	1,600	900	1,080	±	132
2-E25-29P	6	12,900	6,800	8,630	±	940
2-E25-30P	4	8,700	3,500	6,050	±	1,440

TABLE C.43. Nitrate (contd)

Well Name[a]	No. of Samples	Concentration (µg/L)[b,c] Maximum	Minimum	Average[d]		
2-E25-31	6	22,400	7,100	12,900	±	2,810
2-E25-32P	7	1,270	700	913	±	83
2-E25-33	5	11,900	7,000	8,540	±	881
2-E25-34	4	1,200	1,090	1,150	±	30
2-E25-35	5	7,800	5,960	6,740	±	311
2-E25-36	3	6,200	3,400	4,970	±	825
2-E25-37	1	2,000	---	2,000	±	---
2-E25-38	1	1,900	---	1,900	±	---
2-E26-1	1	<2,500	---	<2,500	±	---
2-E26-2	3	<2,500	<2,500	<2,500	±	---
2-E26-4	3	<2,500	<2,500	<2,500	±	---
2-E26-6	1	<2,500	---	<2,500	±	---
2-E26-8	2	<2,500	<2,500	<2,500	±	---
2-E27-7	1	<2,500	---	<2,500	±	---
2-E27-8	3	7,600	7,200	7,470	±	133
2-E27-9	4	8,200	7,400	7,650	±	189
2-E27-10	3	3,300	2,900	3,120	±	117
2-E28-7	1	7,100	---	7,100	±	---
2-E28-18	2	42,600	42,500	42,600	±	50
2-E28-21	3	43,600	41,000	42,200	±	762
2-E28-23	1	7,600	---	7,600	±	---
2-E28-26	3	49,300	43,000	46,900	±	1,980
2-E28-27	4	31,000	23,100	28,500	±	1,840
2-E32-1	1	9,200	---	9,200	±	---
2-E32-2	3	21,600	15,900	19,500	±	1,790
2-E32-3	1	54,000	---	54,000	±	---
2-E32-4	5	29,600	24,500	26,500	±	1,150
2-E33-1	1	38,000	---	38,000	±	---
2-E33-7	1	79,800	---	79,800	±	---
2-E33-9	3	16,000	8,600	11,200	±	2,400
2-E33-10	1	5,920	---	5,920	±	---
2-E33-12[e]	2	<2,500	<2,500	<2,500	±	---
2-E33-20	3	3,900	2,500	3,000	±	451
2-E33-28	4	4,100	3,500	3,930	±	144
2-E33-29	3	7,600	6,900	7,200	±	208
2-E33-30	3	7,400	6,800	7,100	±	173
2-E34-1	1	10,000	---	10,000	±	---
2-E34-2	4	15,400	12,000	13,500	±	716
2-E34-3	3	5,100	4,300	4,670	±	233
2-E34-5	3	13,600	13,200	13,400	±	115
2-E34-6	3	6,500	6,400	6,430	±	33
2-W6-2	5	74,900	24,600	63,800	±	9,810
2-W7-1	3	45,100	42,600	43,600	±	775
2-W7-2	3	42,000	25,600	32,500	±	4,910
2-W7-3	3	3,300	3,000	3,170	±	88
2-W7-4	3	77,000	74,000	75,100	±	968
2-W7-5	3	45,000	43,300	44,400	±	536
2-W7-6	3	5,900	5,300	5,600	±	173

TABLE C.43. Nitrate (contd)

Well Name[a]	No. of Samples	Concentration (µg/L)[b,c] Maximum	Minimum	Average[d]		
2-W8-1	3	30,400	28,200	29,500	±	677
2-W9-1	3	20,300	18,500	19,200	±	557
2-W10-13	5	8,100	7,700	7,860	±	81
2-W10-14	4	22,200	18,500	20,600	±	777
2-W14-6	1	114,000	---	114,000	±	---
2-W15-3	2	130,000	127,000	129,000	±	1,500
2-W15-6	1	5,500	---	5,500	±	---
2-W15-12	1	116,000	---	116,000	±	---
2-W15-15	3	15,300	10,500	13,100	±	1,400
2-W15-16	3	70,700	67,000	69,200	±	1,110
2-W15-17	2	16,800	16,700	16,800	±	50
2-W15-18	3	73,500	68,900	71,500	±	1,350
2-W18-4	1	39,100	---	39,100	±	---
2-W18-9	2	<2,500	<2,500	<2,500	±	---
2-W18-15	1	<2,500	---	<2,500	±	---
2-W18-17	4	3,000	<2,500	<2,280	±	409
2-W18-20	2	<2,500	<2,500	<2,500	±	---
2-W18-21	4	3,000	2,200	2,580	±	165
2-W18-22	3	16,900	15,800	16,200	±	367
2-W18-23	4	5,870	5,700	5,790	±	35
2-W18-24	4	22,000	18,700	20,800	±	745
2-W19-2	4	324,000	101,000	201,000	±	46,200
2-W19-3	3	37,000	21,900	27,700	±	4,710
2-W19-9	1	28,700	---	28,700	±	---
2-W19-13	1	15,900	---	15,900	±	---
2-W19-14	1	11,700	---	11,700	±	---
2-W19-15	1	68,600	---	68,600	±	---
2-W19-16	1	47,600	---	47,600	±	---
2-W19-17	1	10,000	---	10,000	±	---
2-W19-18	4	99,700	40,000	78,100	±	13,100
2-W19-19	5	1,340,000	1,280,000	1,310,000	±	11,700
2-W19-20	5	1,110,000	1,030,000	1,070,000	±	13,800
2-W19-21	2	700	<2,500	<1,600	±	900
2-W19-23	5	495,000	330,000	399,000	±	38,200
2-W19-24	5	1,040,000	927,000	969,000	±	19,700
2-W19-25	4	960,000	836,000	889,000	±	25,900
2-W19-26	2	1,360,000	1,300,000	1,330,000	±	30,000
2-W19-27	2	900	<2,500	<1,700	±	800
2-W22-1	1	6,300	---	6,300	±	---
2-W22-2	1	7,400	---	7,400	±	---
2-W22-22	1	16,900	---	16,900	±	---
2-W23-1	2	58,800	<2,500	<30,700	±	28,200
2-W23-2	3	33,000	30,600	31,700	±	700
2-W23-3	2	21,500	17,900	19,700	±	1,800
2-W23-4	5	4,000	<2,500	<3,280	±	291
2-W23-9	4	223,000	42,300	94,700	±	42,900
2-W23-10	2	96,800	87,100	92,000	±	4,850
2-W23-11	1	<2,500	---	<2,500	±	---

TABLE C.43. Nitrate (contd)

Well Name[a]	No. of Samples	Concentration (µg/L)[b,c] Maximum	Minimum	Average[d]		
2-W27-1	1	96,900	---	96,900	±	---
3-1-3	1	1,100	---	1,100	±	---
3-1-7	4	4,200	1,200	2,000	±	734
3-1-10	2	2,300	1,300	1,800	±	500
3-1-11	13	2,400	500	1,510	±	149
3-1-12	2	1,300	1,200	1,250	±	50
3-1-13	2	4,000	1,400	2,700	±	1,300
3-1-14	2	2,500	1,100	1,800	±	700
3-1-15	3	21,200	2,700	8,900	±	6,150
3-1-16A	4	3,600	1,300	2,650	±	484
3-1-16B	4	<500	<500	<500	±	---
3-1-16C	3	1,500	<500	<933	±	296
3-1-17A	29	3,100	<2,500	<1,600	±	118
3-1-17B	2	<500	<500	<500	±	---
3-1-17C	1	<500	---	<500	±	---
3-1-18A	13	23,600	21,000	22,100	±	197
3-1-18B	1	<500	---	<500	±	---
3-1-19	6	3,800	1,600	2,430	±	339
3-2-1	2	9,400	5,400	7,400	±	2,000
3-2-2	1	4,100	---	4,100	±	---
3-3-7	3	14,900	12,300	14,000	±	835
3-3-9	3	10,700	9,900	10,300	±	233
3-3-10	2	11,700	6,900	9,300	±	2,400
3-4-1	2	16,600	14,300	15,500	±	1,150
3-4-7	2	13,800	11,000	12,400	±	1,400
3-4-11	2	14,800	13,100	14,000	±	850
3-8-1	4	20,900	14,800	17,900	±	1,580
3-8-2	1	21,600	---	21,600	±	---
3-8-3	2	14,300	14,000	14,200	±	150
6-S43-E12	3	23,400	13,300	19,000	±	2,990
6-S41-E13A	6	12,000	6,000	7,620	±	896
6-S41-E13B	5	3,900	3,100	3,580	±	159
6-S40-E14	5	1,000	<500	<760	±	87
6-S37-E14	4	13,000	1,200	4,250	±	2,920
6-S36-E13A	2	6,100	5,200	5,650	±	450
6-S32-E13A	2	32,100	29,400	30,800	±	1,350
6-S32-E13B	2	31,300	26,800	29,100	±	2,250
6-S31-E13	2	34,400	28,300	31,400	±	3,050
6-S31-1P[e]	1	4,000	---	4,000	±	---
6-S30-E15A	2	15,300	12,500	13,900	±	1,400
6-S29-E12	4	23,700	19,000	21,800	±	1,000
6-S28-E0	3	10,300	9,000	9,600	±	379
6-S27-E14	3	28,400	21,000	23,900	±	2,270
6-S24-19	1	<2,500	---	<2,500	±	---
6-S19-11	3	10,500	10,300	10,400	±	67
6-S18-51	1	<2,500	---	<2,500	±	---
6-S14-20A	1	<2,500	---	<2,500	±	---
6-S12-3	2	<2,500	<2,500	<2,500	±	---

TABLE C.43. Nitrate (contd)

Well Name[a]	No. of Samples	Concentration (µg/L)[b,c] Maximum	Minimum	Average[d]		
6-S12-29	1	17,900	---	17,900	±	---
6-S11-E12A	1	20,500	---	20,500	±	---
6-S11-E12AP[e]	1	<2,500	---	<2,500	±	---
6-S7-34	1	<2,500	---	<2,500	±	---
6-S6-E14A	1	5,300	---	5,300	±	---
6-S6-E4B	2	19,600	17,500	18,600	±	1,050
6-S6-E4D	2	26,300	16,500	21,400	±	4,900
6-S3-E12	2	24,200	23,500	23,900	±	350
6-S3-25	1	<2,500	---	<2,500	±	---
6-1-18	2	19,500	19,500	19,500	±	---
6-2-3	2	30,900	30,700	30,800	±	100
6-2-7	1	55,500	---	55,500	±	---
6-2-33A	2	3,600	3,500	3,550	±	50
6-3-45	1	<2,500	---	<2,500	±	---
6-8-17	2	33,900	33,000	33,500	±	450
6-8-25	2	21,000	20,500	20,800	±	250
6-8-32	2	5,000	3,700	4,350	±	650
6-10-E12	2	21,900	21,500	21,700	±	200
6-10-54A	1	12,200	---	12,200	±	---
6-13-64	1	<2,500	---	<2,500	±	---
6-14-38	2	4,000	3,900	3,950	±	50
6-14-47	1	<2,500	---	<2,500	±	---
6-15-15B	1	19,800	---	19,800	±	---
6-17-5	3	68,600	67,500	67,900	±	367
6-17-47	1	<2,500	---	<2,500	±	---
6-17-70	1	46,600	---	46,600	±	---
6-19-43	1	10,300	---	10,300	±	---
6-19-58	1	<2,500	---	<2,500	±	---
6-19-88	1	<2,500	---	<2,500	±	---
6-20-E12	2	31,400	29,500	30,500	±	950
6-20-E12P	1	<2,500	---	<2,500	±	---
6-20-E5A	2	25,500	25,400	25,500	±	50
6-20-E5P	1	<2,500	---	<2,500	±	---
6-20-E5Q	1	<2,500	---	<2,500	±	---
6-20-E5R[e]	1	<2,500	---	<2,500	±	---
6-20-20	3	38,400	32,800	36,100	±	1,690
6-20-39	1	5,500	---	5,500	±	---
6-20-82	1	16,900	---	16,900	±	---
6-21-6	2	48,500	40,500	44,500	±	4,000
6-22-70	2	10,500	10,100	10,300	±	200
6-23-34	6	29,100	27,200	28,200	±	346
6-24-1P[e]	1	<2,500	---	<2,500	±	---
6-24-1Q[e]	1	<2,500	---	<2,500	±	---
6-24-1R[e]	1	<2,500	---	<2,500	±	---
6-24-1S	1	<2,500	---	<2,500	±	---
6-24-1T	1	<2,500	---	<2,500	±	---
6-24-33	4	35,300	33,000	34,300	±	502
6-24-34A	4	33,300	29,000	31,500	±	1,030

TABLE C.43. Nitrate (contd)

Well Name[a]	No. of Samples	Concentration (µg/L)[b,c] Maximum	Minimum	Average[d]		
6-24-34B	4	35,900	34,000	34,800	±	470
6-24-34C	6	37,000	33,000	34,400	±	592
6-24-35	6	28,300	27,400	27,900	±	143
6-24-46	1	9,700	---	9,700	±	---
6-25-33A	3	4,200	3,600	4,000	±	200
6-25-34A	2	29,900	28,800	29,400	±	550
6-25-34B	3	29,100	29,000	29,000	±	33
6-25-34C	5	33,400	30,000	31,300	±	561
6-25-55	2	14,700	14,000	14,400	±	350
6-25-70	2	12,300	11,700	12,000	±	300
6-26-15A	2	33,900	33,000	33,500	±	450
6-26-33	2	29,600	28,200	28,900	±	700
6-26-34	2	28,500	27,200	27,900	±	650
6-26-35A	2	31,000	30,000	30,500	±	500
6-26-35C	2	22,300	22,000	22,200	±	150
6-26-89	1	<2,500	---	<2,500	±	---
6-27-8	2	34,300	33,000	33,700	±	650
6-28-40	2	19,600	17,500	18,600	±	1,050
6-28-40P[e]	1	<2,500	---	<2,500	±	---
6-28-52A	1	<2,500	---	<2,500	±	---
6-29-4	2	32,000	30,800	31,400	±	600
6-29-78	2	7,800	7,200	7,500	±	300
6-31-31	1	3,100	---	3,100	±	---
6-31-31P[e]	1	<2,500	---	<2,500	±	---
6-32-22	2	22,600	19,000	20,800	±	1,800
6-32-43	2	23,200	17,800	20,500	±	2,700
6-32-62	1	25,900	---	25,900	±	---
6-32-70B	3	19,200	18,200	18,700	±	291
6-32-72	1	6,600	---	6,600	±	---
6-32-77	1	5,800	---	5,800	±	---
6-33-42	2	20,000	18,300	19,200	±	850
6-33-56	2	10,400	9,700	10,100	±	350
6-34-39A	1	<2,500	---	<2,500	±	---
6-34-41B	1	3,500	---	3,500	±	---
6-34-42	2	7,000	5,800	6,400	±	600
6-34-51	2	8,800	8,660	8,730	±	70
6-35-9	2	39,000	37,400	38,200	±	800
6-35-66	2	24,700	23,500	24,100	±	600
6-35-70	3	29,200	26,600	27,700	±	777
6-35-78A	3	500	<2,500	<1,830	±	667
6-36-46P[e]	1	<2,500	---	<2,500	±	---
6-36-46Q[e]	3	<2,500	<2,500	<2,500	±	---
6-36-61A	2	20,900	20,000	20,500	±	450
6-36-61B	2	16,700	9,300	13,000	±	3,700
6-36-93	1	49,700	---	49,700	±	---
6-37-E4	1	29,000	---	29,000	±	---
6-37-43	1	10,400	---	10,400	±	---
6-37-82A	1	42,000	---	42,000	±	---

TABLE C.43. Nitrate (contd)

Well Name[a]	No. of Samples	Concentration (µg/L)[b,c] Maximum	Minimum	Average[d]		
6-38-15	2	49,500	46,600	48,100	±	1,450
6-38-65	2	167,000	21,800	94,400	±	72,600
6-38-70	2	243,000	237,000	240,000	±	3,000
6-39-0	1	40,700	---	40,700	±	---
6-39-39	2	33,400	<2,500	<18,000	±	15,500
6-39-79	1	6,300	---	6,300	±	---
6-40-1	2	41,600	40,500	41,100	±	550
6-40-33A	2	<2,500	<2,500	<2,500	±	---
6-40-39	1	<500	---	<500	±	---
6-40-62	2	51,200	48,300	49,800	±	1,450
6-41-1	2	41,900	39,000	40,500	±	1,450
6-41-23	2	12,600	10,400	11,500	±	1,100
6-41-40	1	18,800	---	18,800	±	---
6-42-2	1	41,500	---	41,500	±	---
6-42-12A	2	39,500	39,400	39,500	±	50
6-42-40A	5	6,500	<2,500	<2,560	±	1,070
6-42-40B	5	<2,500	<500	<2,500	±	---
6-42-40C[e]	2	<2,500	<2,500	<2,500	±	---
6-42-42B	4	6,500	6,200	6,380	±	63
6-43-3	2	39,600	39,500	39,600	±	50
6-43-41E	1	9,300	---	9,300	±	---
6-43-41F	1	9,500	---	9,500	±	---
6-43-42J	4	1,800	1,400	1,600	±	115
6-43-43	4	1,100	700	900	±	115
6-43-45	1	1,000	---	1,000	±	---
6-43-88	1	19,200	---	19,200	±	---
6-44-4	1	15,600	---	15,600	±	---
6-44-42	3	1,500	1,300	1,400	±	58
6-44-43B	2	7,200	7,000	7,100	±	100
6-44-64	2	57,500	55,000	56,300	±	1,250
6-45-2	2	39,100	38,500	38,800	±	300
6-45-42	5	7,100	6,000	6,700	±	202
6-45-69A	1	21,700	---	21,700	±	---
6-46-4	2	29,600	28,800	29,200	±	400
6-46-21B	2	17,400	16,700	17,100	±	350
6-47-5	3	34,600	27,800	30,800	±	2,000
6-47-35A	1	14,400	---	14,400	±	---
6-47-46A	2	13,700	13,300	13,500	±	200
6-47-50[e]	1	4,200	---	4,200	±	---
6-47-60	1	23,300	---	23,300	±	---
6-48-7	2	6,800	4,600	5,700	±	1,100
6-48-18	2	5,600	4,300	4,950	±	650
6-48-71	2	23,700	22,700	23,200	±	500
6-49-13E	2	6,100	6,000	6,050	±	50
6-49-28	2	<2,500	<2,500	<2,500	±	---
6-49-55A	5	94,700	63,000	83,900	±	6,670
6-49-55B	2	<2,500	<2,500	<2,500	±	---
6-49-57	5	58,700	43,500	54,200	±	2,860

TABLE C.43. Nitrate (contd)

Well Name[a]	No. of Samples	Concentration (µg/L)[b,c] Maximum	Minimum	Average[d]		
6-49-79	3	41,500	40,600	41,100	±	265
6-49-100C	3	13,200	12,900	13,000	±	88
6-50-30	2	<2,500	<2,500	<2,500	±	---
6-50-42	2	4,000	3,100	3,550	±	450
6-50-45[e]	2	<2,500	<2,500	<2,500	±	---
6-50-48B[e]	2	<2,500	<2,500	<2,500	±	---
6-50-53	2	625,000	596,000	611,000	±	14,500
6-50-85	2	25,500	25,000	25,300	±	250
6-51-46	2	<2,500	<2,500	<2,500	±	---
6-51-63	2	18,900	18,900	18,900	±	---
6-51-75	2	2,700	<2,500	<2,600	±	100
6-52-19	2	5,000	4,600	4,800	±	200
6-52-46A[e]	2	<2,500	<2,500	<2,500	±	---
6-52-48[e]	2	<2,500	<2,500	<2,500	±	---
6-53-50[e]	1	<2,500	---	<2,500	±	---
6-53-103[e]	1	<2,500	---	<2,500	±	---
6-54-34	1	11,900	---	11,900	±	---
6-54-45A	2	<2,500	<2,500	<2,500	±	---
6-54-57[e]	2	<2,500	<2,500	<2,500	±	---
6-55-40	1	20,500	---	20,500	±	---
6-55-44	1	<2,500	---	<2,500	±	---
6-55-50A	2	<2,500	<2,500	<2,500	±	---
6-55-50C	1	<2,500	---	<2,500	±	---
6-55-50D	1	<2,500	---	<2,500	±	---
6-55-70	1	<2,500	---	<2,500	±	---
6-55-76	1	<2,500	---	<2,500	±	---
6-55-89	1	<2,500	---	<2,500	±	---
6-56-43	2	<2,500	<2,500	<2,500	±	---
6-56-53[e]	2	<2,500	<2,500	<2,500	±	---
6-57-29A	1	3,100	---	3,100	±	---
6-59-58	1	3,400	---	3,400	±	---
6-59-80B	2	<2,500	<2,500	<2,500	±	---
6-60-57	1	<2,500	---	<2,500	±	---
6-60-60	1	3,200	---	3,200	±	---
6-61-37	1	3,600	---	3,600	±	---
6-61-41	1	<2,500	---	<2,500	±	---
6-61-62	1	48,800	---	48,800	±	---
6-61-66	1	5,100	---	5,100	±	---
6-62-31	1	64,400	---	64,400	±	---
6-63-25A	2	18,300	17,500	17,900	±	400
6-63-55	2	7,700	6,600	7,150	±	550
6-63-58	2	29,600	21,600	25,600	±	4,000
6-63-90	1	5,400	---	5,400	±	---
6-64-27	1	42,300	---	42,300	±	---
6-64-62	1	37,700	---	37,700	±	---
6-65-23	1	18,300	---	18,300	±	---
6-65-50	2	6,900	4,210	5,560	±	1,350
6-65-59A	1	11,200	---	11,200	±	---

TABLE C.43. Nitrate (contd)

Well Name[a]	No. of Samples	Concentration (µg/L)[b,c] Maximum	Minimum	Average[d]		
6-65-72	2	20,100	17,500	18,800	±	1,300
6-65-83	3	5,400	5,300	5,370	±	33
6-66-23	2	42,500	42,500	42,500	±	---
6-66-38	2	<2,500	<2,500	<2,500	±	---
6-66-39	2	<2,500	<2,500	<2,500	±	---
6-66-58	2	10,500	7,100	8,800	±	1,700
6-66-64	2	23,500	22,500	23,000	±	500
6-66-103	1	<2,500	---	<2,500	±	---
6-67-51	2	2,500	<2,500	<2,500	±	---
6-67-86	3	3,500	3,000	3,230	±	145
6-67-98	2	5,000	4,600	4,800	±	200
6-68-105	1	<2,500	---	<2,500	±	---
6-69-38	2	<2,500	<2,500	<2,500	±	---
6-70-68	2	5,000	5,000	5,000	±	---
6-71-30	2	34,500	32,100	33,300	±	1,200
6-71-52	3	7,500	6,500	6,970	±	291
6-71-77	2	13,500	9,600	11,600	±	1,950
6-72-73	1	4,500	---	4,500	±	---
6-72-88	2	8,000	5,500	6,750	±	1,250
6-72-92	1	8,800	---	8,800	±	---
6-73-61	2	8,800	8,500	8,650	±	150
6-74-44	2	7,600	7,100	7,350	±	250
6-77-36	2	58,900	56,700	57,800	±	1,100
6-77-54	2	8,400	7,600	8,000	±	400
6-78-62	2	9,200	9,000	9,100	±	100
6-80-43P	1	<2,500	---	<2,500	±	---
6-80-43Q	1	<2,500	---	<2,500	±	---
6-80-43R	1	<2,500	---	<2,500	±	---
6-80-43S	1	<2,500	---	<2,500	±	---
6-81-58	5	4,000	2,600	3,180	±	282
6-83-47	1	6,000	---	6,000	±	---
6-84-35AO	1	8,200	---	8,200	±	---
6-87-55	2	17,100	15,100	16,100	±	1,000
6-89-35	2	10,600	10,000	10,300	±	300
6-90-45	2	6,200	3,500	4,850	±	1,350
6-96-49	3	16,300	11,000	13,700	±	1,530
6-97-43	2	17,700	16,600	17,200	±	550
6-97-51A	2	20,500	19,500	20,000	±	500
6-101-48B	2	<2,500	<2,500	<2,500	±	---
11-41-13C	1	7,900	---	7,900	±	---

(a) See Figures 5.1, 5.2, and 5.3 for well locations.
(b) Average concentrations ±2 times the standard error of the calculated mean (no estimate of standard error for one sample or if all data reported at the detector limit).
(c) Nitrate table combines data from two analytical methods with detection limits of 500 and 2500 ppb.
(d) Analytical results reported as less than the detection limit were included in the calculation of the average. When calculation included a "less than" value the average is shown as a "less than" value.
(e) Wells that sample a confined aquifer.

TABLE C.44. Maximum, Minimum, and Average Chromium Concentrations in Ground-Water Samples in 1989

Well Name[a]	No. of Samples	Concentration (µg/L)[b] Maximum	Minimum	Average[c]		
1-B3-1	1	18	---	18	±	---
1-B4-1	1	<10	---	<10	±	---
1-B4-4	1	<10	---	<10	±	---
1-B9-1	1	14	---	14	±	---
1-D2-5	1	169	---	169	±	---
1-D5-12	1	692	---	692	±	---
1-D8-3	1	120	---	120	±	---
1-F5-1	1	<10	---	<10	±	---
1-F5-4	1	13	---	13	±	---
1-F5-6	1	<10	---	<10	±	---
1-F8-1	1	<10	---	<10	±	---
1-H3-1	1	15	---	15	±	---
1-H3-2A	4	94	39	69	±	11.4
1-H3-2B	2	70	61	66	±	4.5
1-H3-2C	1	12	---	12	±	---
1-H4-3	8	208	117	149	±	10.7
1-H4-4	6	198	18	118	±	26.6
1-H4-5	4	129	81	103	±	11.2
1-H4-6	5	101	78	89	±	4.1
1-H4-7	3	114	77	100	±	11.6
1-H4-8	1	63	---	63	±	---
1-H4-9	3	110	49	82	±	17.8
1-H4-10	1	17	---	17	±	---
1-H4-11	1	132	---	132	±	---
1-H4-12A	4	98	31	72	±	15.6
1-H4-12B	3	128	81	100	±	14.4
1-H4-12C	4	349	284	312	±	14.4
1-H4-13	2	56	48	52	±	4.0
1-H4-14	2	420	358	389	±	31.0
1-H4-15A	1	47	---	47	±	---
1-H4-15B	1	81	---	81	±	---
1-H4-16	1	14	---	14	±	---
1-H4-17	1	97	---	97	±	---
1-H4-18	4	201	135	169	±	13.9
1-K-11	1	20	---	20	±	---
1-K-19	1	112	---	112	±	---
1-K-20	1	160	---	160	±	---
1-K-22	1	98	---	98	±	---
1-K-27	1	<10	---	<10	±	---
1-K-28	1	<10	---	<10	±	---
1-K-29	1	<10	---	<10	±	---
1-K-30	1	<10	---	<10	±	---
1-N-2	4	<10	<10	<10	±	---
1-N-3	5	<10	<10	<10	±	---
1-N-4	5	<10	<10	<10	±	---
1-N-14	7	<10	<10	<10	±	---
1-N-16	3	<10	<10	<10	±	---

TABLE C.44. Chromium (contd)

Well Name[a]	No. of Samples	Concentration (µg/L)[b] Maximum	Minimum	Average		
1-N-17	3	<10	<10	<10	±	---
1-N-21	4	<10	<10	<10	±	---
1-N-27	3	<10	<10	<10	±	---
1-N-29	3	<10	<10	<10	±	---
1-N-31	5	<10	<10	<10	±	---
1-N-32	4	<10	<10	<10	±	---
1-N-33	5	<10	<10	<10	±	---
1-N-36	5	<10	<10	<10	±	---
1-N-39	2	<10	<10	<10	±	---
1-N-41	4	<10	<10	<10	±	---
1-N-42	4	<10	<10	<10	±	---
1-N-52	4	<10	<10	<10	±	---
1-N-54	4	<10	<10	<10	±	---
1-N-55	5	<10	<10	<10	±	---
1-N-56	4	<10	<10	<10	±	---
1-N-57	4	<10	<10	<10	±	---
1-N-58	5	<10	<10	<10	±	---
1-N-59	6	<10	<10	<10	±	---
1-N-60	7	<10	<10	<10	±	---
1-N-61	6	<10	<10	<10	±	---
1-N-66	5	<10	<10	<10	±	---
1-N-67	5	<10	<10	<10	±	---
1-N-69	5	<10	<10	<10	±	---
1-N-70	4	39	<10	<17	±	7.2
2-E17-1	2	<10	<10	<10	±	---
2-E17-5	3	<10	<10	<10	±	---
2-E17-6	3	<10	<10	<10	±	---
2-E17-9	3	<10	<10	<10	±	---
2-E17-13	2	<10	<10	<10	±	---
2-E17-14	4	<10	<10	<10	±	---
2-E17-15	4	<10	<10	<10	±	---
2-E17-16	3	<10	<10	<10	±	---
2-E17-17	3	<10	<10	<10	±	---
2-E17-18	4	<10	<10	<10	±	---
2-E17-19	4	<10	<10	<10	±	---
2-E17-20	4	<10	<10	<10	±	---
2-E18-1	4	<10	<10	<10	±	---
2-E18-2	5	<10	<10	<10	±	---
2-E18-3	6	12	<10	<10	±	0.3
2-E18-4	5	<10	<10	<10	±	---
2-E24-2	3	<10	<10	<10	±	---
2-E24-16	4	<10	<10	<10	±	---
2-E24-17	3	<10	<10	<10	±	---
2-E24-18	3	<10	<10	<10	±	---
2-E25-18	3	<10	<10	<10	±	---
2-E25-20	3	<10	<10	<10	±	---
2-E25-22	4	<10	<10	<10	±	---
2-E25-24	4	<10	<10	<10	±	---

TABLE C.44. Chromium (contd)

Well Name[a]	No. of Samples	Concentration (µg/L)[b] Maximum	Minimum	Average[c]		
2-E25-25	14	19	<10	<11	±	0.6
2-E25-26	5	<10	<10	<10	±	---
2-E25-27	3	<10	<10	<10	±	---
2-E25-28	5	<10	<10	<10	±	---
2-E25-29P	15	<10	<10	<10	±	---
2-E25-30P	4	32	<10	<18	±	5.2
2-E25-31	16	42	<10	<12	±	2.0
2-E25-32P	15	<10	<10	<10	±	---
2-E25-33	14	10	<10	<10	±	---
2-E25-34	5	<10	<10	<10	±	---
2-E25-35	5	10	<10	<10	±	---
2-E25-36	3	<10	<10	<10	±	---
2-E25-37	4	13	<10	<11	±	0.8
2-E25-38	4	35	<10	<16	±	6.2
2-E27-8	3	<10	<10	<10	±	---
2-E27-9	4	<10	<10	<10	±	---
2-E27-10	3	<10	<10	<10	±	---
2-E28-26	3	<10	<10	<10	±	---
2-E28-27	4	<10	<10	<10	±	---
2-E32-2	3	<10	<10	<10	±	---
2-E32-3	1	<10	---	<10	±	---
2-E32-4	5	<10	<10	<10	±	---
2-E33-1	1	<10	---	<10	±	---
2-E33-28	4	<10	<10	<10	±	---
2-E33-29	3	14	<10	<11	±	1.3
2-E33-30	3	<10	<10	<10	±	---
2-E34-2	4	92	<10	<49	±	20.4
2-E34-3	3	<10	<10	<10	±	---
2-E34-5	3	11	<10	<10	±	0.3
2-E34-6	3	<10	<10	<10	±	---
2-W6-2	5	41	32	36	±	1.7
2-W7-1	3	<10	<10	<10	±	---
2-W7-2	3	12	12	12	±	---
2-W7-3	3	<10	<10	<10	±	---
2-W7-4	3	14	<10	<12	±	1.2
2-W7-5	3	11	<10	<10	±	0.3
2-W7-6	2	<10	<10	<10	±	---
2-W8-1	3	12	<10	<11	±	0.7
2-W9-1	3	11	<10	<11	±	0.3
2-W10-13	5	<10	<10	<10	±	---
2-W10-14	4	<10	<10	<10	±	---
2-W15-15	3	<10	<10	<10	±	---
2-W15-16	3	12	<10	<11	±	0.7
2-W15-18	3	26	<10	<16	±	4.9
2-W18-21	4	<10	<10	<10	±	---
2-W18-22	3	<10	<10	<10	±	---
2-W18-23	4	<10	<10	<10	±	---
2-W18-24	4	<10	<10	<10	±	---

TABLE C.44. Chromium (contd)

Well Name[a]	No. of Samples	Concentration (µg/L)[b] Maximum	Minimum	Average[c]		
2-W19-19	1	<10	---	<10	±	---
2-W19-20	1	<10	---	<10	±	---
2-W19-21	1	<10	---	<10	±	---
2-W19-23	1	<10	---	<10	±	---
2-W19-24	1	<10	---	<10	±	---
2-W19-26	1	<10	---	<10	±	---
2-W19-27	1	<10	---	<10	±	---
3-1-3	1	<10	---	<10	±	---
3-1-7	4	<10	<10	<10	±	---
3-1-10	2	<10	<10	<10	±	---
3-1-11	2	<10	<10	<10	±	---
3-1-12	2	<10	<10	<10	±	---
3-1-13	2	<10	<10	<10	±	---
3-1-14	2	<10	<10	<10	±	---
3-1-15	3	<10	<10	<10	±	---
3-1-16A	4	<10	<10	<10	±	---
3-1-16B	4	<10	<10	<10	±	---
3-1-16C	3	<10	<10	<10	±	---
3-1-17A	2	<10	<10	<10	±	---
3-1-17B	2	<10	<10	<10	±	---
3-1-17C	1	<10	---	<10	±	---
3-1-18A	2	<10	<10	<10	±	---
3-1-18B	1	<10	---	<10	±	---
3-2-1	2	<10	<10	<10	±	---
3-2-2	1	<10	---	<10	±	---
3-3-7	3	<10	<10	<10	±	---
3-3-9	2	<10	<10	<10	±	---
3-3-10	2	<10	<10	<10	±	---
3-4-1	2	<10	<10	<10	±	---
3-4-7	2	<10	<10	<10	±	---
3-4-11	2	<10	<10	<10	±	---
3-8-1	2	<10	<10	<10	±	---
3-8-2	1	<10	---	<10	±	---
3-8-3	1	<10	---	<10	±	---
6-S43-E12	3	<10	<10	<10	±	---
6-S41-E13A	4	<10	<10	<10	±	---
6-S41-E13B	3	<10	<10	<10	±	---
6-S40-E14	3	<10	<10	<10	±	---
6-S37-E14	4	<10	<10	<10	±	---
6-S36-E13A	2	<10	<10	<10	±	---
6-S32-E13A	2	<10	<10	<10	±	---
6-S32-E13B	2	<10	<10	<10	±	---
6-S31-E13	2	<10	<10	<10	±	---
6-S29-E12	2	<10	<10	<10	±	---
6-23-34	5	<10	<10	<10	±	---
6-24-33	3	<10	<10	<10	±	---
6-24-34A	3	<10	<10	<10	±	---

TABLE C.44. Chromium (contd)

Well Name[a]	Samples	Concentration (µg/L)[b] Maximum	Minimum	Average[c]		
6-24-34B	4	<10	<10	<10	±	---
6-24-34C	6	<10	<10	<10	±	---
6-24-35	6	<10	<10	<10	±	---
6-25-34C	5	<10	<10	<10	±	---
6-32-70B	1	23	---	23	±	---
6-35-66	1	20	---	20	±	---
6-35-70	1	<10	---	<10	±	---
6-35-78A	1	13	---	13	±	---
6-38-70	1	<10	---	<10	±	---
6-39-79	1	<10	---	<10	±	---
6-40-39	1	<10	---	<10	±	---
6-41-40	1	<10	---	<10	±	---
6-42-40A	3	<10	<10	<10	±	---
6-42-42B	4	<10	<10	<10	±	---
6-43-41E	1	<10	---	<10	±	---
6-43-41F	1	<10	---	<10	±	---
6-43-42J	4	<10	<10	<10	±	---
6-43-43	4	10	<10	<10	±	---
6-43-45	1	<10	---	<10	±	---
6-44-42	3	<10	<10	<10	±	---
6-44-43B	2	15	<10	<13	±	2.5
6-44-64	1	<10	---	<10	±	---
6-45-42	1	<10	---	<10	±	---
6-49-55A	3	<10	<10	<10	±	---
6-49-57	3	<10	<10	<10	±	---
6-49-79	1	<10	---	<10	±	---
6-50-53	1	<10	---	<10	±	---
6-65-83	1	19	---	19	±	---
6-67-86	1	25	---	25	±	---
6-71-52	1	<10	---	<10	±	---
6-73-61	1	11	---	11	±	---
6-77-36	1	<10	---	<10	±	---
6-78-62	1	81	---	81	±	---
6-81-58	4	17	<10	<14	±	1.4
6-83-47	1	44	---	44	±	---
6-96-49	1	59	---	59	±	---
6-97-43	1	192	---	192	±	---
11-41-13C	1	<10	---	<10	±	---

(a) See Figures 5.1, 5.2, and 5.3 for well locations.
(b) Average concentrations ±2 times the standard error of the calculated mean (no estimate of standard error for one sample or if all data reported at the detection limit).
(c) Analytical results reported as less than the detection limit were included in the calculation of the average. When calculation included a "less than" value the average is shown as a "less than value."

TABLE C.45. Maximum, Minimum, and Average Carbon Tetrachloride (CCl_4) Concentrations in Ground-Water Samples in 1989

Well Name[a]	No. of Samples	Concentration (µg/L)[b] Maximum	Minimum	Average
1-H3-1	1	<5	---	<5 ± ---
1-H3-2A	1	<5	---	<5 ± ---
1-H3-2B	2	<5	<5	<5 ± ---
1-H3-2C	1	<5	---	<5 ± ---
1-H4-3	1	<5	---	<5 ± ---
1-H4-4	1	<5	---	<5 ± ---
1-H4-5	1	<5	---	<5 ± ---
1-H4-6	1	<5	---	<5 ± ---
1-H4-7	1	<5	---	<5 ± ---
1-H4-8	1	<5	---	<5 ± ---
1-H4-9	1	<5	---	<5 ± ---
1-H4-10	1	<5	---	<5 ± ---
1-H4-11	1	<5	---	<5 ± ---
1-H4-12A	1	<5	---	<5 ± ---
1-H4-12B	1	<5	---	<5 ± ---
1-H4-12C	1	<5	---	<5 ± ---
1-H4-13	2	<5	<5	<5 ± ---
1-H4-14	1	<5	---	<5 ± ---
1-H4-15A	1	<5	---	<5 ± ---
1-H4-15B	1	<5	---	<5 ± ---
1-H4-16	1	<5	---	<5 ± ---
1-H4-17	1	<5	---	<5 ± ---
1-H4-18	1	<5	---	<5 ± ---
1-N-2	3	<5	<5	<5 ± ---
1-N-3	4	<5	<5	<5 ± ---
1-N-4	4	<5	<5	<5 ± ---
1-N-14	6	<5	<5	<5 ± ---
1-N-16	1	<5	---	<5 ± ---
1-N-17	1	<5	---	<5 ± ---
1-N-21	1	<5	---	<5 ± ---
1-N-23	1	<5	---	<5 ± ---
1-N-24	1	<5	---	<5 ± ---
1-N-25	1	<5	---	<5 ± ---
1-N-26	1	<5	---	<5 ± ---
1-N-27	3	<5	<5	<5 ± ---
1-N-29	3	<5	<5	<5 ± ---
1-N-31	5	<5	<5	<5 ± ---
1-N-32	4	<5	<5	<5 ± ---
1-N-33	6	<5	<5	<5 ± ---
1-N-36	5	<5	<5	<5 ± ---
1-N-39	2	<5	<5	<5 ± ---
1-N-41	4	<5	<5	<5 ± ---
1-N-42	4	<5	<5	<5 ± ---
1-N-47	1	<5	---	<5 ± ---
1-N-52	4	<5	<5	<5 ± ---
1-N-54	1	<5	---	<5 ± ---
1-N-55	1	<5	---	<5 ± ---

TABLE C.45. Carbon Tetrachloride (contd)

Well Name[a]	No. of Samples	Concentration (µg/L)[b] Maximum	Minimum	Average
1-N-56	1	<5	---	<5 ± ---
1-N-57	1	<5	---	<5 ± ---
1-N-58	3	<5	<5	<5 ± ---
1-N-59	4	<5	<5	<5 ± ---
1-N-60	5	<5	<5	<5 ± ---
1-N-61	3	<5	<5	<5 ± ---
1-N-66	4	<5	<5	<5 ± ---
1-N-67	4	<5	<5	<5 ± ---
1-N-69	4	<5	<5	<5 ± ---
1-N-70	4	<5	<5	<5 ± ---
2-E16-2	1	<5	---	<5 ± ---
2-E17-1	2	<5	<5	<5 ± ---
2-E17-5	1	<5	---	<5 ± ---
2-E17-9	1	<5	---	<5 ± ---
2-E17-13	1	<5	---	<5 ± ---
2-E17-14	1	<5	---	<5 ± ---
2-E17-15	2	<5	<5	<5 ± ---
2-E17-16	1	<5	---	<5 ± ---
2-E17-17	1	<5	---	<5 ± ---
2-E17-18	1	<5	---	<5 ± ---
2-E17-19	4	<5	<5	<5 ± ---
2-E17-20	4	<5	<5	<5 ± ---
2-E18-1	4	<5	<5	<5 ± ---
2-E18-2	1	<5	---	<5 ± ---
2-E18-3	2	<5	<5	<5 ± ---
2-E18-4	1	<5	---	<5 ± ---
2-E24-2	3	<5	<5	<5 ± ---
2-E24-16	4	<5	<5	<5 ± ---
2-E24-17	3	<5	<5	<5 ± ---
2-E24-18	3	<5	<5	<5 ± ---
2-E25-11	1	<5	---	<5 ± ---
2-E25-22	1	<5	---	<5 ± ---
2-E25-24	1	<5	---	<5 ± ---
2-E25-26	5	<5	<5	<5 ± ---
2-E25-28	5	<5	<5	<5 ± ---
2-E25-29P	1	<5	---	<5 ± ---
2-E25-31	1	<5	---	<5 ± ---
2-E25-32P	4	<5	<5	<5 ± ---
2-E25-34	5	<5	<5	<5 ± ---
2-E25-35	5	<5	<5	<5 ± ---
2-E25-36	3	<5	<5	<5 ± ---
2-E27-8	3	<5	<5	<5 ± ---
2-E27-9	4	<5	<5	<5 ± ---
2-E27-10	3	<5	<5	<5 ± ---
2-E28-26	3	<5	<5	<5 ± ---
2-E28-27	4	<5	<5	<5 ± ---
2-E32-2	3	<5	<5	<5 ± ---
2-E32-3	1	<5	---	<5 ± ---

TABLE C.45. Carbon Tetrachloride (contd)

Well Name[a]	No. of Samples	Concentration (µg/L)[b] Maximum	Minimum	Average
2-E32-4	4	<5	<5	<5 ± ---
2-E33-28	4	<5	<5	<5 ± ---
2-E33-29	3	<5	<5	<5 ± ---
2-E33-30	3	<5	<5	<5 ± ---
2-E34-1	1	<5	---	<5 ± ---
2-E34-2	4	<5	<5	<5 ± ---
2-E34-3	3	<5	<5	<5 ± ---
2-E34-5	3	<5	<3	<4 ± 0.7
2-E34-6	3	<5	<5	<5 ± ---
2-W6-2	4	113	99	104 ± 3.1
2-W7-1	3	<5	<5	<5 ± ---
2-W7-2	3	<5	<5	<5 ± ---
2-W7-3	3	<5	<5	<5 ± ---
2-W7-4	3	222	189	210 ± 10.7
2-W7-5	3	34	27	30 ± 2.1
2-W7-6	3	<5	<5	<5 ± ---
2-W8-1	3	<5	<5	<5 ± ---
2-W9-1	3	<5	<5	<5 ± ---
2-W10-13	5	18	7	12 ± 1.8
2-W10-14	4	<5	<5	<5 ± ---
2-W15-12	1	1,920	---	1,920 ± ---
2-W15-15	3	543	380	454 ± 47.6
2-W15-16	3	8,250	6,650	7,330 ±476.0
2-W15-17	2	<5	<5	<5 ± ---
2-W15-18	3	1,710	189	1,160 ±487.0
2-W18-4	1	194	---	194 ± ---
2-W18-21	4	148	138	143 ± 2.5
2-W18-22	3	<5	<5	<5 ± ---
2-W18-23	4	760	195	575 ±131.0
2-W18-24	4	945	575	727 ± 79.9
2-W19-19	1	10	---	10 ± ---
2-W19-20	1	23	---	23 ± ---
2-W19-21	1	---	---	<5 ± ---
2-W19-23	1	20	---	20 ± ---
2-W19-24	1	14	---	14 ± ---
2-W19-26	1	30	---	30 ± ---
2-W19-27	1	7	---	7 ± ---
3-1-3	1	<5	---	<5 ± ---
3-1-7	3	<5	<5	<5 ± ---
3-1-10	2	<5	<5	<5 ± ---
3-1-11	12	<5	<5	<5 ± ---
3-1-12	2	<5	<5	<5 ± ---
3-1-13	2	<5	<5	<5 ± ---
3-1-14	2	<5	<5	<5 ± ---
3-1-15	3	<5	<5	<5 ± ---
3-1-16A	2	<5	<5	<5 ± ---
3-1-16B	2	<5	<5	<5 ± ---
3-1-16C	1	<5	---	<5 ± ---

TABLE C.45. Carbon Tetrachloride (contd)

Well Name[a]	No. of Samples	Concentration (µg/L)[b] Maximum	Minimum	Average
3-1-17A	25	<5	<5	<5 ± ---
3-1-17B	2	<5	<5	<5 ± ---
3-1-17C	1	<5	---	<5 ± ---
3-1-18A	12	<5	<5	<5 ± ---
3-1-18B	1	<5	---	<5 ± ---
3-1-19	5	<5	<5	<5 ± ---
3-2-1	2	<5	<5	<5 ± ---
3-2-2	1	<5	---	<5 ± ---
3-3-7	3	<5	<5	<5 ± ---
3-3-9	2	<5	<5	<5 ± ---
3-3-10	2	<5	<5	<5 ± ---
3-4-1	2	<5	<5	<5 ± ---
3-4-7	2	<5	<5	<5 ± ---
3-4-11	2	<5	<5	<5 ± ---
3-8-1	2	<5	<5	<5 ± ---
3-8-2	1	<5	---	<5 ± ---
3-8-3	1	<5	---	<5 ± ---
6-S43-E12	3	<5	<5	<5 ± ---
6-S41-E13A	4	<5	<5	<5 ± ---
6-S41-E13B	3	<5	<5	<5 ± ---
6-S40-E14	3	<5	<5	<5 ± ---
6-S37-E14	4	<5	<5	<5 ± ---
6-S36-E13A	2	<5	<5	<5 ± ---
6-S32-E13A	2	<5	<5	<5 ± ---
6-S32-E13B	2	<5	<5	<5 ± ---
6-S31-E13	2	<5	<5	<5 ± ---
6-S29-E12	2	<5	<5	<5 ± ---
6-39-79	3	880	820	850 ± 17.3
6-40-39	1	<5	---	<5 ± ---
6-41-40	1	<5	---	<5 ± ---
6-42-40A	3	<5	<5	<5 ± ---
6-42-40B	1	<5	---	<5 ± ---
6-42-42B	4	<5	<5	<5 ± ---
6-43-41E	1	<5	---	<5 ± ---
6-43-41F	1	<5	---	<5 ± ---
6-43-42J	4	<5	<5	<5 ± ---
6-43-43	4	<5	<5	<5 ± ---
6-43-45	1	<5	---	<5 ± ---
6-44-42	3	<5	<5	<5 ± ---
6-44-43B	2	<5	<5	<5 ± ---
6-77-36	3	<5	<5	<5 ± ---
6-81-58	2	<5	<5	<5 ± ---
11-41-13C	1	<5	---	<5 ± ---

(a) See Figures 5.1, 5.2, and 5.3 for well locations.
(b) Average concentrations ±2 times the standard error of the calculated mean (no estimate of standard error for one sample or if all results reported at detection limit).

TABLE C.46. Summary of United States Testing Company Results on EPA Laboratory Intercomparison Studies Program Samples

Sample Type	Anaylsis	UST Result			EPA Known Value
Air Filter	Gross Alpha	21.7	±	0.6	21
(pCi/filter)	Gross Alpha	7.0	±	0.0	6
	Gross Beta	70.7	±	2.3	62
	^{137}Cs	21.7	±	1.2	20
	^{137}Cs	10.3	±	0.6	12
	^{90}Sr	20.3	±	0.6	20
Milk	^{137}Cs	56.0	±	4.4	50
(pCi/L)	^{89}Sr	31.0	±	3.6	39
	^{90}Sr-	47.7	±	4.0	55
Water	Gross Alpha	6.0	±	0.0	8
(pCi/L)	Gross Alpha	29.7	±	1.2	29
	Gross Alpha	31.4	±	3.5	30
	Gross Alpha	4.0	±	0.0	4
	Gross Beta	3.3	±	0.6	4
	Gross Beta	47.7	±	1.5	57
	Gross Beta	45.3	±	0.6	50
	Gross Beta	7.3	±	0.6	6
	^{133}Ba	50.3	±	1.5	49
	^{133}Ba	63.3	±	1.2	59
	^{60}Co	10.7	±	0.6	10
	^{60}Co	31.7	±	0.6	31
	^{60}Co	32.7	±	0.6	30
	^{51}Cr	237.3	±	14.6	235
	^{134}Cs	9.3	±	0.6	10
	^{134}Cs	19.0	±	1.0	20
	^{134}Cs	37.3	±	0.6	39
	^{134}Cs	27.3	±	0.6	29
	^{137}Cs	11.0	±	0.0	10
	^{137}Cs	21.0	±	1.0	20
	^{137}Cs	21.3	±	0.6	20
	^{137}Cs	65.0	±	0.0	59
	^{3}H	2407.0	±	205.9	2754
	^{3}H	4406.7	±	195.8	4503
	^{3}H	3475.3	±	121.7	3471
	^{131}I	99.7	±	7.5	106
	^{131}I	73.3	±	3.2	83
	^{239}Pu	4.0	±	0.1	4.2
	^{239}Pu	2.9	±	0.1	2.8
	^{226}Ra	4.4	±	0.1	4.9
	^{226}Ra	3.3	±	0.1	3.5
	^{226}Ra	16.7	±	0.2	17.7
	^{226}Ra	8.2	±	0.2	8.7
	^{228}Ra	1.8	±	0.3	1.7
	^{228}Ra	4.0	±	0.2	3.6
	^{228}Ra	18.8	±	0.4	18.3
	^{228}Ra	9.6	±	0.7	9.3

TABLE C.46. Summary of United States Testing Company Results on EPA Laboratory Intercomparison Studies Program Samples (contd)

Sample Type	Anaylsis	UST Result			EPA Known Value
Water (contd)	^{106}Ru	164.7	±	4.9	178
	^{106}Ru	123.0	±	3.6	128
	^{106}Ru	155.7	±	2.5	161
	^{89}Sr	40.7	±	1.5	40
	^{89}Sr	6.3	±	0.6	8
	^{89}Sr	5.0	±	0.0	6
	^{89}Sr	14.0	±	1.0	14
	^{90}Sr	21.3	±	0.6	25
	^{90}Sr	7.7	±	0.6	8
	^{90}Sr	5.7	±	0.6	6
	^{90}Sr	9.0	±	1.0	10
	U (natural)	3.0	±	0.0	3
	^{238}U	4.3	±	0.6	5
	^{238}U	39.3	±	2.9	41
	^{238}U	16.0	±	1.0	15
	^{65}Zn	173.3	±	5.7	159
	^{65}Zn	184.0	±	2.7	165

TABLE C.47. Summary of United States Testing Company Results on DOE Quality Assesment Program Samples

Sample Type	Anaylsis	UST Result			EML Known Value
Air Filter (pCi/filter)	^{241}Am	0.1920	±	0.0384	0.225
	^{241}Am	0.0173	±	0.0019	0.018
	^{7}Be	1180	±	59	1950
	^{7}Be	120	±	4.8	123
	^{144}Ce	302	±	21.14	327
	^{144}Ce	7.22	±	0.7942	7.08
	^{60}Co	126	±	6.3	126
	^{60}Co	8.67	±	0.4335	8.17
	^{134}Cs	132	±	3.96	158
	^{134}Cs	8.32	±	0.2496	9.33
	^{137}Cs	193	±	7.72	189
	^{137}Cs	3.80	±	0.152	3.58
	^{54}Mn	3.99	±	3.71	3.74
	^{54}Mn	4.47	±	0.134	4.17
	^{239}Pu	0.244	±	0.0244	0.27
	^{239}Pu	0.014	±	0.001	0.018
	^{125}Sb	28.70	±	6.03	96.8
	^{90}Sr	2.60	±	0.31	2.39
	^{90}Sr	1.11	±	0.16	0.20
	U (µg)	0.59	±	0.11	0.72
	^{234}U	0.07	±	0.017	0.09
	^{238}U	0.081	±	0.016	0.09
Water (pCi/L)	^{241}Am	0.0043	±	0.0003	0.0045
	^{241}Am	0.300	±	0.024	0.333
	^{144}Ce	146	±	11.68	132
	^{57}Co	0.824	±	0.041	0.88
	^{57}Co	144	±	12.96	135
	^{60}Co	0.917	±	0.018	0.94
	^{60}Co	160	±	12.8	155
	^{134}Cs	2.35	±	0.047	2.73
	^{134}Cs	63	±	6.3	68.3
	^{137}Cs	2.59	±	0.1036	2.55
	^{137}Cs	72.7	±	7.27	68.3
	^{3}H	6.13	±	0.12	6.31
	^{3}H	372	±	0	395
	^{54}Mn	0.30	±	0.006	0.3
	^{54}Mn	69.70	±	6.97	65
	^{239}Pu	0.0068	±	0.0003	0.0059
	^{239}Pu	0.25	±	0.017	0.35
	^{90}Sr	0.637	±	0.08	0.55
	^{90}Sr	28	±	1.40	31.7
	U (µg)	9.63	±	0.48	13.2
	U (µg)	12.60	±	1.89	13.2
	^{234}U	0.0039	±	0.0002	0.0045
	^{234}U	0.14	±	0.0140	0.167
	^{238}U	0.0044	±	0.0003	0.0044
	^{238}U	0.1430	±	0.0143	0.167

TABLE C.47. Summary of United States Testing Company Results on DOE Quality Assessment Program Samples (contd)

Sample Type	Anaylsis	UST Result			EML Known Value
Soil (pCi/g)	^{241}Am	0.275	±	0.050	0.21
	^{241}Am	4.46	±	0.76	2.22
	^{137}Cs	21.9	±	1.10	20.80
	^{137}Cs	692	±	28	642
	^{40}K	25	±	1.5	24.1
	^{40}K	651	±	91.14	561
	^{239}Pu	0.42	±	0.017	0.42
	^{239}Pu	15.3	±	0.77	17.1
	^{90}Sr	1.3	±	0.03	1.09
	^{90}Sr	3.92	±	0.67	5.73
	^{234}U	25	±	1.0	21.7
	^{238}U	26.1	±	2.09	21.7
Vegetation (pCi/g)	^{241}Am	0.014	±	0.0015	0.015
	^{137}Cs	1.82	±	0.04	1.6
	^{137}Cs	54.6	±	1.09	47.9
	^{40}K	30.6	±	0	26.1
	^{40}K	1570	±	125.6	1290
	^{239}Pu	0.021	±	0.0017	0.022
	^{239}Pu	0.074	±	0.012	0.0745
	^{90}Sr	3.93	±	0.04	3.75
	^{90}Sr	1330	±	39.9	1830
	^{234}U	0.0068	±	0.0009	0.01
	^{234}U	0.44	±	0.04	0.6
	^{238}U	0.0068	±	0.0009	0.012
	^{238}U	0.42	±	0.029	0.60

TABLE C.48. WDOH- and PNL-Shared TLD Stations in 1989

Location		Exposure Rate (mR/day)[a]							
		First[b]		Second		Third		Fourth	
		WDOH	PNL	WDOH	PNL	WDOH	PNL	WDOH	PNL
U.S. Ecology	NE Corner	0.22	0.23	0.23	0.31	0.19	0.30	0.25	0.27
	NW Corner	0.23	0.24	0.25	0.26	0.20	0.30	0.25	0.26
	SW Corner	0.29	0.27	0.31	*	0.26	0.32	0.35	0.34
WNP-2 Station 1		0.27	0.24	0.25	0.29	0.18	0.34	0.26	*
WNP-2 Station 4		0.25	0.21	0.20	0.26	0.14	0.31	0.22	0.25
WNP-2 Station 8		0.28	0.26	0.27	0.31	0.23	0.30	0.29	0.27
200-E SE		0.23	0.25	0.21	0.22	0.19	0.29	0.24	0.27
E 200-E		0.25	0.24	0.23	0.22	0.21	0.32	0.24	0.28
N 200-E		0.24	0.24	0.23	0.21	0.20	0.30	0.21	0.28
Rt. 11A, Mile 9		0.23	0.25	0.22	0.21	0.19	0.30	0.21	0.29
GTE Building		0.20	0.22	0.19	0.20	0.18	0.30	0.20	0.27
S 200-E		0.25	0.26	0.25	0.24	0.21	0.33	0.24	0.30
SW of BC Crib		0.24	0.25	0.21	0.23	0.19	0.33	0.23	0.30
Army Loop Camp		0.22	0.23	0.22	0.23	0.19	0.32	0.21	0.30
Yakima Barricade		0.24	0.25	0.23	0.23	0.21	0.33	0.23	0.29
Wye Barricade		0.21	0.21	0.19	0.19	0.17	0.27	0.21	0.24
Moses Lake		0.19	0.19	0.19	0.16	0.17	0.25	0.19	0.28
Connell		0.24	0.22	0.24	0.18	0.17	0.28	0.23	0.28
Richland		0.23	0.22	0.20	0.17	0.19	0.27	0.22	0.26
Sunnyside		0.21	0.21	0.20	0.18	0.18	0.24	0.17	0.29
Yakima		0.21	0.20	0.18	0.17	0.17	0.24	0.20	0.28

(a) TLD results for WDOH and PNL at the same location in units of milliroentgens per day.
(b) First, second, third, and fourth refer to the 1989 calendar quarters.
* No data.

APPENDIX D

ANALYTICAL PROCEDURES AND SAMPLING SUMMARY

APPENDIX D

ANALYTICAL PROCEDURES AND SAMPLING SUMMARY

SURFACE MONITORING: RADIOLOGICAL SAMPLES

All routine environmental surveillance samples are analyzed according to detailed, written analytical procedures that are described in general terms in this section.[a] Minimum detectable concentrations for the various medium/analysis combinations and other analytical information are shown in Table D.1.

AIR SAMPLES

Alpha- and Beta-Emitting Radionuclides are measured by a direct count from the glass fiber filter.[b] Alpha radiation is counted on a low-background, gas-flow proportional counter and beta on a gas-flow proportional counter.

Gamma-Emitting Radionuclides are counted directly from glass fiber filters[b] using a lithium-ion drifted germanium [Ge(Li)] detector with a multichannel, pulse-height analyzer. Listed below are the nuclides that are scanned during the analysis:

^{7}Be	^{99}Mo	$^{144}CePr$
^{22}Na	^{103}Ru	^{147}Nd
^{24}Na	^{106}Ru	^{152}Eu
^{40}K	^{110M}Ag	^{154}Eu
^{46}Sc	^{113}Sn	^{155}Eu
^{51}Cr	^{124}Sb	^{208}Tl
^{54}Mn	^{125}Sb	^{212}Pb
^{59}Fe	^{131}I	^{212}Bi
^{57}Co	^{133}I	^{214}Pb
^{58}Co	^{135}I	^{214}Bi
^{60}Co	^{134}Cs	^{224}Ra
^{65}Zn	^{137}Cs	^{226}Ra Da
^{76}As	^{133}Ba	^{228}Th Da
^{75}Se	^{140}Ba	^{234}Th
^{85}Kr	$^{140}BaLa$	^{232}Th Da
^{85}Sr	^{139}Ce	^{238}U Da
^{95}Zr	^{141}Ce	
^{95}Nb	^{144}Ce	
$^{95}ZrNb$		

Da = decay product

Strontium-90 is leached from glass fiber filters[b] with fuming nitric acid, scavenged with barium chromate, precipitated as a carbonate, transferred to a stainless steel planchet, and counted with a low-background, gas-flow proportional counter.

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

Plutonium is leached from glass fiber filters[b] with nitric acid and passed through an anion-exchange resin. The plutonium on the resin column is eluted with nitric and hydrofluoric acids, electrodeposited on a stainless steel disk, and then counted with an alpha spectrometer.

Tritium in air as titrated water vapor is measured in water vapor collected in silica gel. The

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

water vapor is removed from the gel by heat and vacuum action, and then collected in a freeze trap. The ^3H content of the water vapor is determined with a liquid scintillation spectrometer.

Iodine-131 is collected on TEDA-treated activated charcoal (90% and 70% efficient for methyl iodine at 2.6 and 5.2 m^3/h, respectively) and then counted on a lithium-ion drifted germanium [Ge(Li)] detector with a multichannel, pulse-height analyzer.

Iodine-129 is collected on a special petroleum-based charcoal. Iodine is removed from the charcoal, purified, and determined by mass spectrometry.

Carbon-14 is collected as CO_2 gas using soda lime. The CO_2 is released from the soda-lime sample with acid and injected into a "Benzene Synthesizer" instrument. The CO_2 is quantitatively converted to benzene through a series of catalytic reactions. The benzene product is mixed with scintillation solution and counted on a low-temperature, liquid scintillation counter.

Krypton-85 is removed from the air sample and purified using a specially constructed cryogenic chromatography instrument. The sample is passed through a series of cold traps to remove unwanted gases. The purified ^{85}Kr is then mixed with scintillation solution and counted on a low-temperature, liquid scintillation counter.

WATER SAMPLES

Alpha-Emitting Radionuclides (uranium and plutonium) are extracted into ether from strong nitric acid. The ether phase is evaporated. The residue is plated on a stainless steel planchet and counted with a low-background, gas-flow proportional counter.

Beta-Emitting Radionuclides are counted directly from dried residue using a gas-flow proportional counter.

Gamma-Emitting Radionuclides are counted directly from 500 mL of sample concentrate using a lithium-ion drifted germanium [Ge(Li)] detector with a multichannel, pulse-height analyzer. See page D.1 for a list of radionuclides included in gamma scan analysis.

Strontium-90 in large-volume water samples is precipitated with fuming nitric acid, scavenged with barium chromate, precipitated as a carbonate, transferred to a stainless steel planchet, and counted with a low-background, gas-flow proportional counter. After 15 days, the ^{90}Sr decay product is separated and then counted with a proportional counter.

Tritium samples can be counted directly with a liquid scintillation spectrometer, or the sample can be enriched by alkaline electrolysis and then counted with a liquid scintillation spectrometer.

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

Filter-Resin Samples are analyzed for gamma-emitting radionuclides using a lithium-ion drifted germanium [Ge(Li)] detector with a multichannel, gamma-ray spectrometer. Aliquots of the samples are analyzed by mass

spectrometry for ^{129}I and by chemical separation and alpha spectrometry for plutonium.

MILK

Gamma-Emitting Radionuclides in milk are counted directly using a lithium-ion drifted germanium [Ge(Li)] detector with a multichannel, pulse-height analyzer.

Tritium in water distilled from milk is counted directly with a liquid scintillation spectrometer.

Iodine-129 is separated from milk with an anion-exchange resin, purified, and analyzed by mass spectrometry.

Iodine-131 is removed from milk with an anion-exchange resin. The iodine is eluted with sodium hypochlorite, precipitated as palladium iodide, and beta-counted with a low-background, gas-flow proportional counter.

Strontium-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 lithium-ion drifted germanium [Ge(Li)] detector with a multichannel, pulse-height analyzer.

Tritium in water distilled from farm produce is counted directly with a liquid scintillation spectrometer.

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

Plutonium in foodstuffs is measured as it is in air-filter samples, after samples have been dried, ashed in a furnace, and treated with nitric acid.

Strontium-90 is measured as it is in air samples, but samples are dried, ashed in a furnace, and treated with nitric acid before exposure to fuming nitric acid.

VEGETATION AND WILDLIFE

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

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

SOIL AND SEDIMENT

All soil and sediment samples are pretreated by weighing, drying, and ball milling to a constant particle size of 300 microns or less. Samples not requiring further pretreatment are counted directly to detect gamma- and low-energy photon-emitting radionuclides. For plutonium and strontium analyses requiring chemical separations, 1-gram aliquots of samples are dissolved with concentrated acids by heating in pressurized containers in a microwave oven.

Gamma-Emitting Radionuclides are counted on a lithium-ion drifted germanium [Ge(Li)]

detector with a multichannel, pulse-height analyzer, after the sample is placed in a marinelli beaker.

Plutonium and Strontium-90 are measured after the sample is pretreated. Strontium is precipitated from the sample as strontium oxalate. The sample is then converted and 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 or platinum disk, and counted with an alpha spectrometer.

Uranium analysis is conducted after the sample is pretreated. The sample is counted directly with an LEPD system.

SURFACE MONITORING: NONRADIOLOGICAL SAMPLES

Surface-Water Samples

Water samples collected to monitor Columbia River water quality are analyzed according to standard methods. Most onsite analyses make use of the most applicable methods recommended by the American Public Health Association in their publication *Standard Methods for the Examination of Water and Wastewater: Including Bottom Sediments and Sludges* (APHA 1985). Supplemental U.S. Geological Survey (USGS) samples are analyzed according to approved USGS standard methods.

GROUND-WATER MONITORING: RADIOLOGICAL SAMPLES

All ground-water monitoring samples are analyzed according to detailed, written analytical procedures that are briefly described below. Minimum detectable concentrations for the various medium/analysis combinations and other analytical information are shown in Table D.1.

Total Alpha-Emitting Radionuclides are measured after the samples are evaporated and the salts and solids are dissolved in nitric acid and extracted from the acid by the diethyl ether method. Each sample is then evaporated, dried on a counting dish, and measured by the ZnS scintillation counter. The chemical yield is about 83%.

Total Beta-Emitting Radionuclides are measured after each sample has been evaporated onto a 1-in. counting dish. The residue is then counted with a gas-flow proportional counter.

Gamma-Emitting Radionuclides are measured by analyzing 500-mL samples in polyethylene bottles. A sodium iodide or lithium-ion drifted germanium detector is used to count the samples. The standards are traceable to the National Institute of Standards and Technology (formerly the National Bureau of Standards).

Tritium samples are first distilled from a neutralized aliquot to which holdback carriers have been added. After the first fraction of distillate is discarded, 20 mL are collected in a single vial. Aliquots of distillate are counted with a liquid scintillation spectrometer. Duplicate counts are made to reduce the error of the measurements.

GROUND-WATER MONITORING: CHEMICAL SAMPLES

Samples collected to monitor the quality of the ground water are analyzed according to standard methods. The most applicable methods are recommended by the American Public Health Association in these publications: *Standard Methods for the Examination of Water and Wastewater: Including Bottom Sediments and Sludges* (APHA 1985); *[ASTM's (American Society for Testing and Materials)] Annual Book of ASTM Standards* (Sections 11.01 and 11.02) (ASTM 1987); *Manual on Water;* STP 442A; and *Test Methods for Evaluating Solid Waste: Physical/Chemical Methods* (EPA 1982).

Fluoride is measured by ion chromatography (see "Inorganic Anions") or by an electrode method to attain a lower detection level (50 ppb). A 50-mL aliquot of sample is mixed with ionic-strength buffer. The specific ion electrode is placed in the mixture while it is being gently stirred. The meter reading is compared to a previously developed calibration curve (50 to 25,000 ppb) to determine the sample concentration.

Temperature, pH, and Conductivity are determined in the field according to field instrument instructions.

Coliform Count is determined by multiple-tube fermentation.

Metals are measured by either the Inductively Coupled Plasma (ICP) method or the Graphite Furnace Atomic Absorption (GFAA) method. In either case, the sample is first acid-digested. In the ICP method, the digest is then nebulized, with the resultant aerosol being transported to the plasma torch where excitation occurs. The atomic emission is then measured by an optical spectroscopic technique. In the GFAA method, the digest is dried, ashed, and atomized in a graphite tube furnace. The constituent concentration is proportional to the absorption of hollow-cathode radiation during atomization.

Inorganic Anions (including nitrate) are determined by ion chromatography. After being injected into the ion chromatograph, the sample is pumped through three ion-exchange columns to convert the anions in the sample to their corresponding acids. The separated anions in their acid form are measured using an electrical-conductivity cell.

Volatile Organic Chemicals are determined by Gas Chromatography and Mass Spectrometry (GC/MS). Volatile organic chemicals are introduced to the mass spectrometer by the purge-and-trap method, in which the volatile components are converted from an aqueous phase to a vapor phase, trapped on a sorbent column, and then desorbed onto a gas chromatographic column. This column is heated to elute the components, which are then detected by the mass spectrometer.

Certain Organic Constituents are analyzed by direct aqueous injection, which requires no preparatory steps before the samples are injected into the gas chromatograph and detected by the mass spectrometer. Substances identified in samples by GC/MS techniques are verified by comparing the suspect mass spectra to the mass spectrum of a standard of the suspected substance. The computerized system used to search the mass-spectrometry library is capable of providing a forward comparison using the standard spectra contained in the EPA/National Institute of Health mass spectral data base.

Pesticides, Herbicides, and Polychlorinated Biphenyls are measured by gas chromatography with an appropriate detector. Extractions are performed as necessary. Positive concentrations are verified by reanalysis of the extract using a confirmation gas chomatography column or by GC/MS.

Total Organic Halogens are measured after the sample is passed through a column containing activated carbon. The column is washed to remove trapped inorganic halides, and the carbon is then analyzed to convert the adsorbed organohalides to a titratable species that can be measured by a microcoulometric detector.

Total Organic Carbon is determined by the combustion-infrared method. The sample is sparged with hydrochloric acid to remove inorganic carbon. The homogenized sample is vaporized with an oxidative catalyst, thereby converting the organic carbon to CO_2. The CO_2 is measured with a nondispersive infrared analyzer.

A summary of analytical methods used for chemical ground-water monitoring is shown in Table D.2.

TABLE D.1. Radiological Monitoring Sampling Summary

Medium Sampled	Type of Analysis	Scheduled Frequency of Collection	Approximate Sample Size	Count Time	Minimum Detectable Concentration (MDC)	Analysis Aliquot Size	Sampling Location
Air	Gross alpha	Biweekly	850 m^3	50 min	0.001 pCi/m^3	850 m^3	Off Site/ On Site
	Gross beta	Biweekly	850 m^3	40 min	0.003 pCi/m^3	850 m^3	Off Site/ On Site
	HTO[a]	Monthly	10 m^3	150 min	0.3 pCi/mL	5 mL	Off Site/ On Site
	^{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.	5100 m^3 per station	100 min	0.01 pCi/m^3	2000-10,000 m^3	Off Site/ On Site
	^{90}Sr	Quarterly comp.	5100 m^3 per station	100 min	0.001 pCi/m^3	2000-10,000 m^3	Off Site/ On Site
	^{129}I[d]	Quarterly comp.	850 m^3 per station	NA	0.00001 pCi/m^3	850 m^3	Off Site/ On Site
	^{131}I	Biweekly	850 m^3	100 min	0.01 pCi/m^3	850 m^3	Off Site/ On Site
	Gamma scan (^{137}Cs)	Monthly comp.	1700 m^3 per station	50 min	0.01 pCi/m^3	1700-7700 m^3	Off Site/ On Site
	^{238}Pu	Quarterly comp.	5100 m^3 per station	1000 min	0.000025 pCi/m^3	2000-10000 m^3	Off Site/ On Site
	$^{239,240}Pu$	Quarterly comp.	5100 m^3 per station	1000 min	0.000025 pCi/m^3	2000-10000 m^3	Off Site/ On Site
	U (isotopic)[e]	Quarterly comp.	5100 m^3 per station	1000 min	0.00005 pCi/m^3	2000-10000 m^3	Off Site/ On Site
Ground water	Gross alpha	Semiannually	1 L	100 min	4 pCi/L	100 mL	On Site
	Gross beta	Semiannually	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	1200 min	300 pCi/L	4 mL	On Site
	^{90}Sr	Q,SA[f]	1 L	30 min	0.6 pCi/L	500 mL	On Site
	^{129}I	Annually	4 L	NA	1 x 10^{-6} pCi/L	<1-<50 mL	On Site
	^{129}I	Annually	4 L	100 min	15 pCi/L	4000 mL	On Site
	^{129}I (DWS)	Annually	4 L	1000 min	1 pCi/L	1000 mL	On Site
	$^{239,240}Pu$	Semiannually	1 L	1000 min	0.10 pCi/L	1000 mL	On Site
	Uranium (natural)	M,Q[f]	1 L	100 min	0.5 pCi/L	0.5 mL	On Site
	^{99}Tc	Semiannually	1 L	150 min	15 pCi/L	1000 mL	On Site

TABLE D.1. Radiological Monitoring Sampling Summary (contd)

Medium Sampled	Type of Analysis	Scheduled Frequency of Collection	Approximate Sample Size	Count Time	Minimum Detectable Concentration (MDC)	Analysis Aliquot Size	Sampling Location
Ground water (contd)	^{63}Ni	Semiannually	1L	150 min	10 pCi/L	1000 mL	On Site
	^{14}C	P(0)	200 mL	150 min	20 pCi/L	200 mL	On Site
River water	Gross alpha	Weekly	1 L	50 min	4.0 pCi/L	1 L	Off Site
	Gross beta	Weekly	4 L	20 min	4.0 pCi/L	1 L	Off Site
	Gross alpha	Monthly comp.	40 L	50 min	4.0 pCi/L	500 mL	Off Site
	Gross beta	Monthly comp.	40 L	20 min	4.0 pCi/L	500 mL	Off Site
	^{3}H (enriched)	Monthly comp.	40 L	450 min	50 pCi/L	150 mL	Off Site
	^{89}Sr	Monthly comp.	40 L	100 min	0.6 pCi/L	10 L	Off Site
	^{90}Sr	Monthly comp.	40 L	100 min	0.06 pCi/L	4-10 L	Off Site
	Gamma scan (^{137}Cs)	Monthly comp.	40 L	50 min	8.0 pCi/L	4-10 L	Off Site
	Uranium (isotopic)	Monthly comp.	40 L	1000 min	0.06 pCi/L	100-1000 mL	Off Site
Resin	^{129}I	Quarterly comp.	6000 L water	NA	0.000001 pCi/L	1500-3000 L	Off Site/ On Site
Resin and particulate	Gamma scan (^{137}Cs)	Biweekly	1000 L water	1000 min	0.01 pCi/L	250-500 L	Off Site/ On Site
Resin	$^{239,240}Pu$	Quarterly comp.	6000 L water	24-72 h	0.0005 pCi/L	1500-3000 L	Off Site/ On Site
Particulate	$^{239,240}Pu$	Quarterly comp.	6000 L water	24-72 h	0.00005 pCi/L	1500-3000 L	Off Site/ On Site
Surface water	Gross alpha	Quarterly	10 L	50 min	4.0 pCi/L	500 mL	On Site
	Gross beta	Quarterly	10 L	20 min	4.0 pCi/L	500 mL	On Site
	^{3}H	Quarterly	10 L	150 min	300 pCi/L	5 mL	On Site
	^{89}Sr	Quarterly	10 L	100 min	0.6 pCi/L	4-10 L	On Site
	Gamma scan (^{137}Cs)	Quarterly	10 L	50 min	8.0 pCi/L	4-10 L	On Site
Milk	^{3}H	Monthly	10 L	150 min	300 pCi/L	5 L	Off Site
	^{90}Sr	Quarterly	10 L	100 min	2.0 pCi/L	1 L	Off Site
	^{131}I	Biweekly	10 L	100 min	0.5 pCi/L	4 L	Off Site
	^{131}I	Monthly	10 L	100 min	0.5 pCi/L	4 L	Off Site
	^{129}I	Semiannually	4 L	NA	0.00001 pCi/L	3-4 L	Off Site
	Gamma scan (^{137}Cs)	Biweekly	10 L	1000 min	10 pCi/L	450 mL	Off Site

TABLE D.1. Radiological Monitoring Sampling Summary (contd)

Medium Sampled	Type of Analysis	Scheduled Frequency of Collection	Approximate Sample Size	Count Time	Minimum Detectable Concentration (MDC)	Analysis Aliquot Size	Sampling Location
Milk (contd)	Gamma Scan (^{137}Cs)	Monthly	10 L	1000 min	10 pCi/L	450 mL	Off Site
Fruit	^{3}H	Annually	2 kg	150 min	300 pCi/L	5 mL (water)	Off Site
	^{90}Sr	Annually	2 kg	200 min	0.005 pCi/g	100 g	Off Site
	Gamma scan (^{137}Cs)	Annually	2 kg	1000 min	0.015 pCi/g	250-500 g	Off Site
	$^{239,240}Pu$	Annually	2 kg	1000 min	0.0006 pCi/g	100 g	Off Site
Produce and farm products	^{90}Sr	Annually	2 kg	200 min	0.005 pCi/g	100 g	Off Site
	Gamma scan (^{137}Cs)	Annually	2 kg	1000 min	0.015 pCi/g	250-500 g	Off Site
	$^{239,240}Pu$	Annually	2 kg	1000 min	0.0006 pCi/g	100 g	Off Site
Beef	^{90}Sr	Annually	1 kg	100 min	0.005 pCi/g	100 g	Off Site
	Gamma scan (^{137}Cs)	Annually	1 kg	1000 min	0.015 pCi/g	250-500 g	Off Site
Poultry	^{90}Sr	Semiannually	1 chicken (boneless muscle)	100 min	0.005 pCi/g	100 g	Off Site
	Gamma scan (^{137}Cs)	Semiannually	1 chicken (boneless muscle)	1000 min	0.015 pCi/g	250-500 g	Off Site
Eggs	^{90}Sr	Semiannually	1 doz.	100 min	0.005 pCi/g	100 g	Off Site
	Gamma scan (^{137}Cs)	Semiannually	1 doz.	1000 min	0.015 pCi/g	250-500 g	Off Site
Wine	^{3}H	Annually	1 L	150 min	300 pCi/L	5 mL	Off Site
	Gamma scan (^{137}Cs)	Annually	1 L	50 min	8.0 pCi/L	750 mL	Off Site
Fish fillet	^{90}Sr	20 per year	1 fish fillet	100 min	0.005 pCi/g	100 g	Off Site/ On Site
	Gamma scan (^{137}Cs)	20 per year	1 fish fillet	1000 min	0.015 pCi/g	250-500 g	Off Site/ On Site
Fish carcass	^{90}Sr	20 per year	1 fish carcass	100 min	0.005 pCi/g	100 g	Off Site/ On Site
	Gamma scan (^{137}Cs)	20 per year	1 fish carcass	1000 min	0.015 pCi/g	250-500 g	Off Site/ On Site
Ducks and gamebirds	^{90}Sr	20 per year	1 bird (bone)	100 min	0.005 pCi/g	100 g	On Site
	Gamma scan (^{137}Cs)	32 per year	1 bird (boneless muscle)	1000 min	0.015 pCi/g	250-500 g	On Site

TABLE D.1. Radiological Monitoring Sampling Summary (contd)

Medium Sampled	Type of Analysis	Scheduled Frequency of Collection	Approximate Sample Size	Count Time	Minimum Detectable Concentration (MDC)	Analysis Aliquot Size	Sampling Location
Game birds	Gamma scan (^{137}Cs)	22 per year	1 bird (muscle)	1000 min	0.015 pCi/g	250-500 g	On Site
Deer	Gamma Scan (^{137}Cs)	8 per year	1 kg (muscle)	1000 min	0.015 pCi/g	250-500 g	On Site
	^{90}Sr	8 per year	250 g (bone)	100 min	0.0006 pCi/g	100 g	
	$^{239,240}Pu$	8 per year	1 kg (liver)	1000 min	0.006 pCi/g	100 g	On Site
Rabbits	^{90}Sr	12 per year	250 g (bone)	100 min	0.005 pCi/g	100 g	On Site
	Gamma scan (^{137}Cs)	12 per year	500 g (muscle)	1000 min	0.015 pCi/g	250-500 g	On Site
	$^{239,240}Pu$	12 per year	1 liver	1000 min	0.0006 pCi/g	100 g	On Site
Soil and sediment	^{90}Sr	Annually	1.5 kg	100 min	0.005 pCi/g	100 g	Off Site/ On Site
	Gamma scan (^{137}Cs)	Annually	1.5 kg	100 min	0.02 pCi/g	500 g	Off Site/ On Site
	Uranium (LEPD)	Annually	1.5 kg	500 min	1.0 pCi/g	100 g	Off Site/ On Site
	$^{239,240}Pu$	Annually or quarterly	1.5 kg	1000 min	0.0006 pCi/g	1.0 g	Off Site/ On Site
Native vegetation	Gamma scan (^{137}Cs)	Annually	2 kg	1000 min	0.03 pCi/g	125 g	Off Site/ On Site
	^{90}Sr	Annually	2 kg	200 min	0.005 pCi/g	100 g	Off Site/ On Site
	Total U	Annually	2 kg	NA	0.01 pCi/g	10 g	Off Site/ On Site
	$^{239,240}Pu$	Annually	2 kg	1000 min	0.0006 pCi/g	100 g	Off Site/ On Site
Direct radiation exposure	Thermoluminescent dosimeter (TLD)	Monthly	5 TLDs per holder	NA	1.0 mR[g]	NA	Off Site/ On Site

(a) Tritiated water vapor.
(b) Five locations.
(c) Twelve locations.
(d) Four locations.
(e) Nine locations.
(f) M = monthly, Q = quarterly, SA = semiannually, A = annually, P = periodic.
(g) Absolute sensitivity in the manner it is used is well below one millirem.
NA Not applicable.

TABLE D.2. Analytical Methods for Chemicals in Ground Water

Constituent	Collection and Preservation[a,b]	Methods[c]	Detection Limit, ppb[d]
Barium			6
Cadmium			2
Chromium			10
Silver			10
Sodium			200
Nickel			10
Copper	P, HNO_3 to pH<2	EPA 1982 No. 6010	10
Vanadium			5
Aluminum			150
Manganese			5
Potassium			100
Iron			30
Calcium			50
Zinc			5
Beryllium			5
Strontium			20
Antimony			100
Arsenic	P, HNO_3 to pH<2	EPA 1982 No. 7060	5
Mercury	G, HNO_3 to pH<2	EPA 1982 No. 7470	0.1
Selenium	P, HNO_3 to pH<2	EPA 1982 No. 7740	5
Lead	P, HNO_3 to pH<2	EPA 1982 No. 7421	3
Nitrate			500, 2500[e]
Sulfate			500
Fluoride	P, None	70-IC[f,g]	500
Chloride			500
Phosphate			1000
Total Organic Halogen	G, H_2SO_4 to pH<2 No headspace	EPA 1982 No. 9020	20
Total Organic Carbon	G, H_3PO_4 to pH<2	APHA 1985 No. 505	1000
Total Carbon	G, None	APHA 1985 No. 505	1000
Ammonium ion	G, H_2SO_4 to pH<2	APHA 1985 No. 417, A-E	50
Cyanide	P, NaOH	EPA 1982 No. 9010	10
Fluoride (LDL)[h]	P, None	Specific Ion Electrode	20

TABLE D.2. Analytical Methods for Chemicals in Ground Water (contd)

Constituent	Collection and Preservation[a,b]	Methods[c]	Detection Limit, ppb[d]
Volatile Organic Analysis (see Table D.3 for detailed list)	G, No headspace	EPA 1982 No. 8240	
Gross Alpha	P, HNO_3 to pH<2	EPA 1975 No. 680	4 pCi/L
Gross Beta	P, HNO_3 to pH<2	EPA 1975 No. 680	8 pCi/L
Alkalinity	P, None	APHA 1985 No. 403	---
pH (Lab)	P, None	APHA 1975 No. 423	---
pH	Field measurement		0.01 pH unit[i]
Temperature	Field measurement		0.1°C[i]
Specific Conductance	Field measurement		1 µs
Hexachlorophene			10
Naphthalene			10
Phenol			10
Kerosene			10
Chlorinated Benzenes			10 ppm
1,2-dichlorobenzene			
1,3-dichlorobenzene			
1,4-dichlorobenzene	G, None	EPA 1982 No. 8270	
hexachlorobenzene			
pentachlorobenzene			
1,2,4,5-tetrachlorobenzene			
1,2,3,4-trichlorobenzene			
1,2,3-trichlorobenzene			
1,3,5-trichlorobenzene			
1,2,3,4-tetrachlorobenzene			
1,2,3,5-tetrachlorobenzene			

(a) G = glass, P = plastic.
(b) All samples cooled to 4°C on collection.
(c) Constituents grouped together are analyzed by the same method.
(d) Detection limit units except where indicated.
(e) Detection limit 2500 when five-fold dilution used.
(f) In-house analytical method from United States Testing Company, Inc. (UST) Procedure Manual based on *Test Method. The Determination of Inorganic Anions in Water by Ion Chromatography* (O'Dell et al. 1984).
(g) IC = ion chromatography.
(h) LDL = low detection level.
(i) Measurement resolution.

TABLE D.3. Volatile Organic Compounds and Detection Limits

Constituent	Detection Limit
Acetonitrile	<3 ppm
Ethylene Oxide	<3 ppm
Tetrachloromethane (carbontetrachloride)	<5 ppb
Benzene	<5 ppb
Chloroform	<5 ppb
Toluene	<5 ppb
1,1,1-Trichloroethane	<5 ppb
1,1,2-Trichloroethane	<5 ppb
1,1,2-Trichloroethene (Trichloroethylene)	<5 ppb
Perchloroethylene	<5 ppb
Xylene (O, P)	<5 ppb
Xylene (M)	<5 ppb
Acrolein	<10 ppb
Acrylonitrile	<10 ppb
Bis (Chloromethyl) Ether	<10 ppb
Bromo Acetone	<10 ppb
Chloromethylmethylether	<10 ppb
Crotonaldehyde	<10 ppb
1,2-Dibromo-3-Chloropropane	<10 ppb
1,2-Dibromoethane	<10 ppb
Dibromomethane	<10 ppb
1,4-Dichloro-2-Butene	<10 ppb
Dichlorodifluoromethane	<10 ppb
N,N-Diethylhydrazine	<10 ppb
Hydrogen Sulfide	<10 ppb
Iodo Methane	<10 ppb
Methacrylonitrile	<10 ppb
Methanethiol	<10 ppb
Chloromethane	<10 ppb
1,1-Dichloroethane	<10 ppb
1,2-Dichloroethane	<10 ppb
Methyl Bromide	<10 ppb
Carbon Disulfide	<10 ppb
Chlorobenzene	<10 ppb
2-Chloroethylvinylether	<10 ppb
Methylethyl Ketone	<10 ppb
Methyl Methacrylate	<10 ppb
Ethyl Methacrylate	<10 ppb
Pentachloroethane	<10 ppb
1,1,1,2-Tetrachloroethane	<10 ppb

TABLE D.3. Volatile Organic Compounds and Detection Limits (contd)

Constituent	Detection Limit
Trichloromethanethiol	<10 ppb
Trichlorofluoromethane	<10 ppb
Trichloropropane	<10 ppb
1,2,3-Trichloropropane	<10 ppb
Diethylarsine	<10 ppb
Trans-1,2-Dichloroethene	<10 ppb
1,1-Dichloroethene	<10 ppb
Methylene Chloride	<10 ppb
1,2-Dichloropropane	<10 ppb
1,3-Dichloropropenes	<10 ppb
1,1,2,2-Tetrachloroethane	<10 ppb
Bromoform	<10 ppb
Vinyl Chloride	<10 ppb
Hexone	<10 ppb
Dioxane	<500 ppb
Formaldehyde	<500 ppb
Pyridine	<500 ppb

APPENDIX E

DATA SUMMARIES

APPENDIX E

DATA SUMMARIES

Measuring any physical quantity (e.g., temperature, distance, time, or radioactivity) has some degree of inherent uncertainty. This uncertainty results from the combination of all possible inaccuracies in the measurement process, including such factors as the reading of the result, the calibration of the measurement device, and numerical rounding errors. In this report, individual radioactivity measurements are accompanied by a plus or minus (±) value, which is the uncertainty term known as a two-sigma counting error. Because measuring a radionuclide requires a process of counting random radioactive emissions from a sample, the two-sigma counting error gives information on what the measurement might be if the same sample were counted again under identical conditions. The two-sigma counting error implies that approximately 95% of the time, a recount of the same sample would give a value somewhere between the reported value minus the two-sigma counting error and the reported value plus the two-sigma counting error. Values in the tables that are less than the two-sigma counting error indicate that the reported result might have come from a sample with no radioactivity. Such values are considered as below detection. Also note that each radioactive measurement must have the random background radioactivity of the measuring instrument subtracted; therefore, negative results are possible, especially when the sample has very little radioactivity.

Just as individual values are accompanied by two-sigma counting errors, reported means ($\bar{x}$) are accompanied by two standard errors (SE) of the mean. If the data fluctuate randomly, then the SE is a measure of the uncertainty in the estimated mean of the data due to this randomness. If trends or periodic (e.g., seasonal) fluctuations are present, then the SE is primarily a measure of the variability in the trends and fluctuations about the mean of the data, rather than a measure of the uncertainty of the estimated mean due to random fluctuations in the data.

The mean, $\bar{x}$, was computed as:

$$\bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i$$

where x_i is the ith measurement and n is the number of measurements.

The standard error of $\bar{x}$ was computed as

$$SE = \sqrt{\frac{S^2}{n}}$$

where S^2, the variance of the n measurements, was computed as

$$S_M^2 = \frac{1}{n-1} \sum_{i=1}^{n} (x_i - \bar{x})^2$$

This estimator, S^2, includes the variance among the samples and the counting variance. The estimated S^2 may occassionally be less than the average counting variance.

APPENDIX F

DOSE CALCULATIONS

APPENDIX F

DOSE CALCULATIONS

The radiation dose that the public could have potentially received from 1989 Hanford operations is calculated in terms of the "dose equivalent" and "effective dose equivalent." These dose quantities are given in units of millirem (mrem) [millisievert (mSv)][a] for individuals and in units of person-rem (person-Sv) for the collective dose received by the total population within an 80-km radius of the Site. These quantities provide a way to express the radiation dose, regardless of the type or source of radiation or the means by which it is delivered. The values given in this report may be compared to standards for radiation protection (Table B.5, Appendix B). This appendix describes how the doses were calculated for this report.

The transport of radionuclides from the environment to the body is predicted by empirical models of exposure pathways. These pathways account for inhalation or ingestion of radionuclides present in air, water, and foods. Radionuclides taken into the body may be distributed among different organs and retained for various times. In addition, long-lived radionuclides deposited on the ground become possible sources for long-term external exposure and uptake by agricultural products.

Radionuclide release rates from Hanford Site activities are usually too low to be measured in offsite air, drinking water, and food crops. Therefore, in most cases, the dose calculations were based on measurements made at the point of release (stacks and effluent streams). Environmental concentrations were estimated from these effluent measurements by environmental transport models. Dietary and exposure parameters were then applied to calculate radionuclide intakes and radiation doses to the public. Standardized computer programs were used to perform the calculations. These programs contain internally consistent mathematical models that use site-specific dispersion and uptake parameters. These codes are incorporated in the master code titled GENII (Napier et al. 1988a,b,c), which employs the dosimetry methodology described in ICRP Reports (1979-1982). The assumptions and input data used in these calculations are described below.

TYPES OF DOSE CALCULATIONS PERFORMED

Revised DOE Guidance for Dose Calculations

Calculations of radiation doses to the public from radionuclides released into the environment are performed to demonstrate compliance with applicable standards and regulations.

Beginning in 1985, the DOE required that estimates of radiation exposure to the general public be in terms of the "effective dose equivalent." The effective dose equivalent is a measure of the total risk of potential health effects from radiation exposure. The adoption and use of the effective dose equivalent was previously recommended by the ICRP (1979-1982). As in the past, when concentrations of radionuclides in the environment are too low to measure, then

(a) 1 rem (0.01 Sv) = 1000 mrem (10 mSv).

doses are calculated from effluent data using environmental transport and dosimetry models.

Estimated radiation doses from DOE operations have previously been reported in terms of the dose equivalent (or simply, dose), which is a measure of the energy absorbed by tissue (rads), multiplied by a radiation quality factor, and modified by any other necessary factors. Under this system, standards for radiation protection were presented in terms of the critical organ dose limits and were expressed in rem (or mrem).

The effective dose equivalent is the sum of individual committed (50-year) organ doses multiplied by weighting factors that represent the proportion of the total health-effect risk that each organ would receive from uniform irradiation of the whole body. The committed organ dose may result from irradiation by either internal or external sources, and the two sources are to be summed.

In addition to implementing the effective dose equivalent requirement for offsite population dose calculations, the DOE has also adopted the revised biokinetic models and metabolic parameters for radionuclides given by the ICRP (1979-1982) for estimating radiation dose.

The calculation of the new effective dose equivalent takes into account the long-term internal exposure from radionuclides taken into the body during the current year. In this report, the effective dose equivalent is expressed in rem (or millirem), with the corresponding value in sievert (or millisievert) in parentheses.

The following types of radiation doses were estimated:

1. "Fence-Post" Whole-Body Dose Rate (mrem/h and mrem/yr). The maximum external radiation dose rate during the year in areas accessible by the general public was determined from measurements obtained in proximity to operating facilities.

2. "Maximally Exposed Individual" Dose (mrem). The maximally exposed individual is a hypothetical member of the public residing near the Hanford Site who, by virtue of location and living habits, could receive the highest possible radiation dose from radioactive effluents released from Hanford. All potentially significant short- and long-term exposure pathways to this hypothetical individual were considered, including the following:

- inhalation of airborne radionuclides
- submersion in airborne radionuclides
- ingestion of foodstuffs contaminated by radionuclides deposited on vegetation and the ground by both airborne deposition and irrigation water drawn from the Columbia River downstream of the 100-N Reactor site
- exposure to ground contaminated by both airborne deposition and irrigation water
- drinking of uncontaminated water from deep wells
- ingestion of fish taken from the Columbia River
- recreation along the Columbia River, including boating, swimming, and shoreline activities.

3. 80-km Population Doses (person-rem). Regulatory limits have not been established for population doses. However, evaluation of the collective population doses to all residents within an 80-km radius of Hanford Site operations provides an indication of the overall radiation exposure of the surrounding population. The 80-km population dose equivalent and effective dose equivalent represent the summed products of the individual doses for the number of individuals involved for all potential exposure pathways.

The pathways for the maximally exposed individual were assumed to also be applicable to the offsite population with the addition of drinking water drawn from the Columbia River. Consideration was given, however, to the fraction of the offsite population actually affected by each pathway. The river-related exposure pathways for the population are as follows:

- **Drinking Water.** The cities of Richland and Pasco obtain their municipal water from the Columbia River downstream from the Hanford Site. The city of Kennewick began drawing a portion of its municipal water from the river in late 1980. During 1989, approximately 40% of Kennewick's drinking water was drawn from the Columbia River. A total population of approximately 70,000 in the three cities drinks water derived from the Columbia River.

- **Irrigated Food.** Columbia River water is withdrawn for irrigation of small vegetable gardens and farms in the Riverview district of Pasco in Franklin County. Enough food is grown in this district to feed an estimated 2000 people.

- **River Recreation.** These activities include swimming (10 h/yr), boating (5 h/yr), and shoreline recreation (17 h/yr). An estimated 125,000 people reside adjacent to the river within 80 km of the Hanford Site and are assumed to be affected by these pathways.

- **Fish Consumption.** Population doses from the consumption of fish obtained locally from the Columbia River were calculated from an estimated total annual catch of 15,000 kg/yr (without reference to a specified human group of consumers).

DATA

The data that are needed to perform dose calculations based on measured effluent releases include information on initial transport through the atmosphere or river, transfer or accumulation in terrestrial and aquatic pathways, and public exposure. By comparison, calculations based on measured concentrations of radionuclides in food require data describing only 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 et al. 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 models are annual average dispersion factors ($\bar{X}/Q'$, in units of Ci/m^3 per Ci/s, or s/m^3) that, when combined with annual average release rates, will predict average radionuclide air concentrations for the year. Annual average dispersion factors around the 100, 200, 300, and 400 Areas during 1989 are given in Tables F.5 through F.8. Population exposure to airborne effluents was determined using values of population-weighted atmospheric dispersion factors for each compass sector and distance.

Terrestrial and Aquatic Pathways

Following their release and initial transport through the environment, radioactive materials may enter terrestrial or aquatic pathways that lead to public exposure. These potential pathways include consumption of fish, drinking water, and locally grown food. For example, radioactive material released to the river is diluted and may be withdrawn downstream for irrigation. Radionuclides deposited on plants and soil during irrigation can be taken into plants through their roots and leaves, and may then be eaten by people or farm animals. The numerous transfer factors used for pathway and dose calculations have been documented in GENII (Napier et al. 1988a, 1988b, 1988c).

Important parameters affecting the movement of radionuclides within potential exposure pathways, such as irrigation rates, growing periods, and holdup periods, are listed in Table F.9.

Certain parameters are specific to either "maximally exposed" or "average" individuals. Note that beginning in 1987, the food categories in Tables F.9 and F.10 were regrouped and combined into fewer categories than in previous years. This new arrangement reduced the number of calculations required without notably changing the calculated doses.

Public Exposure

The potential offsite radiation dose is related to the extent of external exposure to or intake of radionuclides that are released from Hanford Site operations. Tables F.10 through F.12 give the parameters describing the diet, residency, and river recreation assumed for "maximally exposed" and "average" individuals.

DOSE CALCULATION DOCUMENTATION

The Hanford Dose Overview Panel has the responsibility for defining standard, documented computer codes and input parameters to be used for radiation dose calculations for the public in the vicinity of the Hanford Site. Only those procedures, models, and parameters defined by the Hanford Dose Overview Panel were used to calculate the radiation doses. The calculations were then reviewed by the Dose Overview Panel. Summaries of dose calculation documentation for this report are given in Tables F.13 through F.17.

TABLE F.1. Distribution of Population in 80-km Radius of the 100-N Area by Population Grid Sector[a]

	Number of People					
Direction	0-16 km	16-32 km	32-48 km	48-64 km	64-80 km	Totals
N	36	953	420	1,492	7,583	10,484
NNE	5	285	561	18,531	1,350	20,732
NE	0	624	1,013	2,691	259	4,587
ENE	0	620	5,884	1,129	429	8,062
E	0	294	625	2,742	605	4,266
ESE	0	306	1,493	596	247	2,642
SE	0	54	2,113	28,922	5,001	36,090
SSE	0	0	35,127	50,292	3,354	88,773
S	0	127	4,592	2,041	176	6,936
SSW	0	258	1,676	12,603	625	15,162
SW	0	547	4,946	16,747	469	22,709
WSW	0	680	1,699	8,297	15,274	25,950
W	18	395	936	5,149	75,686	82,184
WNW	54	573	377	490	1,598	3,092
NW	74	277	425	515	683	1,974
NNW	64	277	438	1,030	4,696	6,505
Totals	251	6,270	62,325	153,267	118,035	340,148

(a) Based on 1980 census data.

TABLE F.2. Distribution of Population in 80-km Radius of the 200 Areas' Hanford Meteorological Tower by Population Grid Sector[a]

	Number of People					
Direction	0-16 km	16-32 km	32-48 km	48-64 km	64-80 km	Totals
N	0	174	1,124	772	1,957	4,027
NNE	0	92	656	5,547	14,822	21,117
NE	0	262	5,930	2,963	596	9,751
ENE	0	235	773	2,366	435	3,809
E	0	340	1,329	1,659	588	3,916
ESE	0	283	1,374	230	652	2,539
SE	0	6,757	48,661	50,519	3,474	109,411
SSE	0	1,997	13,161	2,717	5,218	23,093
S	0	1,532	1,489	195	1,799	5,015
SSW	0	905	5,283	652	129	6,969
SW	0	1,190	19,786	2,182	459	23,617
WSW	5	1,840	5,063	15,088	4,573	26,569
W	32	648	949	6,874	78,635	87,138
WNW	73	444	802	833	2,833	4,985
NW	0	555	398	493	1,454	2,900
NNW	0	246	456	864	4,521	6,087
Totals	110	17,500	107,234	93,954	122,145	340,943

(a) Based on 1980 census data.

TABLE F.3. Distribution of Population in 80-km Radius of the 300 Area by Population Grid Sector[a]

	Number of People					
Direction	0-16 km	16-32 km	32-48 km	48-64 km	64-80 km	Totals
N	289	241	989	5,655	5,317	12,491
NNE	307	475	841	1,950	2,269	5,842
NE	18	966	2,583	562	205	4,334
ENE	307	465	349	470	238	1,829
E	291	114	137	174	687	1,403
ESE	338	288	863	594	17,891	19,974
SE	2,549	26,150	2,922	877	1,235	33,733
SSE	7,161	30,357	1,114	1,117	1,113	40,862
S	15,561	6,651	96	17,223	5,127	44,658
SSW	11,124	4,034	99	1,209	2,038	18,504
SW	10,066	3,931	706	182	181	15,066
WSW	4,429	1,810	5,531	8,988	621	21,379
W	294	984	2,226	16,878	16,293	36,675
WNW	0	0	692	1,543	1,679	3,914
NW	0	0	74	923	785	1,782
NNW	0	0	8	875	1,212	2,095
Totals	52,734	76,466	19,230	59,220	56,891	264,541

(a) Based on 1980 census data.

TABLE F.4. Distribution of Population in 80-km Radius of the 400 Area by Population Grid Sector[a]

Direction	Number of People 0-16 km	16-32 km	32-48 km	48-64 km	64-80 km	Totals
N	0	78	859	811	16,267	18,015
NNE	20	343	5,728	2,945	1,021	10,057
NE	114	377	760	1,033	217	2,501
ENE	211	1,041	2,644	492	451	4,839
E	229	600	183	169	183	1,364
ESE	229	442	544	292	1,060	2,567
SE	344	25,267	13,654	2,105	952	42,322
SSE	10,829	40,933	5,688	719	2,364	60,533
S	11,760	9,385	1,525	5,611	15,691	43,972
SSW	1,446	4,550	583	185	1,927	8,691
SW	179	1,538	5,234	535	239	7,725
WSW	0	1,206	7,748	14,956	481	24,391
W	0	190	3,339	6,089	17,171	26,789
WNW	0	0	932	1,221	3,176	5,329
NW	0	0	295	903	705	1,903
NNW	0	0	264	1,302	1,182	2,748
Totals	25,361	85,950	49,980	39,368	63,087	263,746

(a) Based on 1980 census data.

TABLE F.5. Annual Average Atmospheric Dispersion ($\overline{X}/Q'$) Around the 100-N Area During 1989 for an 89-Meter Release Height[a]

	$\overline{X}/Q'$ (s/m³)									
Direction	0.8 km	2.4 km	4.0 km	5.6 km	7.2 km	12 km	24 km	40 km	56 km	72 km
N	7.32E-08	4.19E-08	2.94E-08	2.17E-08	1.69E-08	9.74E-09	4.43E-09	2.46E-09	1.66E-09	1.24E-09
NNE	4.50E-08	2.54E-08	1.87E-08	1.42E-08	1.12E-08	6.63E-09	3.05E-09	1.68E-09	1.13E-09	8.39E-10
NE	5.58E-08	3.56E-08	2.51E-08	1.85E-08	1.43E-08	8.14E-09	3.64E-09	1.99E-09	1.33E-09	9.84E-10
ENE	7.52E-08	5.13E-08	3.79E-08	2.85E-08	2.24E-08	1.31E-08	5.98E-09	3.32E-09	2.24E-09	1.67E-09
E	1.02E-07	7.55E-08	5.72E-08	4.38E-08	3.48E-08	2.08E-08	9.86E-09	5.61E-09	3.86E-09	2.91E-09
ESE	6.94E-08	5.21E-08	3.96E-08	3.04E-08	2.42E-08	1.45E-08	6.82E-09	3.85E-09	2.63E-09	1.98E-09
SE	3.61E-08	3.86E-08	3.09E-08	2.38E-08	1.89E-08	1.12E-08	5.16E-09	2.87E-09	1.94E-09	1.45E-09
SSE	3.27E-08	3.73E-08	2.90E-08	2.22E-08	1.75E-08	1.02E-08	4.67E-09	2.57E-09	1.73E-09	1.29E-09
S	7.23E-08	5.42E-08	3.97E-08	2.95E-08	2.30E-08	1.31E-08	5.85E-09	3.18E-09	2.12E-09	1.57E-09
SSW	5.86E-08	4.44E-08	3.28E-08	2.45E-08	1.91E-08	1.10E-08	4.93E-09	2.68E-09	1.79E-09	1.32E-09
SW	4.36E-08	3.50E-08	2.60E-08	1.94E-08	1.52E-08	8.74E-09	3.91E-09	2.13E-09	1.42E-09	1.05E-09
WSW	5.09E-08	3.48E-08	2.53E-08	1.90E-08	1.50E-08	8.90E-09	4.18E-09	2.36E-09	1.61E-09	1.21E-09
W	7.85E-08	5.72E-08	4.50E-08	3.50E-08	2.81E-08	1.70E-08	8.10E-09	4.57E-09	3.12E-09	2.34E-09
WNW	6.16E-08	4.81E-08	3.79E-08	2.90E-08	2.30E-08	1.35E-08	6.14E-09	3.35E-09	2.24E-09	1.66E-09
NW	8.67E-08	5.40E-08	4.01E-08	3.01E-08	2.37E-08	1.37E-08	6.18E-09	3.37E-09	2.25E-09	1.66E-09
NNW	6.54E-08	3.79E-08	2.87E-08	2.19E-08	1.73E-08	1.02E-08	4.67E-09	2.56E-09	1.72E-09	1.27E-09

(a) Calculated from meteorological data collected at the 100-N Area and the Hanford Meteorology Tower.

TABLE F.6. Annual Average Atmospheric Dispersion ($\overline{X}/Q'$) Around the 200 Areas During 1989 for an 89-Meter Release Height[a]

	$\overline{X}/Q'$ (s/m³)									
Direction	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	2.91E-08	3.44E-08	2.85E-08	2.25E-08	1.82E-08	1.10E-08	5.23E-09	2.95E-09	2.01E-09	1.50E-09
NNE	3.55E-08	3.03E-08	2.15E-08	1.59E-08	1.24E-08	7.15E-09	3.28E-09	1.83E-09	1.24E-09	9.24E-10
NE	4.44E-08	3.38E-08	2.56E-08	1.96E-08	1.56E-08	9.29E-09	4.34E-09	2.42E-09	1.64E-09	1.22E-09
ENE	4.68E-08	3.71E-08	2.73E-08	2.07E-08	1.64E-08	9.81E-09	4.67E-09	2.67E-09	1.84E-09	1.39E-09
E	4.90E-08	4.80E-08	3.83E-08	3.00E-08	2.42E-08	1.47E-08	7.08E-09	4.03E-09	2.76E-09	2.08E-09
ESE	6.93E-08	4.65E-08	3.70E-08	2.92E-08	2.37E-08	1.46E-08	7.01E-09	3.97E-09	2.71E-09	2.03E-09
SE	1.13E-07	7.30E-08	5.46E-08	4.13E-08	3.26E-08	1.91E-08	8.70E-09	4.78E-09	3.21E-09	2.38E-09
SSE	1.02E-07	6.42E-08	4.58E-08	3.39E-08	2.63E-08	1.51E-08	6.69E-09	3.62E-09	2.40E-09	1.77E-09
S	1.07E-07	8.33E-08	6.14E-08	4.51E-08	3.46E-08	1.91E-08	7.97E-09	4.11E-09	2.65E-09	1.91E-09
SSW	9.20E-08	6.16E-08	4.27E-08	3.08E-08	2.34E-08	1.28E-08	5.43E-09	2.85E-09	1.86E-09	1.35E-09
SW	8.45E-08	5.30E-08	3.63E-08	2.59E-08	1.95E-08	1.05E-08	4.32E-09	2.23E-09	1.44E-09	1.04E-09
WSW	6.40E-08	3.98E-08	2.85E-08	2.08E-08	1.59E-08	8.71E-09	3.65E-09	1.90E-09	1.23E-09	8.94E-10
W	9.77E-08	6.46E-08	4.72E-08	3.47E-08	2.67E-08	1.49E-08	6.34E-09	3.33E-09	2.18E-09	1.58E-09
WNW	5.92E-08	3.99E-08	2.80E-08	2.04E-08	1.58E-08	8.92E-09	3.95E-09	2.13E-09	1.42E-09	1.05E-09
NW	6.81E-08	4.75E-08	3.38E-08	2.48E-08	1.92E-08	1.09E-08	4.82E-09	2.62E-09	1.75E-09	1.29E-09
NNW	3.25E-08	3.11E-08	2.41E-08	1.85E-08	1.48E-08	8.79E-09	4.12E-09	2.32E-09	1.58E-09	1.18E-09

(a) Calculated from meteorological data collected at the Hanford Meteorology Tower.

TABLE F.7. Annual Average Atmospheric Dispersion ($\overline{X}/Q'$) Around the 300 Area During 1989 for a 10-Meter Release Height[a]

	$\overline{X}/Q'$ (s/m³)									
Direction	0.8 km	2.4 km	4.0 km	5.6 km	7.2 km	12 km	24 km	40 km	56 km	72 km
N	4.81E-06	9.92E-07	4.71E-07	2.91E-07	2.04E-07	9.97E-08	3.87E-08	1.95E-08	1.25E-08	8.95E-09
NNE	2.88E-06	5.72E-07	2.69E-07	1.65E-07	1.16E-07	5.63E-08	2.17E-08	1.09E-08	6.95E-09	4.98E-09
NE	2.97E-06	5.89E-07	2.77E-07	1.70E-07	1.19E-07	5.79E-08	2.23E-08	1.12E-08	7.14E-09	5.12E-09
ENE	2.17E-06	4.10E-07	1.91E-07	1.17E-07	8.12E-08	3.94E-08	1.51E-08	7.53E-09	4.80E-09	3.43E-09
E	2.62E-06	5.36E-07	2.54E-07	1.57E-07	1.10E-07	5.37E-08	2.08E-08	1.04E-08	6.69E-09	4.80E-09
ESE	1.93E-06	3.91E-07	1.85E-07	1.14E-07	7.99E-08	3.91E-08	1.51E-08	7.59E-09	4.85E-09	3.48E-09
SE	2.58E-06	5.46E-07	2.61E-07	1.61E-07	1.13E-07	5.55E-08	2.17E-08	1.10E-08	7.04E-09	5.06E-09
SSE	3.71E-06	7.94E-07	3.81E-07	2.36E-07	1.66E-07	8.19E-08	3.21E-08	1.63E-08	1.05E-08	7.53E-09
S	4.58E-06	9.79E-07	4.68E-07	2.90E-07	2.04E-07	1.00E-07	3.92E-08	1.98E-08	1.27E-08	9.17E-09
SSW	2.01E-06	3.94E-07	1.85E-07	1.13E-07	7.89E-08	3.83E-08	1.47E-08	7.31E-09	4.66E-09	3.33E-09
SW	1.13E-06	2.05E-07	9.44E-08	5.71E-08	3.94E-08	1.88E-08	7.02E-09	3.45E-09	2.18E-09	1.55E-09
WSW	8.81E-07	1.58E-07	7.22E-08	4.36E-08	3.01E-08	1.43E-08	5.33E-09	2.62E-09	1.65E-09	1.17E-09
W	2.23E-06	4.26E-07	1.98E-07	1.21E-07	8.37E-08	4.02E-08	1.52E-08	7.51E-09	4.75E-09	3.38E-09
WNW	3.26E-06	6.69E-07	3.17E-07	1.96E-07	1.37E-07	6.70E-08	2.59E-08	1.30E-08	8.32E-09	5.97E-09
NW	4.73E-06	1.00E-06	4.80E-07	2.97E-07	2.09E-07	1.03E-07	4.00E-08	2.02E-08	1.30E-08	9.31E-09
NNW	3.80E-06	8.06E-07	3.86E-07	2.39E-07	1.68E-07	8.28E-08	3.24E-08	1.64E-08	1.05E-08	7.56E-09

(a) Calculated from meteorological data collected at the 300 Area and the Hanford Meteorology Tower.

TABLE F.8. Annual Average Atmospheric Dispersion ($\overline{X}/Q'$) Around the 400 Area During 1989 for a 10-Meter Release Height[a]

	$\overline{X}/Q'$ (s/m³)									
Direction	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	5.12E-06	1.03E-06	4.85E-07	2.98E-07	2.08E-07	1.01E-07	3.91E-08	1.96E-08	1.25E-08	8.95E-09
NNE	3.91E-06	7.74E-07	3.64E-07	2.24E-07	1.56E-07	7.60E-08	2.92E-08	1.46E-08	9.35E-09	6.70E-09
NE	3.02E-06	6.10E-07	2.88E-07	1.77E-07	1.24E-07	6.05E-08	2.34E-08	1.17E-08	7.50E-09	5.38E-09
ENE	2.23E-06	4.49E-07	2.13E-07	1.31E-07	9.17E-08	4.50E-08	1.74E-08	8.79E-09	5.63E-09	4.04E-09
E	2.55E-06	5.08E-07	2.39E-07	1.47E-07	1.03E-07	5.02E-08	1.94E-08	9.73E-09	6.23E-09	4.47E-09
ESE	2.60E-06	5.33E-07	2.53E-07	1.56E-07	1.09E-07	5.34E-08	2.07E-08	1.04E-08	6.65E-09	4.77E-09
SE	3.53E-06	7.28E-07	3.46E-07	2.13E-07	1.50E-07	7.33E-08	2.85E-08	1.44E-08	9.21E-09	6.61E-09
SSE	2.86E-06	5.75E-07	2.72E-07	1.68E-07	1.17E-07	5.76E-08	2.24E-08	1.13E-08	7.23E-09	5.20E-09
S	3.13E-06	6.55E-07	3.12E-07	1.93E-07	1.35E-07	6.62E-08	2.57E-08	1.29E-08	8.27E-09	5.94E-09
SSW	2.55E-06	5.21E-07	2.46E-07	1.52E-07	1.06E-07	5.17E-08	2.00E-08	1.00E-08	6.41E-09	4.60E-09
SW	1.43E-06	2.79E-07	1.30E-07	7.96E-08	5.54E-08	2.68E-08	1.02E-08	5.12E-09	3.26E-09	2.33E-09
WSW	1.21E-06	2.30E-07	1.07E-07	6.49E-08	4.50E-08	2.16E-08	8.17E-09	4.04E-09	2.56E-09	1.82E-09
W	1.56E-06	3.02E-07	1.42E-07	8.69E-08	6.05E-08	2.94E-08	1.13E-08	5.62E-09	3.58E-09	2.56E-09
WNW	1.47E-06	2.87E-07	1.35E-07	8.23E-08	5.73E-08	2.77E-08	1.06E-08	5.25E-09	3.33E-09	2.38E-09
NW	2.06E-06	4.10E-07	1.93E-07	1.18E-07	8.27E-08	4.03E-08	1.55E-08	7.75E-09	4.95E-09	3.54E-09
NNW	3.38E-06	6.97E-07	3.31E-07	2.04E-07	1.43E-07	7.02E-08	2.72E-08	1.37E-08	8.77E-09	6.29E-09

(a) Calculated from meteorological data collected at the 400 Area and the Hanford Meteorology Tower.

TABLE F.9. Food Pathway Parameters Used in 1989 Dose Calculations

	Holdup, days (except as noted)[a]		Growing Period, days	Yield, kg/m²	Irrigation Rate, L/m²/month
	Maximally Exposed Individual	Average Individual			
Leafy vegetables	1	14	90	1.5	150
Other vegetables	5	14	90	4	170
Fruit	5	14	90	2	150
Cereal	180	180	90	0.8	0
Eggs	1	18	90	0.8	0
Milk	1	4			
Hay	(100)[b]	(100)	45	2	200
Pasture	(0)	(0)	30	1.5	200
Red Meat	15	34			
Hay	(100)	(100)	45	2	200
Grain	(100)	(180)	90	0.8	0
Poultry	1	34	90	0.8	0
Fish	24 h	24 h	---	---	---
Drinking water	24 h	24 h	---	---	---

(a) Holdup is the time between harvest and consumption.
(b) Values in ( ) are the holdup in days between harvest and consumption by farm animals.

TABLE F.10. Dietary Parameters Used in 1989 Dose Calculations

	Consumption, kg/yr	
	Maximally Exposed Individual	Average Individual
Leafy vegetables	30	15
Other vegetables	220	140
Fruit	330	64
Grain	80	72
Eggs	30	20
Milk[a]	270	230
Red Meat	80	70
Poultry	18	8.5
Fish	40	---[b]
Drinking water[a]	730	440

(a) Units L/yr.
(b) Average individual consumption not identified; radiation doses were calculated based on estimated total annual catch of 15,000 kg.

TABLE F.11. Residency Parameters Used in the 1989 Dose Calculations

Parameter	Exposure, h/yr: Maximally Exposed Individual	Exposure, h/yr: Average Individual
Ground contamination	4,383	2,920
Air submersion	8,766	8,766
Inhalation[a]	8,766	8,766

(a) Inhalation rates: Adult 270 cm^3/s.

TABLE F.12. Recreational Parameters Used in the 1989 Dose Calculations

Parameter	Exposure, h/yr[a]: Maximally Exposed Individual	Exposure, h/yr[a]: Average Individual
Shoreline	500	17
Boating	100	5
Swimming	100	10

(a) Assumed river water travel times from 100-N to the point of aquatic recreation were 8 h for the maximally exposed individual and 13 h for the average individual. Correspondingly lesser times were used for other locations.

TABLE F.13. Documentation of 100-N Area Airborne Release Dose Calculation for 1989

Facility name:	100-N Area
Releases:	See Table G.1
Meteorological conditions:	1989 annual average, calculated from data collected at the 100-N Area and the Hanford Meteorology Station from January 1989 through December 1989, using the computer code HANCHI (see Table F.5)
$\bar{X}/Q'$:	Maximally exposed individual, 4.0×10^{-9} s/m^3 at 30 km SE; 80-km population, 7.1×10^{-4} person-s/m^3
Release height:	89-m effective stack height
Population distribution:	340,000 (see Table F.1)
Computer code:	GENII, Version 1.436, 1-29-90
Doses calculated:	Chronic, 1-year exposure, 50-year committed internal dose equivalent, and annual effective dose equivalent to individual and population
Pathways considered:	External exposure to plume and ground deposits Inhalation Ingestion of locally produced foods
Files addressed:	Radionuclide Library, Rev. 8-29-88 Food Transfer Library, Rev. 8-29-88 External Dose Factor Library, Rev. 5-9-88 Internal Dose Factor Library, Rev. 8-29-88

TABLE F.14. Documentation of 100-N Area Liquid Release Dose Calculation for 1989

Facility name:	100-N Area
Releases:	See Table G.5
Mean river flow:	99,410 cfs (2815 m^3/s)
Shore-width factor:	0.2
Population distribution:	70,000 for drinking water pathway 125,000 for aquatic recreation 2000 for consumption of irrigated foodstuffs 15,000 kg/yr total harvest of Columbia River fish
Computer code:	GENII, Version 1.436, 1-29-90
Doses calculated:	Chronic, 1-year exposure, 50-year committed internal dose equivalent, and annual effective dose equivalent to individual and population
Pathway considered:	External exposure to irrigated soil, to river water, and to shoreline sediments Ingestion of aquatic foods and irrigated farm products
Files addressed:	Radionuclide Library, Rev. 8-29-88 Food Transfer Library, Rev. 8-29-88 External Dose Factor Library, Rev. 5-9-88 Internal Dose Factor Library, Rev. 8-29-88 Bioaccumulation Factor Library, Rev. 3-7-90

TABLE F.15. Documentation of 200 Areas Airborne Release Dose Calculation for 1989

Facility name:	200 Areas
Releases:	See Table G.1
Meteorological conditions:	1989 annual average, calculated from data collected at the Hanford Meteorology Station from January 1989 through December 1989, using the computer code HANCHI (see Table F.6)
$\bar{X}/Q'$:	Maximally exposed individual, 6.5×10^{-9} s/m^3 at 26 km ESE; 80-km population, 9.3×10^{-4} person-s/m^3
Release height:	89-m effective stack height
Population distribution:	341,000 (see Table F.2)
Computer code:	GENII, Version 1.436, 1-29-90
Doses calculated:	Chronic, 1-year exposure, 50-year committed internal dose equivalent, and annual effective (whole-body) dose equivalent to individual and population
Pathways considered:	External exposure to plume and ground deposits Inhalation Ingestion of locally produced foods
Files addressed:	Radionuclide Library, Rev. 8-29-88 Food Transfer Library, Rev. 8-29-88 External Dose Factor Library, Rev. 5-9-88 Internal Dose Factor Library, Rev. 8-29-88

TABLE F.16. Documentation of 300 Area Airborne Release Dose Calculation for 1989

Facility name:	300 Area
Releases:	See Table G.1
Meteorological conditions:	1989 annual average, calculated from data collected at the 300 Area and the Hanford Meteorology Station from January 1989 through December 1989, using the computer code HANCHI (see Table F.7)
$\bar{\chi}/Q'$:	Maximally exposed individual, 9.0×10^{-8} m^3/s at 13 km N; 80-km population, 7.6×10^{-3} person-s/m^3
Release height:	10 m
Population distribution:	265,000 (see Table F.3)
Computer code:	GENII, Version 1.436, 1-29-90
Doses calculated:	Chronic, 1-year exposure, 50-year committed internal dose equivalent, and annual effective (whole-body) dose equivalent to individual and population
Pathways considered:	External exposure to plume and ground deposits Inhalation Ingestion of locally produced foods
Files addressed:	Radionuclide Library, Rev. 8-29-88 Food Transfer Library, Rev. 8-29-88 External Dose Factor Library, Rev. 5-9-88 Internal Dose Factor Library, Rev. 8-29-88

TABLE F.17. Documentation of 400 Area Airborne Release Dose Calculation for 1989

Facility name:	400 Area
Releases:	See Table G.1
Meteorological conditions:	1989 annual average, calculated from data collected at the 400 Area and the Hanford Meteorology Station from January 1989 through December 1989, using the computer code HANCHI (see Table F.8)
$\bar{X}/Q'$:	Maximally exposed individual, 6.9×10^{-8} s/m^3 at 11 km NE; 80-km population, 4.7×10^{-3} person-s/m^3
Release height:	10 m
Population distribution:	264,000 (see Table F.4)
Computer code:	GENII, Version 1.436, 1-29-90
Doses calculated:	Chronic, 1-year exposure, 50-year committed internal dose equivalent, and annual effective (whole-body) dose equivalent to individual and population
Pathways considered:	External exposure to plume and ground deposits Inhalation Ingestion of locally produced foods
Files addressed:	Radionuclide Library, Rev. 8-29-88 Food Transfer Library, Rev. 8-29-88 External Dose Factor Library, Rev. 5-9-88 Internal Dose Factor Library, Rev. 8-29-88

APPENDIX G

EFFLUENTS AND WASTE DISPOSAL

APPENDIX G

EFFLUENTS AND WASTE DISPOSAL

The operating contractors at Hanford have the responsibility to control, monitor, sample, and report effluents released into the environment from their facilities. This section briefly summarizes the planned and unplanned releases of effluents that occurred at Hanford during 1989 as reported by the contractors.

EFFLUENTS AND WASTE DISPOSAL

Radioactive and nonradioactive materials were released to the environment during operations at Hanford in 1989. These releases consisted of airborne effluents (gases or particles), liquid effluents, and solid wastes. Both anticipated and unanticipated releases occurred. The formal reporting of effluent release data was the responsibility of the operating contractors. Radioactive discharges to the environment were reported to DOE. Nonradioactive discharges to the Columbia River were reported to EPA through monthly National Pollutant Discharge Elimination System (NPDES) Discharge Monitoring Reports.

Airborne Releases

Radioactive and nonradioactive effluents discharged to the atmosphere during 1989 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, the Plutonium Uranium Extraction (PUREX) Plant, and organic liquids evaporated from scientific laboratories.

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 1989 are summarized in Tables G.3 and G.4.

Radioactive liquids discharged into the Columbia River from operating facilities during 1989 are listed in Table G.5. The reported discharges are from liquid effluent systems in the 100 Areas, and include seepage into the river from the 1301-N and 1325-N Liquid Waste Disposal Facilities. The ^{3}H, ^{99}Tc, and ^{129}I that may have entered the Columbia River through springs from the unconfined aquifer and the small quantities of other radionuclides that may have reached the Columbia River from ground disposal in the 300 Area (Table G.3) are not included in the releases listed in Table G.5. However, the quantities of these radionuclides entering the river have been estimated, and the

estimates have been included in the calculation of potential radiation doses to the public (see Section 4.8). Nonradioactive liquids released to the Columbia River were monitored according to the individual requirements of each NPDES-permitted discharge point.

Solid-Waste Burial

Solid radioactive wastes were buried in trenches or special retrievable storage facilities within the 200 Areas. Radioactive materials in solid wastes included fission and activation products, uranium, and transuranics. Solid wastes containing ^{238}U or transuranic radionuclides were packaged and buried separately from other wastes for planned retrieval at a future date. Table G.6 lists the quantities of radionuclides buried during 1989 as low-level waste.

Nonradioactive solid wastes were buried in sanitary landfills near the 200 Areas. The quantities of nonradioactive solid wastes buried during 1989 are also included in Table G.6.

TABLE G.1. Radionuclides in Gaseous Effluents Discharged to the Atmosphere in 1989

Radionuclide[b]	Half-Life	Release, Ci[a]			
		100 Areas	200 Areas	300 Area	400 Area
^{3}H	12.3 yr		180.	(c)	1.2
^{14}C	5730 yr		0.22		
^{41}Ar	1.8 h				22.
^{54}Mn	312 d	0.008			
^{60}Co	5.3 yr	0.88		$<2.3 \times 10^{-7}$	
^{90}Sr	28.8 yr	2.3×10^{-5}	0.0046[d]	0.00089[e]	
^{103}Ru	39.4 d		0.00021		
^{106}Ru	367 d		0.022		
^{113}Sn	115 d		0.00052		
^{125}Sb	2.7 yr		0.00097		
^{129}I	1.6×10^{7} yr		0.11		
^{131}I	8.0 d		(<) 0.017	1.5×10^{-4}	$<9.4 \times 10^{-6}$
^{134}Cs	2.1 yr	0.31			
^{137}Cs	30.0 yr	0.55	0.0013		$<9.7 \times 10^{-6}$
^{147}Pm	2.62 yr		0.00017		
^{155}Eu	4.96 yr	1.9×10^{-4}			
^{208}Tl	3.1 min		0.026		
^{212}Pb	10.6 h		0.13		
^{212}Bi	60.6 min		0.077		
^{212}Po	3×10^{-7} s		0.051		
^{216}Po	0.15 s		1.2		
^{220}Rn	55.6 s		1600.		
^{234}U	2.4×10^{5} yr		1.1×10^{-5}		
^{235}U	7.0×10^{8} yr		3.8×10^{-7}		
^{236}U	2.3×10^{7} yr		8.7×10^{-7}		
^{238}U	4.5×10^{9} yr		6.3×10^{-6}	$<6.4 \times 10^{-8}$	
^{238}Pu	87.7 yr	1.8×10^{-7}	8.2×10^{-6}		
$^{239,240}Pu$	2.4×10^{4} yr	5.7×10^{-7}	0.00082[f]	$<6.6 \times 10^{-6}$[g]	
^{241}Pu	14.4 yr		0.0019		
^{241}Am	433 yr		7.4×10^{-5}		

(a) Except as noted in this table, all effluent releases are as reported by operating contractors via the DOE's Effluent Information System.
(b) The activity values are for the listed radionuclides only. For those radionuclides whose radioactive daughters are not listed, the daughter activity is added during the dose calculations.
(c) Blank entry indicates no value reported by the operating contractor.
(d) Includes 4.6×10^{-3} Ci reported as gross beta, assumed to be ^{90}Sr for dose calculations.
(e) Includes 8.9×10^{-4} Ci reported as gross beta products, assumed to be ^{90}Sr for dose calculations.
(f) Includes 4.8×10^{-4} Ci reported as gross alpha, assumed to be ^{239}Pu for dose calculations.
(g) Includes 6.3×10^{-6} Ci reported as gross alpha, assumed to be ^{239}Pu for dose calculations.

TABLE G.2. Nonradioactive Constituents in Gaseous Effluents Discharged to the Atmosphere in 1989

Constituent	Release, kg[a]			
	100 Areas	200 Areas	300 Area	1100 Area
Particulates	16,000	149,000	11,000	510
Nitrogen oxides	47,000	412,000	130,000	2,700
Sulfur oxides	220,000	718,000	230,000	1,700
Carbon monoxide	4,000	53,900	17,000	100
Hydrocarbons	800	27,000	8,600	7
Ammonia	---[b]	6,840	---	---

(a) Values are those reported by operating contractors.
(b) --- indicates no value reported by the operating contractor.

TABLE G.3. Radionuclides in Liquid Effluents Discharged to Ground Disposal Facilities in 1989

Radionuclide	Half-Life	Release, Ci[a]			
		100 Areas	200 Areas	300 Area	400 Area
^{3}H	12.3 yr	74	390	(b)	
^{54}Mn	312 d	5.0			
^{60}Co	5.3 yr	33			
^{90}Sr	28.8 yr	28	0.3		
^{99}Tc	2.1×10^{5}		0.11		
^{106}Ru	367 d		2.1		
^{113}Sn	115 d		0.022		
^{125}Sb	2.7 yr	1.0			
^{129}I	1.6×10^{7} yr	ND			
^{134}Cs	2.1 yr	0.52			
^{137}Cs	30.2 yr	23	0.86		
^{144}Ce	284 d	1.8			
^{147}Pm	2.62 yr		0.60		
Unidentified beta			2.0[c]	<0.096	<0.00064
Unidentified alpha			0.28[d]		
^{234}U	2.4×10^{5} yr		0.043	0.0025	
^{235}U	7.0×10^{8} yr		0.0015	0.0001	
^{236}U	2.3×10^{7} yr		0.0035		
^{238}U	4.5×10^{9} yr		0.025	0.0019	
^{238}Pu	87.7 yr	0.0046	0.0093		
$^{239,240}Pu$	2.4×10^{4}	0.023	0.31		
^{241}Pu	14.4 yr		0.062		
^{241}Am	433 yr		0.54		

(a) Values are those reported by operating contractors.
(b) Blank entry indicates no value reported by the operating contractor.
(c) Assumed to be ^{90}Sr for dose calculations.
(d) Assumed to be ^{239}Pu for dose calculations.

TABLE G.4. Nonradioactive Constituents in Liquids Discharged to Ground Disposal Facilities in 1989

Constituent	Release, kg[a]			
	100 Areas	200 Areas	300 Area	400 Area
Ammonia	(b)	4,990		
Total organic carbon		5,990	4,600	45
Nitrates		16,100	3,000	
Copper			20	
Aluminum sulfate	180,000		4,900	
Ammonium hydroxide		1,090		
Hydrazine	25			
Polyacrylamide	250		36	
Sodium sulphate	450,000			
Lead			<11	
Silver			<9	
Volume (m^3)	1,300,000	1,700,000	1,900,000	16,000

(a) Values are those reported by operating contractors.
(b) Blank entry indicates no value reported by the operating contractor.

TABLE G.5. Radionuclides in Liquid Effluents Discharged to the Columbia River in 1989 from the 100 Areas

Radionuclide	Half-Life	Release, Ci[a]
^{3}H	12.3 yr	74
^{60}Co	5.3 yr	0.078
^{90}Sr	28.8 yr	1.7
^{137}Cs	30.2 yr	0.073
$^{239,240}Pu$	2.4×10^{4} yr	8.4×10^{-5}

(a) Values are those reported by contractors.

TABLE G.6. Composition of Solid Wastes Buried on the Site During 1989

Constituent	Quantities[a]
Radioactive (low level)	
Uranium	2.2×10^6 g
Plutonium	1.4×10^2 g
Americium	0.0 g
Thorium	2.7×10^3 g
Strontium	2.4×10^3 Ci
Ruthenium	3.3 Ci
Cesium	1.8×10^5 Ci
Other fission and activation products	1.9×10^5 Ci
Nonradioactive	
Nonhazardous trash, refuse	4.4×10^4 m^3
Asbestos	3.0×10^3 m^3
Septic sludge	1.0×10^3 m^3

(a) Values are those reported by the operating contractors.

APPENDIX REFERENCES

American Public Health Association (APHA). 1975. **Standard Methods for the Examination of Water and Wastewater.** 14th ed., APHA Washington D.C.

American Public Health Association (APHA). 1985. **Standard Methods for the Examination of Water and Wastewater: Including Bottom Sediments and Sludges.** 16th ed. APHA, Washington, D.C.

American Society for Testing and Materials. (ASTM). 1987. **Annual Book of ASTM Standards.** Section 11, Water and Environment Technology. Vol. 11.01 - Water (I), Vol. 11.-02 - Water (II), ASTM, Philadelphia.

Association of Official Analytical Chemists (AOAC). 1975. **Statistical Manual of the AOAC.** AOAC, Arlington, Virginia.

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

Napier, B. A., R. A. Peloquin, D. L. Strenge, and J. V. Ramsdell. 1988a. **Conceptual Representation.** Volume 1 of **GENII - The Hanford Environmental Radiation Dosimetry Software System.** PNL-6584, Vol. 1, Pacific Northwest Laboratory, Richland, Washington.

Napier, B. A., R. A. Peloquin, D. L. Strenge, and J. V. Ramsdell. 1988b. **User's Manual.** Volume 2 of **GENII - The Hanford Environmental Radiation Dosimetry Software System.** PNL-6584, Vol. 2, Pacific Northwest Laboratory, Richland, Washington.

Napier, B. A., R. A. Peloquin, D. L. Strenge, and J. V. Ramsdell. 1988c. **Code Maintenance Manual.** Volume 3 of **GENII - The Hanford Environmental Radiation Dosimetry Software System.** PNL-6584, Vol. 3, Pacific Northwest Laboratory, Richland, Washington.

O'Dell, J. W., J. D. Pfaff, M. E. Gales, and G. D. McKee. 1984. **Test Method. The Determination of Inorganic Anions in Water by Ion Chromatography - Method 300.0.** EPA-600/4-84-017, U.S. Environmental Protection Agency, Cincinnati, Ohio.

Sommer, D. J., R. G. Rau, and D. C. Robinson. 1981. **Population Estimates for the Area Within a 50-mile Radius of Four Reference Points on the Hanford Site.** PNL-4010, Pacific Northwest Laboratory, Richland, Washington.

U.S. Environmental Protection Agency (EPA). 1975. **Handbook of Radiochemical Analytical Methods**, EPA-680/4-75-001, National Environmental Research Center, Office of Research and Development, EPA, Las Vegas, Nevada.

U.S. Environmental Protection Agency (EPA). 1976. **National Interim Primary Drinking Water Regulations.** EPA-570/9-76-003, Office of Water Supply, Washington, D.C.

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

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

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

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

Washington State Department of Social and Health Services (WDSHS). August 1983 (Revised). **Public Water Supplies.** Washington Administrative Code, Chapter 248-54, Olympia, Washington.

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