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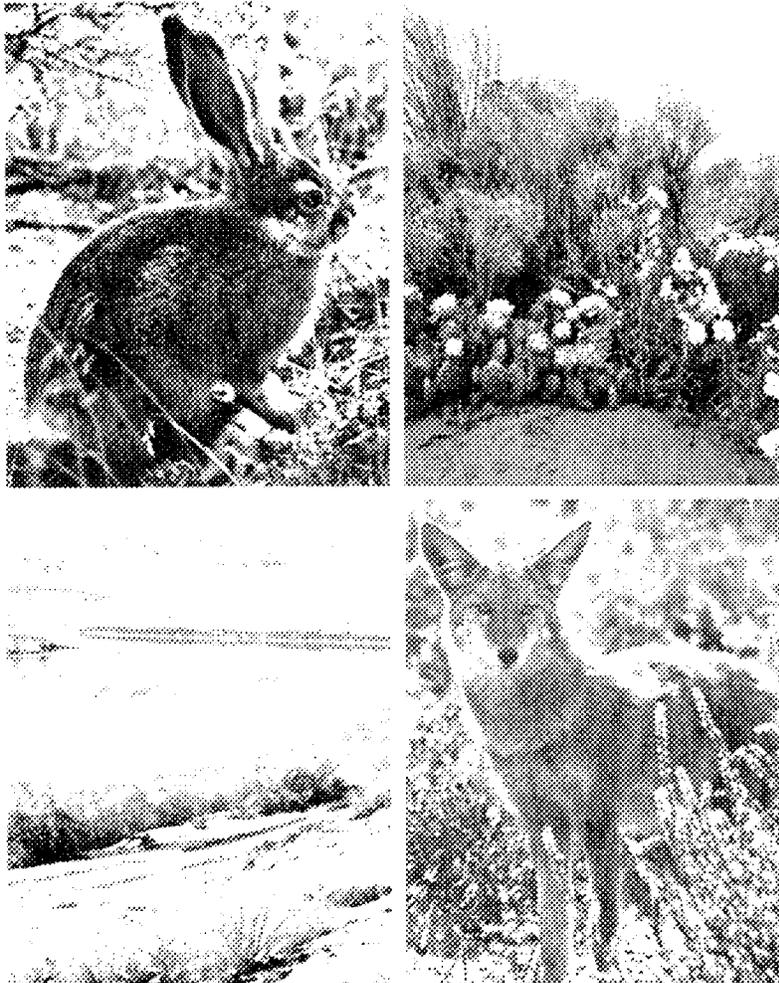
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## Environmental Monitoring at Hanford for 1984



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



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## **Environmental Monitoring at Hanford For 1984**

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## PREFACE

The Environmental Monitoring Program at Hanford is conducted at the Pacific Northwest Laboratory (PNL) by Battelle Memorial Institute, Pacific Northwest Division under contract to the Department of Energy (DOE). The data collected provide an historical record of the levels of radionuclides and radiation attributable to natural causes, worldwide fallout, and Hanford operations. The program continued throughout 1984 to monitor the environment offsite as well as onsite, during normal and unusual operating conditions. During 1984 the PUREX plant completed a year of operation, the complementary  $UO_3$  plant was restarted and operated most of the year, and the Plutonium Reclamation Facility was started at Z Plant to recover plutonium from waste materials.

The Environmental Monitoring Program has published results for offsite and onsite surface monitoring activities as separate reports in past years; groundwater monitoring activities also have been reported in a separate document. Ground-water results are again detailed separately and reported as *Ground-Water Surveillance at Hanford for CY 1984* (PNL-5408). For consistency and clarity, however, all results from the Environmental Monitoring Program for 1984 are reported in this single document including a brief summary of ground-water surveillance results. In addition to combining offsite and onsite results, features in earlier reports have been revised and new material has been added in an attempt to improve the readability of this 1984 report. These improvements include:

- an extensive glossary defining scientific terms in common language and a useful list of commonly used acronyms and abbreviations,
- summaries, in boldface type, preceeding each major section and highlighting monitoring activities and results,
- clear illustrations emphasizing 1984 results and comparing them with results reported over the past five years, and
- a separate chapter detailing the radiological impact from 1984 operations.

An appendix contains data and data summaries for results obtained during 1984 that include statistical estimates of errors. This information is intended for readers with a scientific interest in technical detail or for those who wish to evaluate results in a manner not included here. This report, then, has been written in an effort to address the needs of interested laypeople as well as individuals with a background in science. The environmental program will continue to respond to the technical needs of the site and to communicate results to interested individuals, special interest groups, and the news media.

## **ACKNOWLEDGMENTS**

The authors wish to acknowledge those at PNL who participated in the operation of the Hanford Environmental Monitoring Program during 1984 and those who helped prepare this report. Special thanks to C. S. Cline for contributing the discussion on ground water and to R. L. Kathren for reviewing the manuscript and providing valuable suggestions.

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## SUMMARY

Environmental surveillance activities performed by the Pacific Northwest Laboratory for the Department of Energy's Hanford Site for 1984 are discussed in this report. Samples of environmental media were collected in support of the Hanford Environmental Monitoring Program to determine radionuclide concentrations in the Hanford environs. Radiological impacts in terms of radiation dose equivalents as a result of Hanford operations are also discussed. The results provided in this report are summarized in the following highlights.

**Airborne Radioactivity**—Gross beta radioactivity concentrations in airborne particulates at all sampling locations were lower in 1984 than during 1983 as a result of declining levels of worldwide fallout. Gross alpha and radionuclide concentrations in the onsite and offsite environs were similar to previous years, with the exception of  $^{85}\text{Kr}$ ,  $^{129}\text{I}$  and  $^3\text{H}$ . Slightly higher levels of  $^{85}\text{Kr}$  and  $^{129}\text{I}$  were noted at several onsite and offsite locations. The sampling location in close proximity to the PUREX plant also detected increased  $^3\text{H}$ . All concentrations both onsite and offsite were well below applicable concentration guides.

**Water Monitoring**—Very low levels of radionuclides were detected in samples of Columbia River water during 1984. Radionuclides consistently observed in measurable quantities in the river were  $^3\text{H}$ ,  $^{90}\text{Sr}$ ,  $^{129}\text{I}$ ,  $^{137}\text{Cs}$ , Uranium and  $^{239,240}\text{Pu}$ . Except for  $^{137}\text{Cs}$  and  $^{239,240}\text{Pu}$ , concentrations of these radionuclides were slightly higher at the downstream sampling site compared to the upstream site; however, downstream concentrations were considerably below applicable concentration guides. The major source of radionuclides added to the river was assumed to be from ground water moving beneath the site into the river. All radionuclides detected in the Columbia River also occur naturally or are present in worldwide fallout.

Concentrations of radionuclides in onsite ponds during 1984 were similar to those measured in previous years in most cases. Elevated concentrations of  $^3\text{H}$  in B Pond were attributed to increased discharges of  $^3\text{H}$  to the pond from PUREX operations.

**Nonradiological Monitoring**—The emission of nonradiological pollutants consisted of  $\text{NO}_x$  and did not exceed EPA and local limits. Nonradiological water quality parameters for the Hanford reach of the Columbia River were within Washington State Water Quality Standards except for a single instance where the pH standard was exceeded. There was no apparent association of this occurrence with Hanford operations, nor any indication of reduced river water quality.

**Ground Water**—An extensive ground-water monitoring program was performed for the Hanford Site during 1984. The  $^3\text{H}$  and nitrate plumes continued to move slowly toward the Columbia River. All  $^3\text{H}$  results were within applicable concentration guides. Detailed results of the program will be reported in PNL-5408 to be published later in 1985.

**Foodstuffs**—Low levels of radionuclides were observed in most foodstuff samples and were attributed to worldwide fallout. There was no indication in any of the samples that radionuclides associated with Hanford operations were present.

**Wildlife**—Samples of deer, rabbits, game birds, waterfowl and fish were collected onsite or in the Columbia River at locations where the potential for radionuclide uptake was most likely, or at the nearest locations where wildlife samples were available. Radionuclide levels in deer were near those attributable to worldwide fallout. Cobalt-60 and  $^{137}\text{Cs}$  were detected in more whitefish samples near operating areas than at locations upstream of Hanford, but the concentrations were similar at both locations. Game birds and waterfowl showed low levels of  $^{137}\text{Cs}$  attributable to operations. Low levels of  $^{90}\text{Sr}$  and  $^{137}\text{Cs}$  typical of previous years were detected in 100 and 200 area rabbit samples. Concentrations were low enough that any radiation dose resulting from consumption of the edible portion of any fish or animal containing the highest observed concentration would be well below the applicable radiation protection standard.

**Soil and Vegetation**—Low concentrations of naturally occurring and fallout radionuclides were measured in samples of soil and vegetation collected in the Hanford environs. There were

no indications of any geographical differences in radionuclide concentrations and thus no discernible effect from Hanford operations.

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

**Radiological Impact**—An assessment of the 1984 potential radiological impacts attributable to the Hanford operations indicated that measured and calculated radiation doses to the public continued to be low, and well below applicable regulatory limits. The calculated fifty-year whole body dose potentially received by a hypothetical

maximally exposed individual was about 2 mrem. This is an increase of 1 mrem over the whole body dose reported in 1983, and was attributed to increased <sup>90</sup>Sr releases to the Columbia River. The DOE Radiation Protection Standard for whole body dose to the maximally exposed individual is 500 mrem per year. The calculated fifty-year whole body dose to the population living within 80 km of the site was about 5 man-rem as compared to 4 man-rem reported in 1983. These doses are significantly less than doses potentially received from other common sources of radiation. They also can be compared to the approximate 100 mrem and 34,000 man-rem received annually by an average individual and the surrounding population, respectively, as a result of naturally occurring and worldwide fallout radiations in the Hanford environs.

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## INTRODUCTION

**A variety of 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 storage of waste products. The Department of Energy (DOE) conducts effluent control, effluent monitoring, and environmental monitoring at the Hanford Site through contractor organizations to ensure compliance with applicable rules and regulations. The Environmental Monitoring Program has been conducted since 1965 by the Pacific Northwest Laboratory (PNL) which is operated for the DOE by the Battelle Memorial Institute. This report briefly describes the Hanford Site and ongoing operations, the nature of the Environmental Monitoring Program, and the results and interpretation of environmental monitoring data for 1984. The impact of Hanford Operations was assessed by calculating the potential dose received by people living in the vicinity of the Hanford Site.**

An environmental monitoring program has been conducted at the Hanford Site for the past 42 years. The results have been recorded since 1948 in quarterly reports. Since 1958, the results have been publicly available as annual reports. Results in recent years have been published as two separate reports under the titles; *Environmental Surveillance at Hanford for CY—* (the offsite report), and *Environmental Status of the Hanford Site for CY—* (the onsite report). Reports in the offsite series for the past ten years are noted in the Bibliography. This combined report summarizes the data collected for calendar year 1984 and includes information on all samples and measurements made in the offsite and onsite environment.

The Environmental Monitoring Program provides for the measurement, interpretation, and evaluation of samples and other measurements to assess environmental impact, determine compliance with pertinent regulations, and evaluate the adequacy of onsite waste management practices. The program also includes an evaluation of major pathways of potential environmental impact, with emphasis on the most significant pathways.

This report emphasizes the radiological status of the Hanford environment and vicinity. In general, the data were compared both to background or control measurements taken at distant locations during 1984 and to data obtained during the past five years. The last section discusses an assessment of radiological impacts at the

Hanford Site and on the surrounding environment. Potential doses are calculated for a hypothetical maximally exposed individual and for local population. The maximum dose rate at a publicly accessible area is also discussed.

Radionuclide data are expressed in terms of curies, picocuries, or attocuries. The curie is the fundamental unit used to express radioactivity and defines the amount of a radioactive substance present based on its rate of radioactive disintegration. A microcurie ( $\mu\text{Ci}$ ) is one millionth ( $10^{-6}$ ) of a curie. A picocurie (pCi) is one millionth-millionth ( $10^{-12}$ ) of a curie. An attocurie (aCi) is one millionth-millionth-millionth ( $10^{-18}$ ) of a curie. Environmental monitoring results are often very small numbers that are best expressed as picocuries or attocuries. As an additional aid in expressing small and variable environmental results, data are graphed using either linear or log (compressed) scales. Log scales are clearly identified on the graph whenever they are used to reduce the size of the figure.

Detailed results for 1984 are listed in Appendix A, and a glossary and list of acronyms and abbreviations are presented in Appendix B. Applicable standards and special permits are presented in Appendix C. Sample analysis procedures are described in Appendix D, and data analysis methods are summarized in Appendix E. Dose calculation methods and details used in the calculation for 1984 are given in Appendix F. Effluent data are also presented in Appendix F.

## DESCRIPTION OF THE HANFORD SITE

The U.S. Department of Energy's Hanford Site is located in a rural region of southeastern Washington and occupies an area of 1500 km<sup>2</sup>. The site, shown in Figure 1, lies about 320 km east of Portland, Oregon, 270 km southeast of Seattle, Washington, and 200 km southwest of Spokane, Washington. The Columbia River flows through the northern edge of the Hanford Site and forms part of its eastern boundary.

### SITE CHARACTERISTICS

The desert plain on which Hanford is located has a sparse covering of vegetation and is primarily suited for grazing. The most broadly distributed type of vegetation on the site is the sagebrush/cheatgrass/bluegrass community. The mule deer is the most abundant big game mammal on the site, and the most abundant small game animal is the cottontail rabbit. The raccoon is the most abundant furbearing animal. The osprey, golden eagle, and bald eagle are all occasional visitors to

the relatively large areas of uninhabited land comprising the Hanford Site.

The bedrock beneath the site consists of thick basalt layers which have been warped and folded to produce features of the landscape known as the Rattlesnake Hills, Gable Mountain, and Yakima Ridge. The basalt beneath the site is thicker than 3600 m in many places. Resting on the basalt bedrock is a layer of sands, silts, and gravels up to 300 m thick. Water flows over the

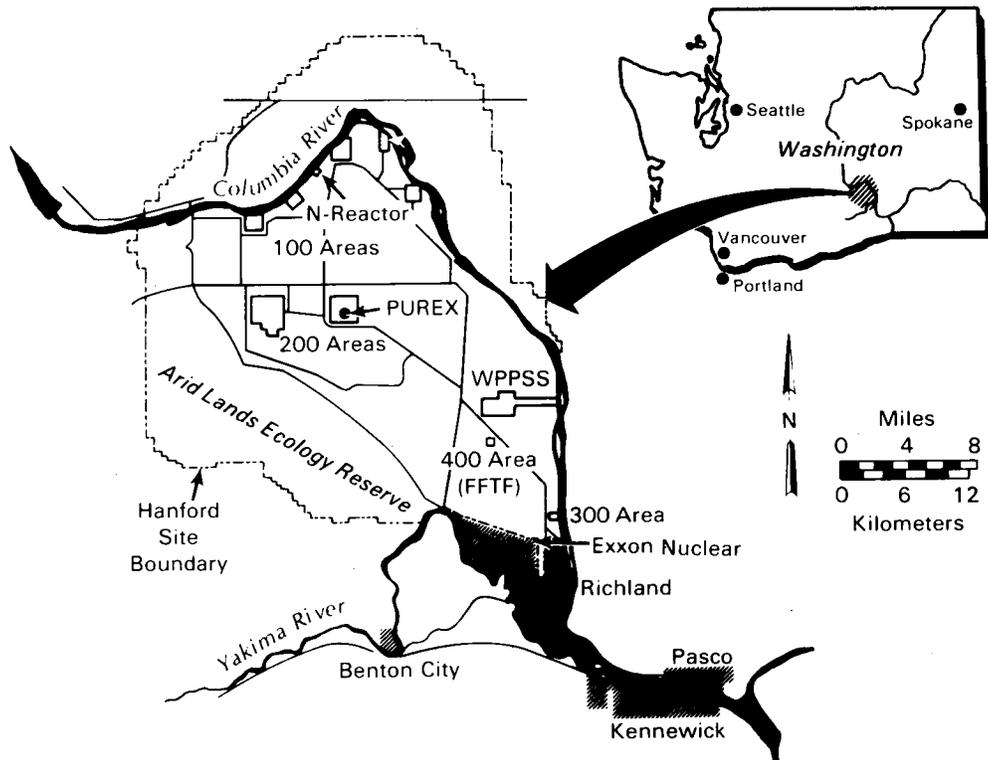


FIGURE 1. DOE's Hanford Site

surface of the basalt rock and through the covering of sand, silt, and gravel and makes up the unconfined aquifer. The surface of the unconfined aquifer is the water table. The unconfined aquifer and its water table have been affected by the disposal of waste water at Hanford for a number of years. The depth to the water table ranges from less than 0.3 m near the Columbia River to over 106 m near the center of the site. Water from the unconfined aquifer slowly flows eastward into the Columbia River through springs and seeps. The confined aquifers consist of ground water under pressure and are found deep within the ancient layers of basalt. The confined aquifers have not been affected by Hanford operations.

The Hanford reach of the Columbia River extends from Priest Rapids Dam to the head of Lake Wallula behind McNary Dam downstream of the site. It is the last free-flowing reach of the Columbia River in the United States. Water quality for the Hanford Reach is designated as Class A by the State of Washington and is suitable for all uses including raw drinking water, recreation and wildlife. Monthly average river water temperatures range from about 3°C (37°F) in February to 19°C (67°F) in August. Other surface water on the site consists of West Lake a small natural pond, a number of ditches, and four artificial ponds created for routine disposal of cooling water as well as industrial, laboratory and sanitary wastes.

Hanford's climate is mild and dry; the area receives approximately 16 cm of precipitation annually. About 40% of the total precipitation occurs during November, December, and January, with only 10% falling in July, August, and September. Approximately 45% of all precipitation from December through February is snow. The average maximum and minimum temperatures in July are 32°C (90°F) and 16°C (61°F). For January, the respective averages are 3°C (37°F) and -6°C (22°F).

Monthly average wind speeds range from about 10km/h in the summer to 14km/h in the winter. The prevailing regional winds are from the northwest with strong drainage and crosswinds causing complicated surface flow patterns. The region is a typical desert area with frequent strong inversions that occur at night and break during the day, causing unstable and turbulent conditions.

The principal use of land near the Hanford Site is agriculture. Agricultural lands occur north and east of the Columbia River and south of the Yakima River and consist of orchards, alfalfa, wheat, vegetables and vineyards. Use of the Hanford Site north of the Columbia River is divided between a state wildlife recreation area and a federal wildlife refuge. The northeast slope of the Rattlesnake Hills is designated as the Arid Lands Ecology Reserve and is used for ecological research by DOE and university researchers.

The population center nearest to the Hanford Site is the Tri-Cities area (Richland, Pasco, and Kennewick), which is situated on the Columbia River downstream from the site and has a combined population of approximately 90,000. Approximately 340,000 people live within an 80-km radius of the Hanford Site in the Yakima area, the Tri-Cities, several small communities, and the surrounding agricultural area. Considerably more detail on site characteristics and activities is available in the *Final Environmental Statement, Waste Management Operations, Hanford Reservation* (USERDA 1975).

## MAJOR ACTIVITIES

Established in 1943, the Hanford project was originally designed, built, and operated to produce plutonium for nuclear weapons. At one time, nine production reactors were in operation, including eight with once-through cooling by treated river water. Between December 1964 and January 1971, all eight reactors with once-through cooling were deactivated. N Reactor, the remaining production reactor in operation, has a closed primary cooling loop.

Four major operating areas exist at the Hanford Site. The "100 Areas" include facilities for the N-Production Reactor and the eight deactivated production reactors along the Columbia River.

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

Privately owned facilities located within the Hanford Site boundaries include the Washington Public Power Supply System generating station adjacent to N Reactor, the Washington Public Power Supply System power reactor and office buildings, and a radioactive waste burial site operated by U.S. Ecology. The Exxon fuel fabrication facility is located immediately adjacent to the southern boundary of the Hanford Site.

Principal DOE operating contractors at Hanford during 1984 were:

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

Battelle Memorial Institute—responsible for operating PNL for DOE. This includes research and development in the physical, life and environmental sciences, chemistry, and advanced methods of nuclear waste management. Environmental monitoring also is a part of PNL activities.

UNC Nuclear Industries (UNC)—responsible for fabricating N Reactor fuel, operating N Reactor, and decommissioning formerly utilized DOE facilities including shutdown production reactors.

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

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

Highlights of operational activities at Hanford during 1984 were:

- N Reactor again operated for 201 days during which time it supplied steam used by the Washington Public Power System to generate 860 MW of electrical power. Since its startup, N Reactor has supplied steam for the production of over 50 billion kilowatt-hours of electric power, which has been supplied to the Bonneville Power Administration grid covering the Pacific Northwest.
- The PUREX fuel reprocessing facility in 200-E Area completed one year of operation. The depleted uranium processing facility (UO<sub>3</sub> Plant) operated as needed from January through the end of 1984. The Plutonium Reclamation Facility at Z Plant began operations in January.
- The FFTF completed two 100-day full power operating campaigns and achieved a 66% annual capacity factor.
- Two retired 100 area facilities were decommissioned during 1984: the 117H Filtration Building and the 115F Gas Recirculation Building. Various other retired facilities underwent the initial stages of decommissioning.

Work at Hanford during 1984 also included Hanford National Environmental Research Park studies, Arid Land Ecology studies, and Basalt Waste Isolation Program activities, as well as continued operation of a variety of national research and laboratory facilities. The Washington Public Power Supply System Nuclear Project No. 2 began commercial operation to produce electricity in December.

## ENVIRONMENTAL MONITORING PROGRAM

All DOE sites are required to conduct environmental monitoring programs and report results on an annual basis. The policy of the DOE is to ensure that radiation doses to members of the public are maintained as low as reasonably achievable consistent with technology and cost and below applicable dose standards. The basic purpose of the Environmental Monitoring Program is to estimate and assess radiation doses to individuals and groups of individuals (a population) that may have been exposed to radioactive materials and radiation in the environment from present and past operations of Hanford facilities. The risk to people is evaluated by comparing the calculated potential doses received from Hanford sources to those received from background and fallout radiations and to established standards. Another purpose of the program is to detect and clarify any increasing trends in environmental radiation dose rates and radioactive material concentrations found in various kinds of environmental samples as a result of Hanford operations. Finally, the purpose of the program is to inform the public as well as federal, state and local regulatory agencies that the operations at Hanford are environmentally sound and meet applicable environmental regulations.

### PROGRAM SCOPE

The scope or extent of the Environmental Monitoring Program encompasses all pollutants with emphasis on radioactive materials. To some degree, the scope of the program varies with the anticipated routine release, or potential release, of pollutants and the severity of their possible impact. The scope of the program also includes a feedback system to evaluate the adequacy and effectiveness of containment and effluent control systems. The appropriate facility manager is notified if off-standard conditions or adverse trends are detected in the environment near operating areas.

### PROGRAM OBJECTIVES

There are four principal objectives of the Environmental Monitoring Program. The first is to assess dose impacts and other impacts from site operations on the public and the local environment. The second is to verify operational control measures for the containment of radioactive materials within controlled areas. The third is to monitor the environment to determine buildup of long-lived radionuclides. The fourth is to provide information to the public that the program is capable of adequately assessing impacts and identifying noteworthy changes in the radiological and nonradiological status of the environment.

### PROGRAM CRITERIA

Criteria or the bases for the Environmental Monitoring Program are derived from the general

requirements set forth in applicable federal, state, and local regulations and recommendations given in the monitoring guide published for use at DOE sites (Corley et al. 1981). Specific criteria have been developed by identifying exposure pathways and critical radionuclides. These identifications have taken advantage of the long operating experience at Hanford.

The initial step in designing an effective environmental monitoring program is the identification of significant pathways by which radioactive materials may be transported. The only routes available for transporting significant quantities of radioactive material from Hanford operations are the atmosphere, Columbia River, and ground water. Figure 2 illustrates these potential routes and the subsequent network of possible exposure pathways to man. The significance of each pathway is determined from data recording the amount of radioactive material potentially available to be transported along the pathway and its resultant radiation dose. Recent estimates of whole body radiation dose to a hypothetical maximum exposed individual from Hanford operations has been about 1 mrem per year. The monitoring program has been designed to detect the equivalent of at least 0.1 mrem in any pathway. To ensure that radiological analyses of samples are sufficiently sensitive to detect 0.1 mrem, minimum detectable concentrations of various radionuclides in air, water, and food have been calculated and are given in Table D.1, Appendix D. The minimum detectable concentrations for other types of samples also are listed in the table.



## ENVIRONMENTAL PROTECTION STANDARDS AND PERMITS

Operations at the Hanford Site are controlled to conform to a variety of federal and state standards and permits. Nonradiological releases and impacts are subject to the same State and Federal laws and regulations as any civilian facility. Radiological releases and impacts were regulated during 1984 by DOE orders pursuant to the Atomic Energy Act.

Environmental radiation protection standards are published in DOE ORDER 5480.1A *Environmental Protection, Safety, and Health Protection Program of DOE Operations* (USDOE 1981a). These standards are based on guidelines originally recommended by the Federal Radiation Council (FRC) and other scientific groups such as the International Commission on Radiological Protection (ICRP) and the National Commission on Radiation Protection and Measurements (NCRP). The standards govern exposures to ionizing radiation from DOE operations. DOE ORDER 5480.1A also lists radionuclide concentration guides for air and water. A concentration guide is the concentration of a given radionuclide in air or water that could be inhaled or consumed continuously without exceeding the radiation protection standard. Specific standards are listed and referenced in Appendix C.

The State of Washington has promulgated water quality standards for the Columbia River (Washington State Department of Ecology 1982). Of importance to Hanford operations is the designation of the Hanford reach of the Columbia River as Class A Excellent. This designation requires that the water be usable for substantially all needs including raw drinking water, recreation, and wildlife. Class A water standards are summarized in Appendix C. Benton-Franklin-Walla Walla Counties Air Pollution Control Authority Ambient Air Quality Standards for nitrogen dioxide in air also are given in Appendix C. In addition, various special permits are required to conduct Hanford activities. These include discharge permits and sample collection permits as defined in Appendix C. The Clean Air Act of 1977 (42 U.S.C. 1857 et seq. 1977) requires issuance of Prevention of Significant Deterioration (PSD) permits for facilities emitting pollutants which may affect air quality. A PSD permit was issued to Hanford by EPA in 1980 and limits

the amount of NO<sub>x</sub> released annually from PUREX and the UO<sub>3</sub> plants. The Clean Water Act requires the issuance of permits for liquid discharges to the Columbia River under the National Pollutant Discharge Elimination System (NPDES). Eight Hanford discharge points have been issued NPDES permits by EPA. These permits control the release of nonradiological liquid discharges to the river and require sampling, monitoring and reporting for each discharge.

## PROGRAM DESCRIPTION

The Environmental Monitoring Program provides for the measurement and interpretation of the impact of Hanford operations on the public as well as both the onsite and offsite environment. Radiological impacts are expressed in terms of radiation exposures. The concentrations of radioactive materials are compared to applicable standards, concentration guides, and natural levels of radiation and radioactive materials (including worldwide fallout). The program is designed to examine all significant exposure pathways including direct radiation exposure from operating facilities. Numerous samples were collected and analyzed according to a published schedule (Blumer et al. 1983). Table 1

TABLE 1. Geographical Distribution of Environmental Sample and Measurement Locations

Sample Types	Sample Locations				
	Total Number	Onsite	Perimeter	Communities	Distant
Air	48	23	15	5	5
Ground Water	339	339	—	—	—
Columbia River	3	—	2	1	—
Ponds	4	4	—	—	—
Foodstuffs	7	—	5	—	2
Wildlife	12	12	—	—	—
Soil & Vegetation	31	16	13	1	1
Dose Rate	54	26	17	6	5
Waste Site Surveys	83	83	—	—	—
Roadway Surveys	16	16	—	—	—

summarizes the geographic distribution of environmental sample and measurement locations. Schedules, records, and data were maintained in a computer system.

Unscheduled work also was conducted as part of the monitoring program. Results were used to answer public concerns, make program improvements, and add information about potential environmental impacts. For example, specific concerns or complaints expressed by local residents were investigated and answered. The environmental dosimeter network recently was expanded to include duplicate coverage with dosimeters placed by the State of Washington, the Nuclear Regulatory Commission, the Washington Public Power Supply System, and U.S. Ecology. Technical work in the form of special studies was performed and reported separately, e.g., the report on seepage of ground water into the Columbia River (McCormack and Carlile, 1984). Results from another special study on the ratio of various plutonium isotopes in soil samples collected for the past three years will be reported later.

Most analyses for radioactivity were conducted by United States Testing Company, Inc. (UST), Richland, Washington under subcontract. Unique analyses UST was unable to perform ( $^{129}\text{I}$  and  $^{239,240}\text{Pu}$  in Columbia River water) were conducted by PNL analytical laboratories. Water quality measurements, temperature, and flow rates for the Columbia River were made by the U.S. Geological Survey (USGS) under subcontract. Quality assurance and quality control were an integral part of the program. Details on sampling, analysis, measurement, dose assessments, and quality assurance are discussed in the sections describing results.

#### **RELATED PROGRAMS**

There are a number of other programs related to the site-wide Environmental Monitoring Program reported here.

##### **Operating Areas Surveillance**

Each of the major operating contractors, i.e., UNC, RHO, WHC, and PNL measure and record the amounts of liquids, gases, and solids released to the environment. Effluent releases, as reported by the operating contractors, are summarized later in this report. Environmental measurements

also are made near facilities by the operating contractors to audit the control of environmental releases and the general conditions of the local environment affected by their operations. Annual environmental reports are published by UNC and RHO.

##### **Drinking Water Surveillance**

Drinking water was supplied to the Hanford Site during 1984 by seventeen separate systems. Twelve of the systems utilized Columbia River water as a raw water source, four systems utilized ground water, and one system (Richland municipal) used a combination of the two. Each system consisted of a raw water supply, treatment equipment, and distribution piping. The systems ranged in size from several large facilities serving extensive areas to nine small units supplying individual complexes or single facilities. All were operated by DOE contractors with the exception of the City of Richland municipal system which was operated by the city. The municipal system provided water to DOE facilities at the 700, 1100, and 3000 Areas. Monitoring of the drinking water on the Hanford Site is a joint effort between HEHF and PNL, with HEHF specializing in the areas of chemical and microbiological quality and PNL focusing on radiological quality. The primary purpose of the Drinking Water Program is the protection of the health of Hanford workers consuming water derived from sources on the Hanford Site. This aim is met through the evaluation of compliance with applicable drinking water standards. Details and results were published in the annual report, *Hanford Sanitary Water Quality Surveillance, CY 1984*, (Maas 1985).

##### **Nonradiological Air Monitoring**

Nonradiological pollutants in atmospheric releases from chemical processing plants and fossil-fueled steam plants at Hanford consisted primarily of the oxides of nitrogen ( $\text{NO}_x$ ) and particles of fly ash. A nine-station ambient air nitrogen dioxide ( $\text{NO}_2$ ) sampling network was operated by HEHF in 1984. Results are summarized later in the "Nonradiological Monitoring Results" Section.

##### **Wildlife Census**

A census has been taken annually of several kinds of wildlife for a number of years to obtain

information on population trends associated with the changing status of the Hanford Site. The census is made of species that are rare, threatened, or endangered as listed by the U.S. Fish and Wildlife Service and those that are of recreational or commercial importance.

The spawning populations of chinook salmon, in the Hanford reach of the Columbia River have been determined by counting the number of redds (nests). These counts have been made yearly since 1947. The largest numbers of redds have been recorded in the years since 1981 with more than 7000 recorded in 1984. The increase was attributed to the elimination of other spawning habitats in the Columbia River and to increased fisheries management efforts.

The increased numbers of spawning salmon have attracted wintering bald eagles to feed on the carcasses of salmon that die after spawning. The greatest number of bald eagles was counted in the 1984-1985 winter when 41 birds were noted along the Hanford reach.

The long-billed curlew is a non-game bird that is native to the Columbia Basin region of eastern Washington. The nesting habitat of the curlew has decreased with an increase in land use for irrigated agriculture. The undeveloped land of the Hanford Site continued to provide suitable nesting habitat for this threatened species. Nesting populations on the site appeared to be stable.

One of the longest and most detailed studies of Hanford wildlife is the nesting census of the western Canada goose on 20 islands in the Hanford reach. This census has been conducted since 1950 and results have shown a decline in the number of goose nests since the late 1950's. The decline was attributed to the presence of coyotes on Locke Island, an island that once supported 100 nests but presently supports none. During the past five years, however, the number of goose nests has remained relatively stable on the other islands.

## AIR MONITORING

**Airborne transport of radioactive materials from the Hanford Site to the surrounding region represented the most direct potential exposure pathway to the public. Radioactivity was measured by a network of 48 continuously operating air samplers located onsite, adjacent to or distant from the Hanford Site. Data from these samplers included the measurement of radioactive particulates, radioiodines, tritium,  $^{14}\text{C}$  and a noble gas.**

**With the exception of  $^{85}\text{Kr}$ ,  $^{129}\text{I}$ , and  $^{239,240}\text{Pu}$ , sample results from the offsite environs did not indicate the presence of detectable levels of radionuclides that could have been attributed to Hanford. Data collected from perimeter and distant sampling locations reflected an expected increase in  $^{85}\text{Kr}$  and  $^{129}\text{I}$  levels in ambient air. Radionuclide concentrations from air samplers located onsite were comparable to data collected in previous years, except at a few locations in close proximity to PUREX where increased levels of  $^3\text{H}$ ,  $^{85}\text{Kr}$ ,  $^{129}\text{I}$ , and  $^{239,240}\text{Pu}$  were noted.**

### SAMPLE COLLECTION AND ANALYSIS

Radioactivity in air was measured by a network of continuously operating air samplers at 23 locations on the Hanford Site, 15 near the site perimeter, five in nearby communities and five locations somewhat distant from the site (Figure 3). Air samplers on the Hanford Site were located primarily around the major operating areas in order to characterize the maximum potential impact from site operations. The site perimeter samplers provided for general coverage in all directions but with emphasis in the prevailing downwind directions to the south and east of the site. The network also included samplers located in the communities of Benton City, Richland, Pasco, Connell and Othello, thereby providing coverage for population centers adjacent to the Hanford Site. Samplers were located in the distant communities of Sunnyside, Moses Lake, Washtucna, Walla Walla, and at McNary Dam to provide data for comparison.

The routine schedule for the collection of air samples is described in a master schedule published yearly (Blumer et al. 1983). Particulate and radioiodine samples were collected at all sampling locations. In addition, several of the air sampling locations contained tritium,  $^{14}\text{C}$ , and  $^{85}\text{Kr}$  collection units.

Particulate airborne radionuclides were sampled by drawing air at a flow rate of  $2.6\text{ m}^3/\text{h}$  through a 5-cm diameter high-efficiency fiberglass filter.<sup>(a)</sup> The filters were collected biweekly and analyzed for gross beta radioactivity after a seven-day holding period during which short-lived naturally occurring radon and thoron daughters collected by the filter decayed.

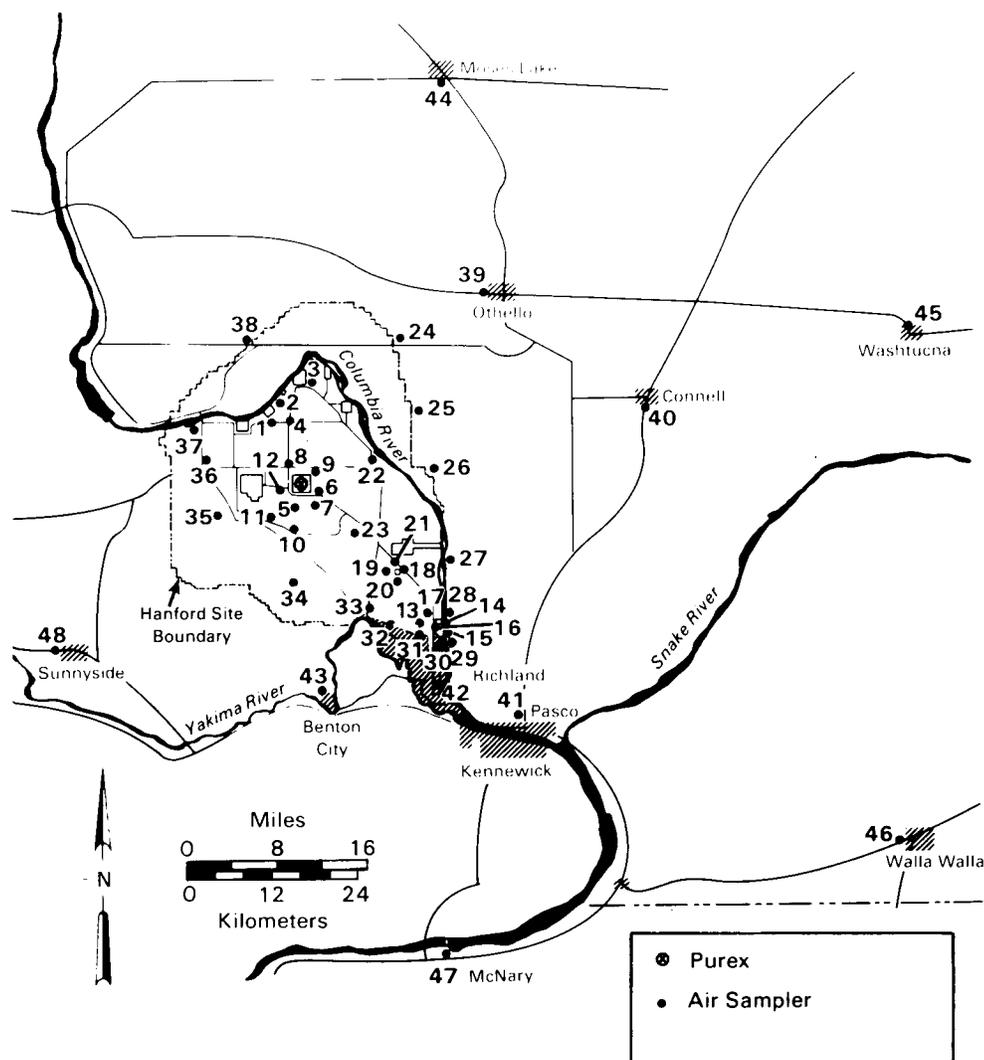
In addition, various filters also were analyzed in a similar manner for gross alpha radioactivity. The air filters were then combined monthly by geographical location and analyzed as a composite for gamma-emitting radionuclides, primarily  $^{137}\text{Cs}$ . On a quarterly basis, the monthly composites for each geographical group were combined and analyzed for strontium and plutonium. Sampling locations are shown in Figure 3. Sample composite groups are listed in Table A.1, Appendix A.

Radioiodines were collected using 6.3-cm diameter by 2.5-cm deep cartridges containing activated charcoal.<sup>(b)</sup> These cartridges were placed downstream of the particulate filter at each of the air sampling stations. Charcoal cartridges from several of the sampling locations were exchanged on a biweekly frequency and analyzed for  $^{131}\text{I}$ . The remaining cartridges were exchanged monthly to maintain fresh adsorption media, but were analyzed only if  $^{131}\text{I}$  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.

The tritium collection unit consisted of three cartridges containing silica gel through which a stream of air was passed at a flow rate of  $0.01\text{ m}^3/\text{h}$ . The silica gel removed tritium in the form

(a) Measured efficiencies exceed 99% for DOP (dioctylphthalate) particles.

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



**FIGURE 3.** Air Sampling Locations (See Table A.1, Appendix A, for location number key)

of water vapor (HTO). Moisture collected by the silica gel was removed by heating and then by condensing the trapped water. The silica gel cartridges were exchanged every two weeks.

The  $^{14}\text{C}$  ( $\text{CO}_2$ ) collection units consisted of a single cartridge containing sufficient soda lime to collect about 5 g of carbon over an eight-week sampling period. The sample flow rate was  $0.03 \text{ m}^3/\text{h}$ .

Samples of ambient  $^{85}\text{Kr}$  were collected using a small laboratory pump that transferred a sample at a low flow rate into a collection bag. Samples

of about  $0.3 \text{ m}^3$  were collected over four-week sampling periods.

### RESULTS

Results of gross beta and gross alpha radioactivity in airborne particulate samples collected in 1984 are given in Table A.2, Appendix A. Gross beta concentrations, as well as gross alpha concentrations, were similar at all sampling locations, averaging  $0.02 \text{ pCi}/\text{m}^3$  and  $0.001 \text{ pCi}/\text{m}^3$ , respectively. No contribution to the general level of airborne particulate radioactivity could be attributed to 1984 Hanford operations based

on a comparison of samples collected onsite, near the site perimeter and at distant locations. Therefore, airborne alpha and beta radioactivity levels observed in 1984 were attributed to worldwide fallout and natural sources.

A comparison of long-lived gross beta radioactivity in airborne particulate samples collected during 1984 with samples collected in previous years (Figure 4) shows that airborne radioactivity levels have decreased markedly. The elevated airborne radioactivity levels, which began in late 1980 and continued until late 1981, were attributed to an atmospheric nuclear test conducted by the People's Republic of China in October 1980.

Table A.3, Appendix A summarizes the results of air samples analyzed for specific radionuclides of potential Hanford origin. With the exception of  $^{85}\text{Kr}$ ,  $^{129}\text{I}$  and  $^{239,240}\text{Pu}$ , radionuclide concentrations at offsite locations were similar to each other regardless of the sample locations, indicating the source to be worldwide fallout. A similar situation occurred onsite with the exception of a few sampling locations in close proximity to PUREX that showed higher levels of radionuclides, particularly  $^{85}\text{Kr}$ ,  $^{129}\text{I}$ ,  $^3\text{H}$  and  $^{239,240}\text{Pu}$ . Onsite results from each of the sampling stations located near the major operating areas are provided in Tables A.4 through A.10, Appendix A.

Coinciding with the resumption of operations at PUREX, ambient air concentrations of  $^{85}\text{Kr}$  began gradually to increase at all sampling locations as shown in Figure 5. The map in Figure 6 shows the average  $^{85}\text{Kr}$  concentrations in 1984 at each of the sampling locations in relation to their respective distances from PUREX. As would be expected, concentrations onsite were higher than those recorded at offsite locations. Although there were measurable quantities of  $^{85}\text{Kr}$  detected throughout the sampling network, all concentrations were well below the DOE Concentration Guide of 300,000 pCi/m<sup>3</sup>.

Quarterly air sampling for  $^{129}\text{I}$  began in July 1984 at the locations identified in Figure 7. Historically,  $^{129}\text{I}$  concentrations in ambient air have been associated with fuel reprocessing activities. As shown in the histograms in Figure 7, the restart of PUREX operations resulted in the detection of  $^{129}\text{I}$  at all locations where samples were collected. Concentrations are reported in attocuries per cubic meter of air. Concurrent with  $^{85}\text{Kr}$  data, concentrations onsite were higher than those observed at offsite locations. All  $^{129}\text{I}$  concentrations, however, were very low and much below the DOE Concentration Guide of 20 pCi/m<sup>3</sup> (20,000,000 aCi/m<sup>3</sup>).

Tritium was detected more frequently and at higher levels at the sampling locations adjacent

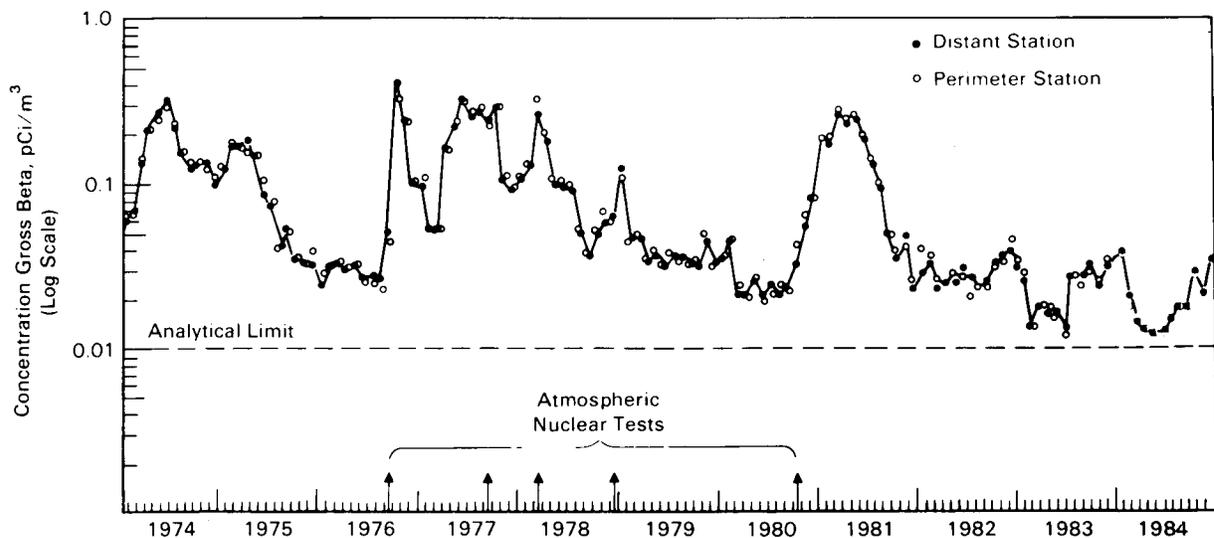
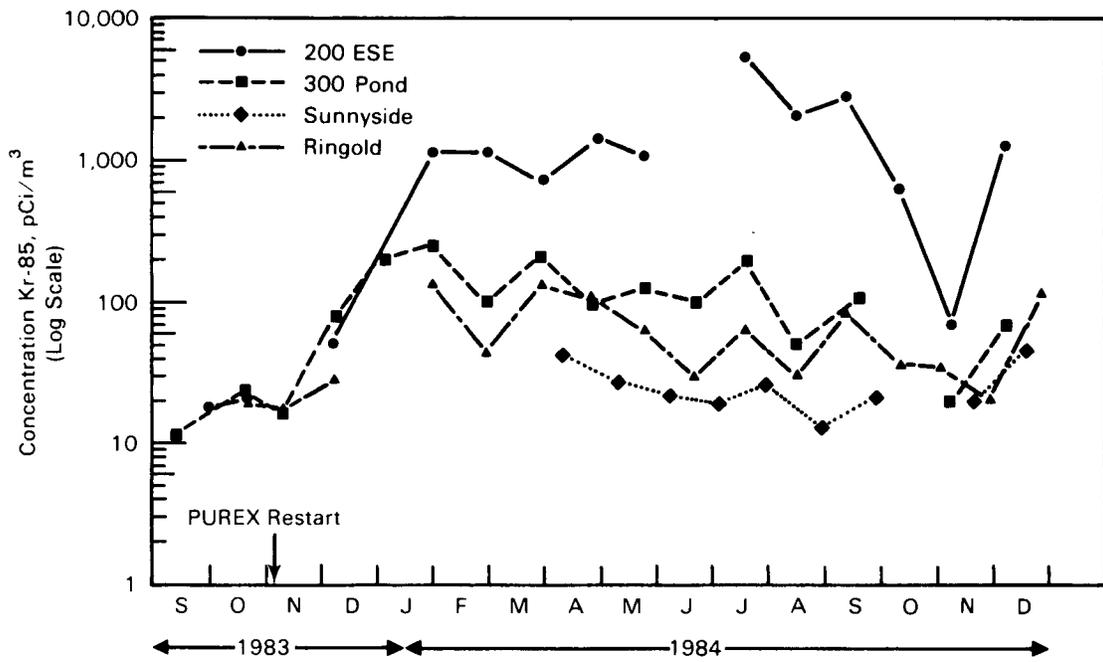
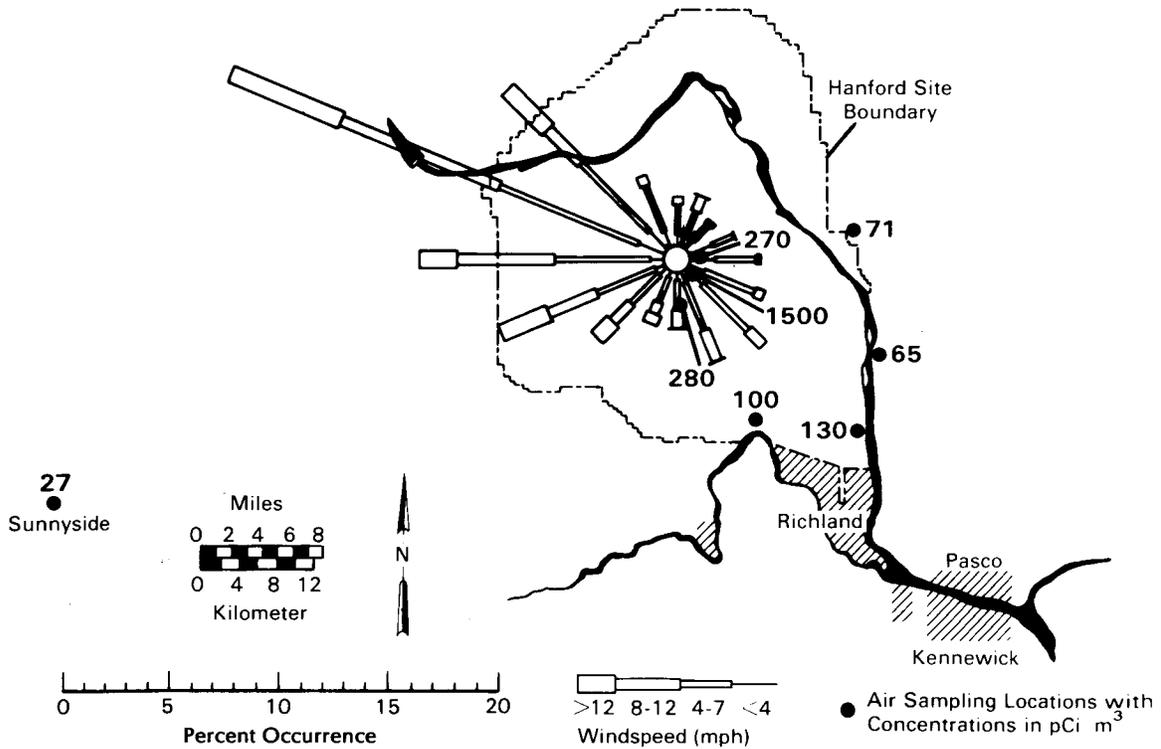


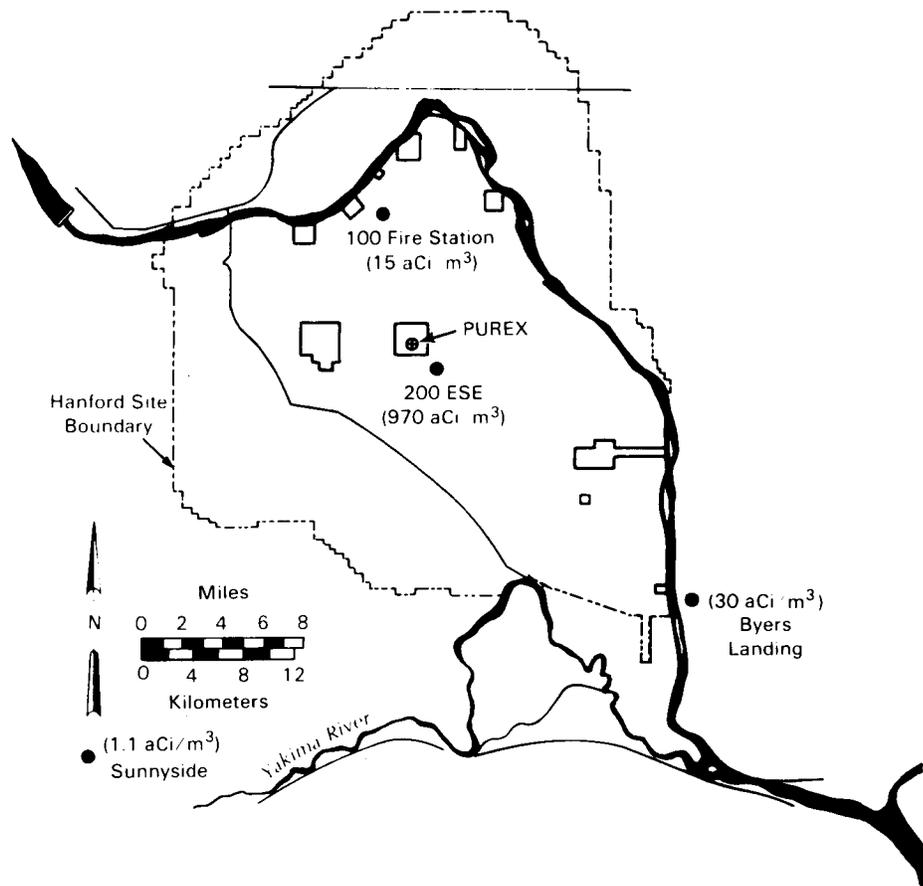
FIGURE 4. Monthly Average Gross Beta Radioactivity in Airborne Particulate Samples, 1974 to 1984



**FIGURE 5.** Krypton-85 Concentrations in Air at Selected Locations in the Hanford Environs for 1983 and 1984



**FIGURE 6.** Annual Average <sup>85</sup>Kr Concentrations in Air and the 200 Area Windrose Showing the Directions from which the Wind Blew During 1984



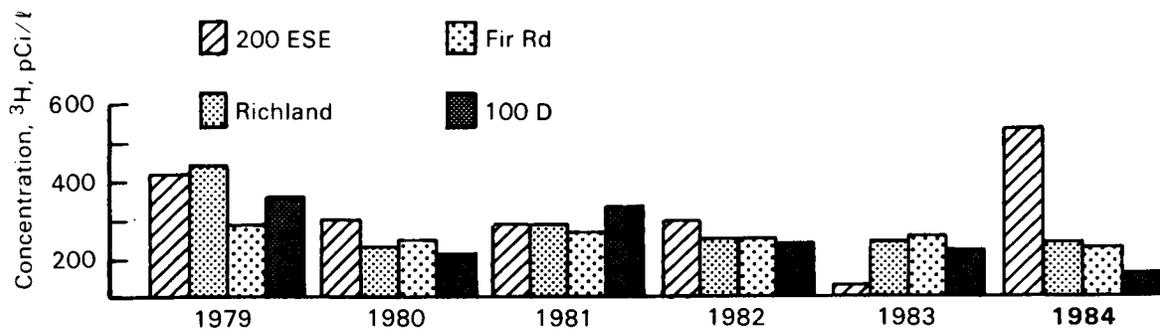
**FIGURE 7.** Iodine-129 Concentrations in Air in the Hanford Environs for 1984

to the PUREX Plant in 1984 than at other locations. Results for other sampling locations were similar to levels reported in previous years. Tritium, measured in picocuries per liter of atmospheric water vapor (HTO), has been historically sampled at the four locations identified in the histograms in Figure 8. The effect of PUREX activities in 1984 on nearby sampling locations was apparent by the increase in the average  $^3\text{H}$  concentration at the 200 ESE location from 1983 to 1984 (Figure 8). Beginning in mid-1983 all  $^3\text{H}$  data were also calculated in terms of  $\text{pCi}/\text{m}^3$ . Monthly data collected since mid-1983 at 200 ESE are plotted in terms of  $\text{pCi}/\ell$  and  $\text{pCi}/\text{m}^3$  in Figure 9. The correlation between the data is easily noted in this figure. The DOE Concentration Guide is  $200,000 \text{ pCi}/\text{m}^3$ .

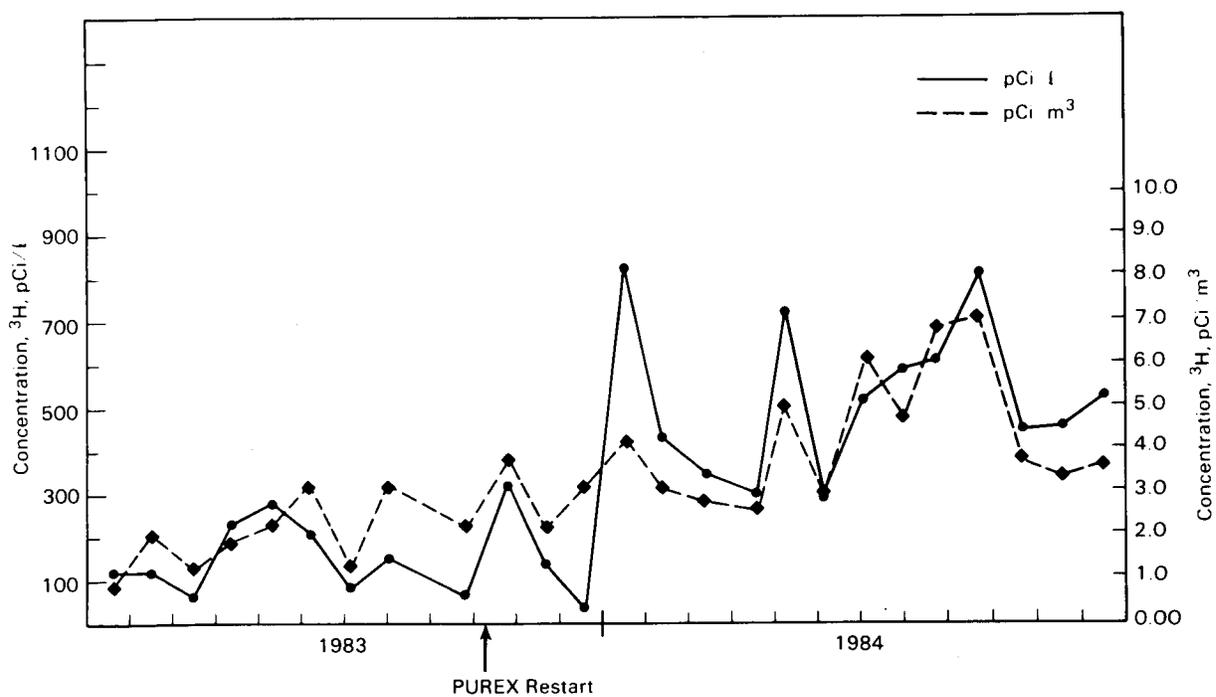
The 1984 average  $^{239,240}\text{Pu}$  concentrations in ambient air represented by each of the sample

composite groups are illustrated in the map showing lines of equal concentrations (Figure 10). Slightly higher concentrations occurred in a downwind direction from the PUREX Plant and continued to just beyond the site boundary. All other offsite locations were similar to one another and represent background levels due to worldwide fallout. Concentrations are very low and are reported in attocuries per cubic meter of air. Although there were measurable quantities of  $^{239,240}\text{Pu}$  in the Hanford environs, all concentrations were well below the applicable DOE Concentration Guide of  $0.06 \text{ pCi}/\text{m}^3$  ( $60,000 \text{ aCi}/\text{m}^3$ ).

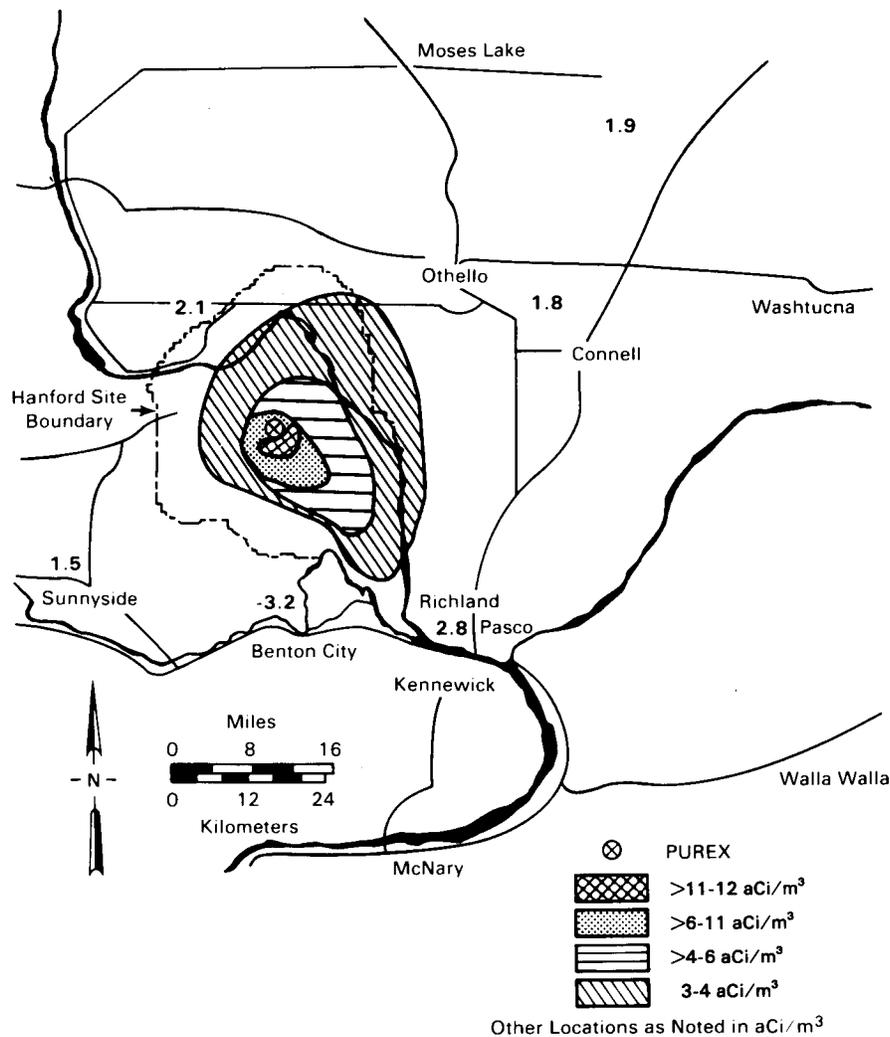
The histogram in Figure 11 shows an abrupt decrease from previous years in quarterly  $^{239,240}\text{Pu}$  concentrations in air measured at all stations for the last calendar quarter of 1983 and all of 1984. The reason for this apparent reduction in concentration is that several changes were made in



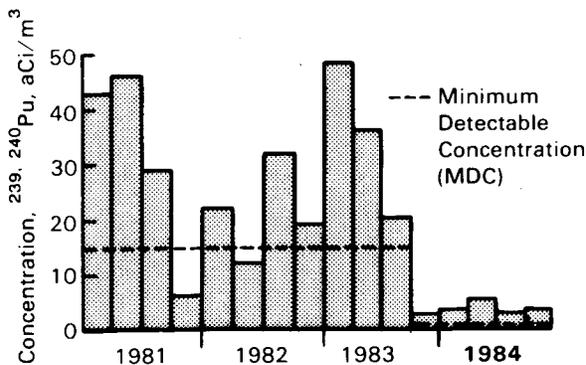
**FIGURE 8.** Average Annual Tritium Concentrations in Atmospheric Water Vapor at Representative Locations, 1979 to 1984



**FIGURE 9.** Comparison of <sup>3</sup>H Concentrations in Water Vapor (pCi/l) and Ambient Air (pCi/m<sup>3</sup>) at 200 ESE Location



**FIGURE 10.** Plutonium-239,240 Concentrations in Air in the Hanford Environs for 1984



**FIGURE 11.** Quarterly <sup>239,240</sup>Pu Concentrations in air at all Locations, 1981 to 1984

the analytical procedure which improved the sensitivity of <sup>239,240</sup>Pu measurements and lowered the minimum detectable concentration. When quarterly average concentrations were calculated, results less than the minimum detectable concentrations were included as real values. Thus, when the minimum detectable level was high, data averages were biased high. A reduction in the minimum detectable concentration resulted in lower "less-than" values and a truer estimate of the actual air concentration. Nationwide ambient levels of <sup>239,240</sup>Pu in air from fallout are in the range of 0.5 to 4 aCi/m<sup>3</sup>, as reported by the EPA (EPA, 1983a). Therefore, unlike previous years, the data reported for 1984 are of sufficient sensitivity to confirm these background levels in the environment around Hanford.

## SURFACE-WATER MONITORING

The Columbia River constituted the primary environmental exposure pathway for radioactivity in liquid effluents. Radionuclides in the river have decreased significantly since the shutdown of the old single-pass production reactors and the installation of liquid effluent control systems at N Reactor. However, Columbia River water continued to be an environmental media in which radionuclides associated with Hanford operations were identified on a routine basis.

In addition to the river, four onsite ponds were sampled for radioactivity. These ponds were accessible to migrating waterfowl as well as other animals. A potential biological pathway existed for the removal and dispersal of contaminants that may have been present in the pond water and sediments.

### COLUMBIA RIVER

Because the Columbia River is used as a source of drinking water and for crop irrigation, as well as for recreational activities, it continues to be closely monitored for radionuclides of potential Hanford origin. Samples from upstream and downstream of the site are analyzed for selected radionuclides at frequencies commensurate with their half-life and importance as verifiers of waste containment or indicators of potential environmental impacts. Radionuclides of primary significance in the river are  $^3\text{H}$ ,  $^{60}\text{Co}$ ,  $^{89}\text{Sr}$ ,  $^{90}\text{Sr}$ ,  $^{131}\text{I}$ ,  $^{129}\text{I}$ ,  $^{137}\text{Cs}$ ,  $^{239,240}\text{Pu}$ , and uranium.

#### Sample Collection and Analysis

Samples of Columbia River water were collected throughout 1984 at the upstream and downstream locations shown in Figure 12. Two types of samplers were used: a conventional cumulative-type sampler that intermittently collected a measured volume of river water in a large container, and a specially designed large-volume sampler that continuously collected waterborne radionuclides from the river on a series of filters and ion-exchange resins.

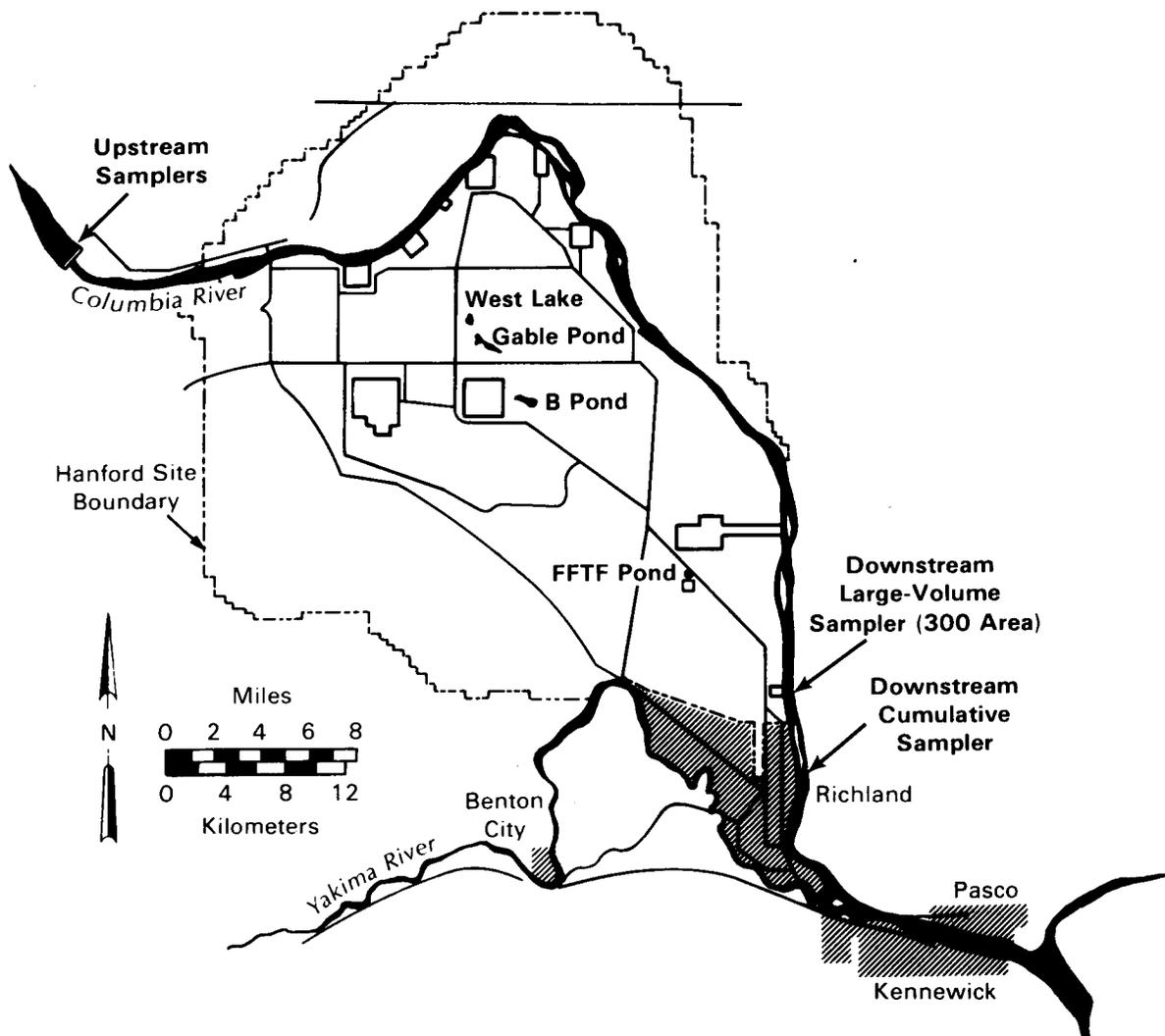
The cumulative samplers consisted of a clock-activated solenoid valve that periodically diverted a continuously flowing stream of Columbia River water into a container. Approximately 30 ml of water were diverted into the container every 30 minutes so that by the end of each monthly sampling period about 40 l were accumulated. The cumulative sampler was used to collect river water samples for tritium,  $^{89}\text{Sr}$ ,  $^{90}\text{Sr}$ , and uranium analyses.

The large-volume sampler used river water continuously pumped at a rate of 50 ml/min. Particles greater than 0.45  $\mu\text{m}$  in diameter were removed from the sample stream by a series of filters, and dissolved radionuclides were accumulated on a mixed-bed, ion-exchange resin column. The filtration media were exchanged at two-week intervals during which time approximately 1,000 l of river water were pumped through the sampler. Samples were analyzed for gamma-emitting radionuclides,  $^{129}\text{I}$ , and plutonium.

#### Results

Results of the analysis of Columbia River water samples are summarized in tabular form in Appendix A (Tables A.11 and A.12). Selected significant results are graphed and discussed below. Radionuclides consistently observed in measurable quantities in river water were  $^3\text{H}$ ,  $^{90}\text{Sr}$ ,  $^{129}\text{I}$ ,  $^{137}\text{Cs}$ , U, and  $^{239,240}\text{Pu}$ . While  $^3\text{H}$  and U occur naturally, all are also present in worldwide fallout and effluents from nuclear operations at Hanford.

The Hanford contribution of low levels of radionuclides to the river was partially attributed to the flow of ground water from the unconfined aquifer underlying the site and into which process cooling water and low-level liquid wastes have been discharged. Results of routine ground-water monitoring have indicated that water discharged to the aquifer in various operating areas, along with the soluble contaminants, has flowed toward the Columbia River. Seepage of ground water from the unconfined aquifer into the Columbia River has been observed as natural spring flows along the shoreline both at and



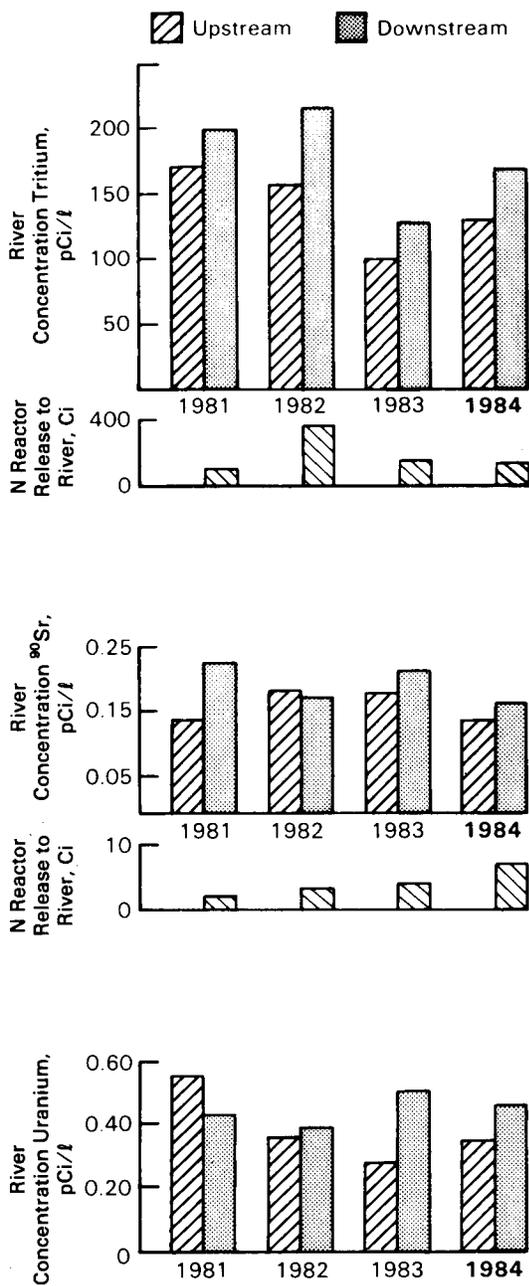
**FIGURE 12.** Columbia River Water Sampling Locations and Onsite Ponds

below the waterline (McCormack and Carlile 1984). Because most springs are visible only during periods of unusually low river flow, routine access is not possible. Monitoring the unconfined aquifer is the most effective method for monitoring the discharge of radionuclides through spring flows to the Columbia River.

Concentrations of tritium measured upstream and downstream of Hanford (Figure 13) during 1984 were 130 pCi/l and 170 pCi/l, respectively. Sources of tritium were effluent releases from 100 N (140 Ci during 1984) and ground water containing tritium that has migrated to the river (see "Ground-Water Monitoring" chapter).

Contributions from these sources observed in downstream concentrations of tritium were difficult to distinguish from one another due to the relatively high background concentrations in the Columbia River. Concentrations measured during 1984 were not appreciably different from those measured in previous years. All observed concentrations were well below the DOE Concentration Guide of 3,000,000 pCi/l.

An apparent difference in  $^{90}\text{Sr}$  concentrations between upstream and downstream sampling locations was reported in 1981 (Sula et al. 1982). The sampling frequency for  $^{90}\text{Sr}$  was increased from quarterly to monthly in 1982 as a result of



**FIGURE 13.** Annual Average Tritium, Strontium-90 and Uranium Concentrations in the Columbia River, 1981 to 1984

the 1981 measurements, and monthly sampling has continued to the present. Strontium-90 concentrations during 1984 for the monthly cumulative samples averaged 0.14 pCi/l and 0.17 pCi/l at the upstream and downstream locations,

respectively. The DOE Concentration Guide for  $^{90}\text{Sr}$  is 300 pCi/l. Observation of  $^{90}\text{Sr}$  concentrations for the past five years (see Figure 13) indicates that, other than 1981, differences between upstream and downstream locations have been very slight.

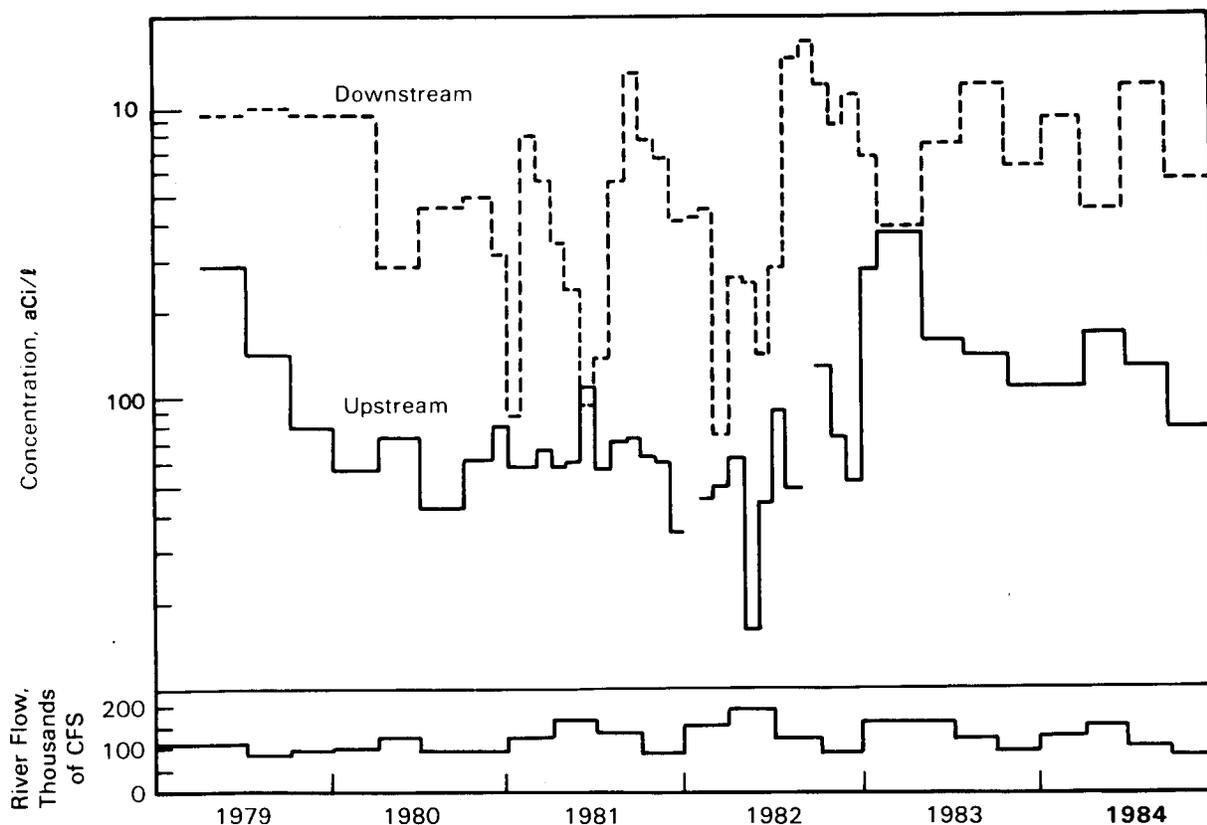
Average concentrations of  $^{89}\text{Sr}$  in upstream and downstream water samples were essentially the same in 1984 (0.13 pCi/l and 0.15 pCi/l, respectively), well below the DOE Concentration Guide of 3,000 pCi/l. The only source of  $^{89}\text{Sr}$  to the river was N Reactor, which discharged 0.91 Ci to the river in 1984.

As in past years, the upstream average concentration of uranium (Figure 13) was slightly lower than the downstream concentration (0.33 pCi/l and 0.45 pCi/l respectively). The DOE Concentration Guide for uranium is 600 pCi/l. There was no direct discharge of uranium to the river. Uranium is known to be a primary constituent in the ground water beneath the 300 Area (Prater et al. 1984).

Iodine-131 was observed at very low concentrations in several downstream samples, as in previous years. The average downstream concentration of  $^{131}\text{I}$  during 1984 was 0.017 pCi/l, compared to the DOE Concentration Guide of 300 pCi/l. The N Reactor, which reported 4.4 Ci discharged to the river during 1984, was the only Hanford source of  $^{131}\text{I}$  to the river. The positive  $^{131}\text{I}$  identifications in the downstream samples correlated with extended periods of N Reactor operations and seasonally low river flow rates.

The Hanford contribution of  $^{129}\text{I}$  to the river was attributed to the flow of ground water from the unconfined aquifer. Figure 14 provides a comparison of  $^{129}\text{I}$  upstream and downstream of the site during the past five years and shows the effect of river flow rate on the observed downstream levels. As shown in this figure, the differences between the upstream and downstream locations during 1984 were similar to previous years. The average upstream and downstream concentrations of  $^{129}\text{I}$  during 1984 were 12 aCi/l and 74 aCi/l, well below the DOE Concentration Guide of 60,000,000 aCi/l.

The average upstream concentration of  $^{137}\text{Cs}$  was nearly identical to the downstream; such was the case also for  $^{239,240}\text{Pu}$ . For both radionuclides, measured concentrations were consistent with



**FIGURE 14.** Columbia River Flow Rates and I-129 Concentrations

previous years, and well below applicable DOE Concentration Guides. Cobalt-60 was observed more frequently in downstream than upstream samples. The annual average particulate and dissolved concentrations downstream were 0.0076 pCi/l and 0.012 pCi/l respectively. Both are considerably lower than the DOE concentration Guide of 30,000 pCi/l. Potential Hanford sources of  $^{60}\text{Co}$  were effluents from N Reactor (1.3 Ci during 1984) and resuspension of  $^{60}\text{Co}$  deposited in the river-bed during past operations of the single-pass production reactors. Concentrations in the downstream samples were similar to those observed in previous years.

#### ONSITE PONDS

The four onsite ponds are located outside of operating area exclusion fences (Figure 12). Two of the ponds, Gable Pond and B Pond near the 200 East Area, were excavated in the mid-1950's for disposal of chemical process cooling water and wastes occasionally containing low levels of

radioactive contamination. The FFTF Pond, excavated in 1978, is a sewage disposal and treatment lagoon and does not routinely receive radioactive wastes. The fourth pond, West Lake, is a natural lake interconnected with the ground water and does not receive direct discharges from site facilities.

#### Sample Collection and Analysis

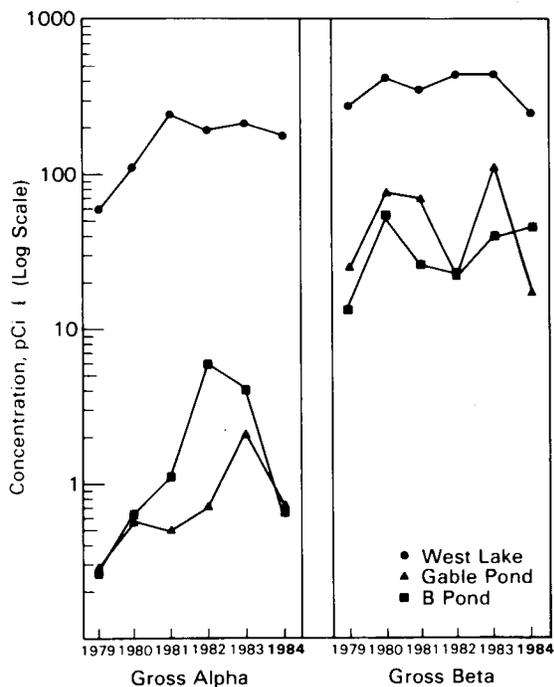
Grab samples of 10l of water from each pond were collected quarterly during 1984. Unfiltered sample aliquots were analyzed for gross alpha, gross beta, gamma emitters,  $^3\text{H}$ , and  $^{90}\text{Sr}$ . The FFTF Pond samples were analyzed for  $^{22}\text{Na}$  instead of  $^{90}\text{Sr}$ . Results for 1984 samples are summarized and graphed below; data values are tabulated in Table A.13, Appendix A.

#### Results

As in past years the highest gross alpha and gross beta concentrations were observed at West Lake

(Figure 15), which is constantly recharged from a deep aquifer with only minor exchange of water between the pond and the unconfined aquifer (Gephart et al. 1976). Special water samples collected and analyzed in 1975 indicated the radioactivity in the pond to be primarily from naturally occurring uranium (Speer, Fix and Blumer 1976). Therefore, the observed radioactivity was the result of naturally occurring radionuclides in the pond recharge that have been concentrated by evaporation over the years. Concentrations of gross alpha and gross beta in West, Gable and B Ponds were consistent with concentrations measured in past years; concentrations in FFTF Pond were nearly undetectable.

Tritium analysis of all pond water samples was initiated in 1983. Concentrations for the past two years appear in Table 2. The concentration of tritium in West Lake samples reflected the concentrations known to occur in nearby ground water. A similar situation occurred at FFTF where



**FIGURE 15.** Annual Average Gross Alpha and Gross Beta Concentrations in Onsite Ponds

**TABLE 2.** Tritium Concentration in Onsite Ponds

Location	No. of Samples	Average Concentration, pCi/l	
		1983	1984
West Lake	4	1300 ± 1200	940 ± 170
Gable Pond	4	190 ± 160	220 ± 120
B Pond	4	230 ± 220	5600 ± 4500
FFTF Pond	4	22,000 ± 5000	29,000 ± 9800

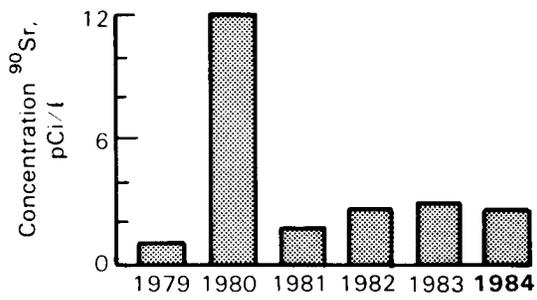
(a) Average ± two standard error of the calculated mean (95% confidence interval).

the source of pond water was from the pumping and subsequent discharge of local ground water. Tritium levels in the FFTF Pond were noted to be about the same as concentrations in the local ground water. Ground water at the FFTF site is known to contain tritium from past effluent discharges in the 200 Areas (Prater et al. 1984). Elevated concentrations of tritium in B Pond were attributed to increased tritium discharged to the pond from PUREX operations.

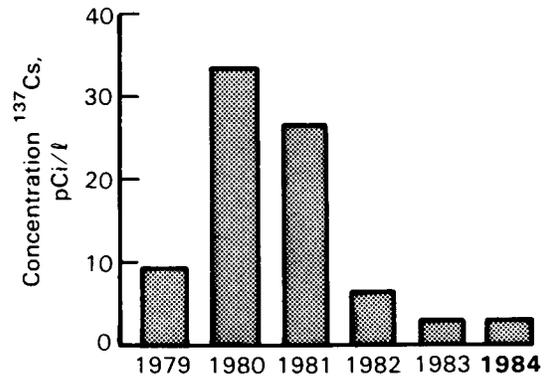
Cesium-137 and <sup>90</sup>Sr concentrations in B Pond were similar to those observed in 1983 (Figures 16 and 17). The 1984 average <sup>90</sup>Sr concentration was calculated omitting an abnormally high concentration (33 pCi/l) measured during the second quarter.<sup>(a)</sup> Effluent discharges to B Pond during that quarter, as measured by the operating contractor, indicated no apparent elevated release of <sup>90</sup>Sr to B Pond, suggesting that the concentration measured in the pond sample was incorrect. Concentrations of these two radionuclides increased in 1980, but have fallen off in subsequent years and appear to have stabilized.

Although no radionuclides are routinely discharged to FFTF Pond, there is a potential for an accidental release. Thus, <sup>22</sup>Na is routinely monitored in FFTF Pond samples as an indicator of process failure. As in past years, results were below the detection level.

(a) All data are reported in Table A.13, Appendix A.



**FIGURE 16.** Annual Average Strontium-90 Concentrations in B Pond Water



**FIGURE 17.** Annual Average Cesium-137 Concentrations in B Pond Water

## FOODSTUFFS MONITORING

Alfalfa and several types of foodstuffs, including milk, leafy vegetables, fruits, beef, chickens, eggs, and wheat were collected at several locations in the Hanford Site environs during 1984. Samples were collected primarily from locations in the prevalent downwind directions, i.e., to the south and east of the site. Samples also were collected in generally upwind directions somewhat distant from the site to provide information on radioactivity levels that could be attributed to worldwide fallout. Foodstuffs collected in the Riverview Area were irrigated with Columbia River water and thus provided information regarding radionuclide concentrations in food potentially attributable to radionuclides in the river water. All samples were analyzed for  $^{90}\text{Sr}$  and  $^{137}\text{Cs}$ . Milk samples were analyzed also for  $^{131}\text{I}$ ,  $^{129}\text{I}$ ,  $^{89}\text{Sr}$ , and tritium. Fruit samples were analyzed for  $^3\text{H}$ ,  $^{90}\text{Sr}$ , and  $^{137}\text{Cs}$ .

Samples collected during 1984, as in recent years, indicated no apparent Hanford contribution to radioactivity levels in locally produced foodstuffs. Tritium,  $^{90}\text{Sr}$  and  $^{137}\text{Cs}$  were found in a number of the samples; however, the concentrations measured in samples collected near the Hanford Site were similar to those measured in samples collected away from the site. Iodine-131 was detected in a single milk sample. There are no radionuclide concentration limits for foodstuffs. Impact was assessed from predicting radiation dose from food consumption.

### MILK

Samples of raw, whole milk were collected from several local dairy farms near the site perimeter and in the prevalent downwind directions to evaluate possible Hanford impacts. Samples also were collected from dairy farms near Sunnyside and Moses Lake to provide indications of the general concentrations of radionuclides in milk attributable to worldwide fallout. The sampling locations are shown in Figure 18 and listed in Table A.14, Appendix A. Samples were collected biweekly throughout the year from the Sagemoor and Sunnyside areas. Samples from the other areas were collected monthly during the year.

Iodine-131 was detected in only one milk sample collected in the Sagemoor Area. The concentration was low enough (0.94 pCi/l) that no significant radiation exposure would occur from drinking the milk.

Cesium-137 was identified in about 25% of the samples. Concentrations in all cases were low and within the range attributable to worldwide fallout (USEPA 1984a).

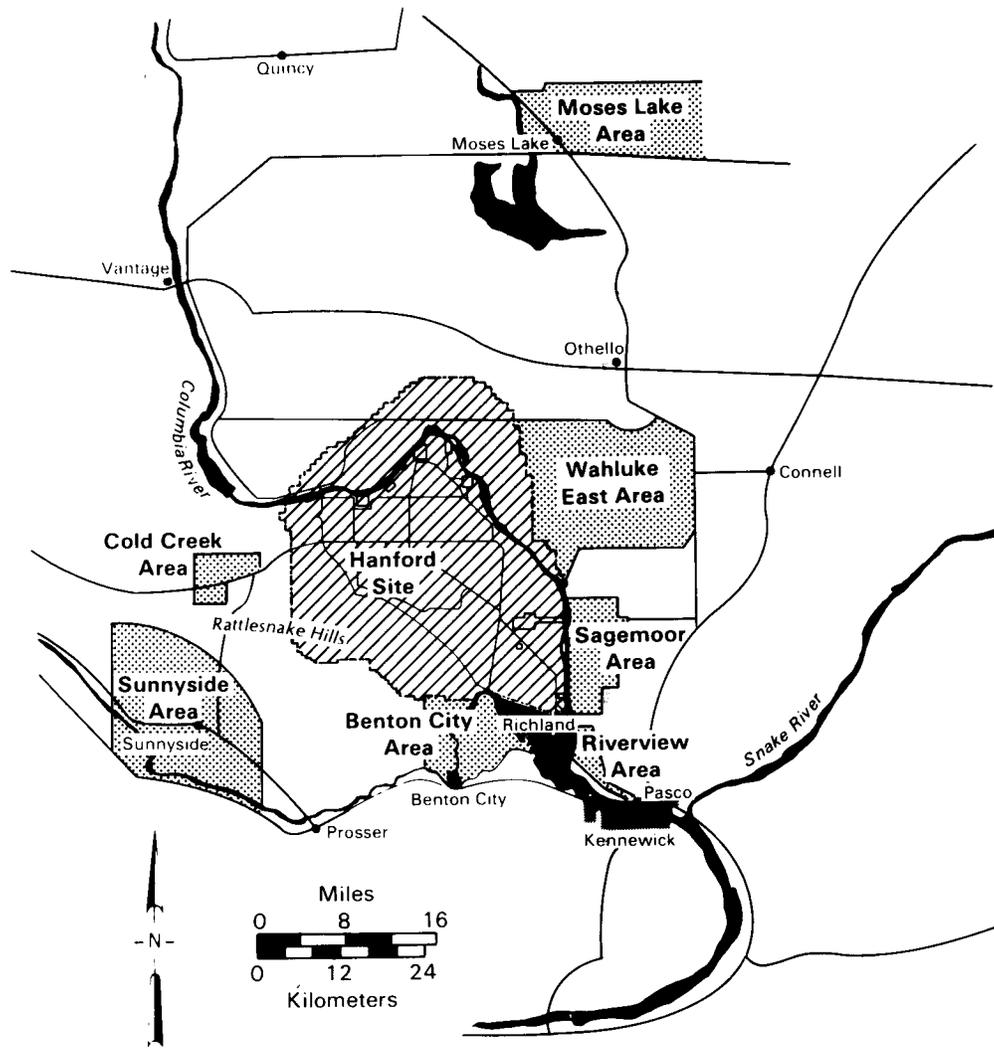
A portion of the milk sample was analyzed for  $^{89}\text{Sr}$  and  $^{90}\text{Sr}$ . Strontium-89 was not regularly detected in the milk; however,  $^{90}\text{Sr}$  was observed in most samples analyzed. Maximum and average concentrations were similar at all locations, both near and distant, and were comparable to concentrations observed in recent years. Aver-

age  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  concentrations in milk for 1984 and the previous five years are shown in Figure 19. The effects of atmospheric nuclear testing are reflected in the somewhat higher  $^{137}\text{Cs}$  values for 1979 and 1980, while the  $^{90}\text{Sr}$  data have been consistently low for the past several years.

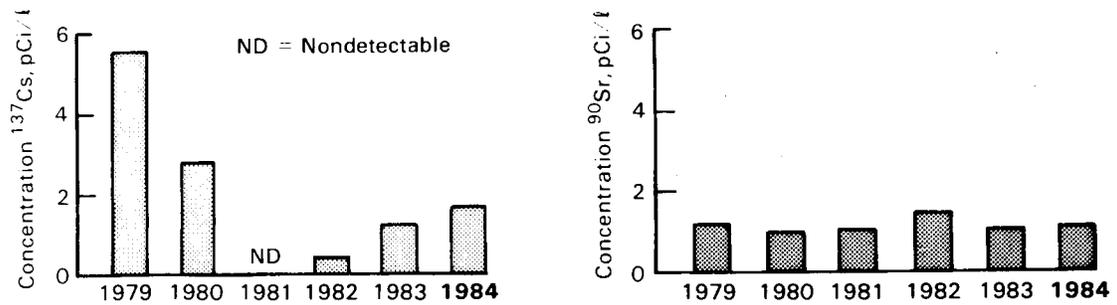
Analyses for  $^{129}\text{I}$  and tritium were performed on selected milk samples in 1984. Tritium was identified in nearly half of the samples, and  $^{129}\text{I}$  in all of the samples. Concentrations, however, were low, and no differences were apparent between near-site and distant sampling locations.

### LEAFY VEGETABLES

Samples of leafy vegetables (i.e., spinach, leaf lettuce, turnip greens or mustard greens) were obtained once during the summer from gardens located within the sampling areas listed in Table A.15, Appendix A. The leafy vegetables provide an indication of radionuclides present in locally grown produce. Three replicate samples, each composed of mixtures of the edible portions of the various leafy vegetables grown at the sampling location, were obtained. Samples were analyzed for  $^{90}\text{Sr}$  and  $^{137}\text{Cs}$ , and results are provided in Table A.13. Strontium-90 was identified in most samples but with no apparent difference between distant and nearby locations. Cesium-137 was identified in about 7% of the samples without any indication of a difference



**FIGURE 18.** Foodstuffs Sampling Areas



**FIGURE 19.** Cesium-137 and Strontium-90 Concentrations in Milk, 1979 to 1984

between locations. There were no important changes in  $^{90}\text{Sr}$  and  $^{137}\text{Cs}$  concentrations when compared to recent years, as shown in Figure 20.

### FRUIT

Samples of apples, cherries, or grapes were collected at picking time from the areas listed in Table A.14, Appendix A. Three replicate samples were collected at each sampling location, and the edible portions were analyzed for  $^3\text{H}$ ,  $^{90}\text{Sr}$  and  $^{137}\text{Cs}$ . Results are provided in Table A.16.

Tritium was identified in about half of the samples analyzed, and  $^{90}\text{Sr}$  in about 90% of the samples. Grapes had slightly higher tritium concentrations than the other fruits, but otherwise there were no apparent differences between fruit types or sampling locations. As in recent years,  $^{137}\text{Cs}$  was generally not detectable in fruit samples.

### WHEAT AND ALFALFA

Samples of field-dried wheat and alfalfa were collected from the areas listed in Table A.17, Appendix A. Three replicate samples, each of wheat and alfalfa, were collected at each loca-

tion following the final cutting of the growing season and analyzed for  $^{90}\text{Sr}$  and  $^{137}\text{Cs}$ . Results of the analysis are shown in Table A.17.

When sampling of wheat and alfalfa began in 1982, variable moisture content in the samples from different locations may have contributed to the variability in results. Beginning in 1983 samples were reported on a dry weight basis, eliminating variability due to different moisture contents. As in 1983,  $^{90}\text{Sr}$  was identified in nearly all of the samples, and  $^{137}\text{Cs}$  was identified in very few samples in 1984. No distinct difference in radionuclide concentrations was apparent in the samples from near the site compared to samples collected far from the site.

### BEEF, POULTRY AND EGGS

Samples of locally produced chickens, eggs and beef were collected from the areas listed in Table A.18, Appendix A. Table A.18 provides results of analysis of the samples for  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$ . Results were all very low and generally near detection levels. Cesium-137 and  $^{90}\text{Sr}$  concentrations in beef for 1984 and the previous 5 years are shown in Figure 21.

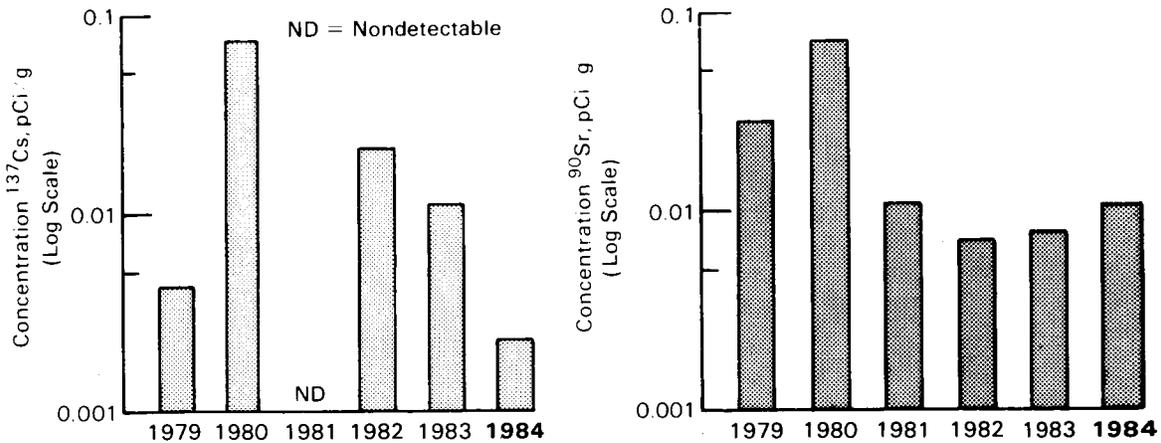
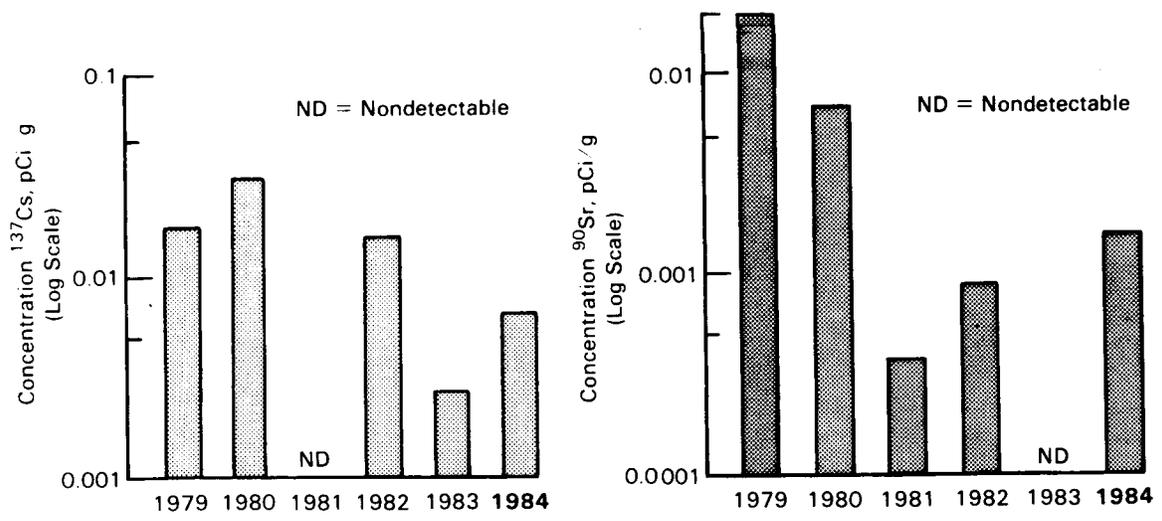


FIGURE 20. Cesium-137 and Strontium-90 Concentrations in Leafy Vegetables, 1979 to 1984



**FIGURE 21.** Cesium-137 and Strontium-90 Concentrations in Beef, 1979 to 1984

## WILDLIFE MONITORING

The Hanford Site serves as a refuge for waterfowl, upland game birds, and a variety of other animals. Wildlife have access to several areas near site facilities (e.g., waste-water ponds) that contain low levels of radionuclides attributable to site operations. Sampling was performed in areas where the potential existed for uptake of radionuclides by wildlife. The number of animals that visited these areas was small compared to the total wildlife population, and, as a result, human consumption of animals from the sampling locations was unlikely. Nevertheless, these samples helped provide an estimate of the potential dose impact if onsite game animals were consumed.

Fish were collected from the Hanford reach of the Columbia River. Results provided an indication of the radionuclide concentrations in local fish so that the potential dose to humans for this pathway could be evaluated. Fish collected from the Hanford reach of the Columbia River showed no important difference in radionuclide concentration compared to upstream samples. Analytical results of terrestrial wildlife samples collected during 1984 were similar to those observed in recent years. The dose that could have been received by consuming any of the sampled wildlife at the maximum radionuclide concentrations measured in 1984 would be well below applicable DOE dose standards.

### DEER

Samples taken from road-killed deer (Figure 22) were used to provide an indication of the general levels of radionuclides in Hanford Site deer. Six deer were sampled and analyzed for  $^{137}\text{Cs}$  in muscle and  $^{239,240}\text{Pu}$  in liver. Results indicated the presence of detectable levels of  $^{137}\text{Cs}$  in only one deer at 0.007 pCi/g. The livers of two animals contained detectable quantities of  $^{239,240}\text{Pu}$  with the maximum concentration of 0.0005 pCi/g. The concentrations were in the range generally attributed to worldwide fallout, and the median values were consistent with those observed in previous years as shown in Figures 23 and 24. Individual results for 1984 are shown in Table A.19, Appendix A.

### FISH

Fish were caught at various locations along the Columbia River, and boneless fillets were analyzed for  $^{60}\text{Co}$ ,  $^{90}\text{Sr}$ , and  $^{137}\text{Cs}$ . Median concentrations for  $^{60}\text{Co}$  and  $^{137}\text{Cs}$  in whitefish and bass over recent years are shown in Figures 25 and 26. Whitefish were collected both upstream of Hanford near Priest Rapids Dam and within the site near 100-D Area. Bass were collected near 100-F Area.

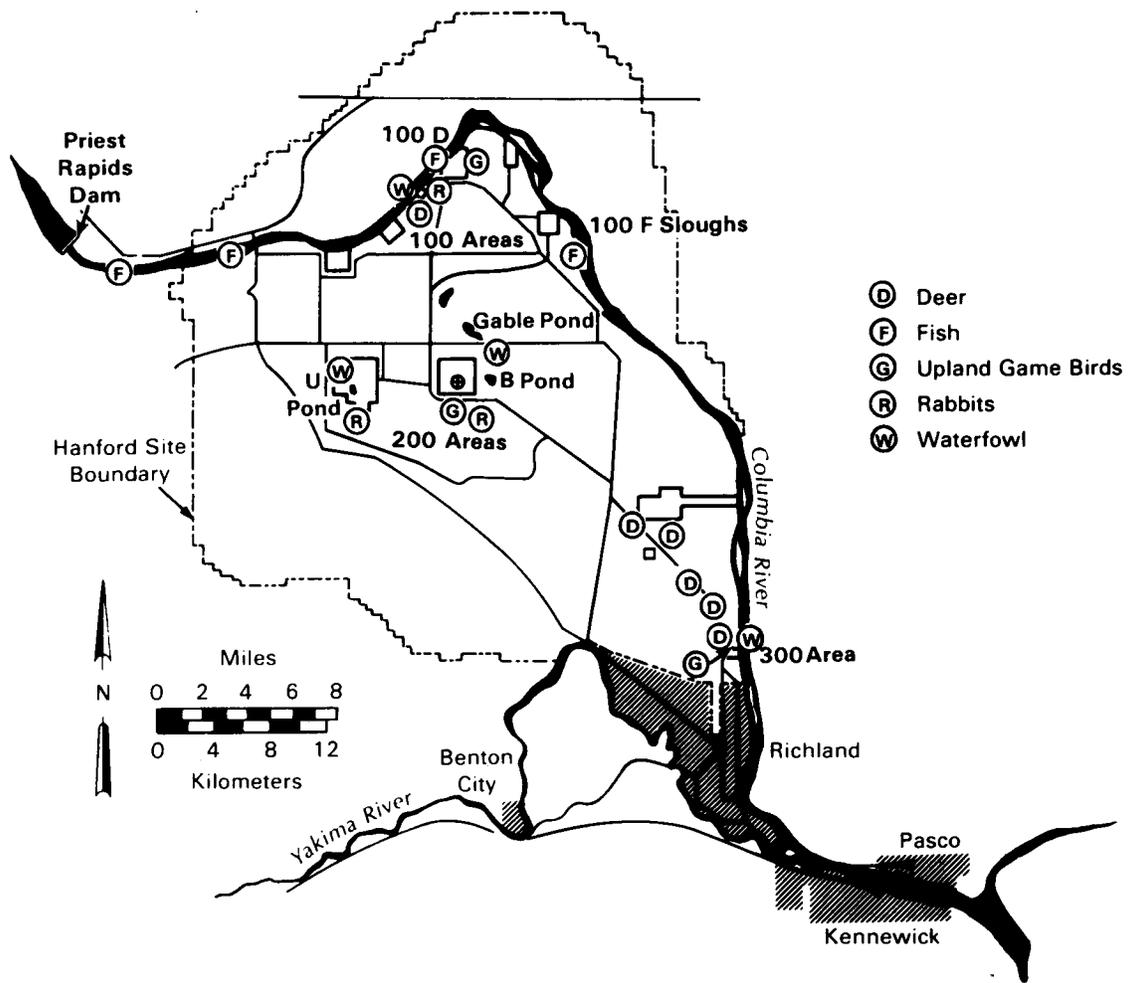
Cobalt-60 and  $^{137}\text{Cs}$  were identified more frequently in whitefish samples collected along the Hanford reach of the river near 100-D Area than in samples collected upstream of the site, but the

concentration differences were not quantifiably different. The presence of the  $^{60}\text{Co}$  in the fish may be associated with residual radioactivity in sediments of the Columbia River from past operations or effluent releases from N Reactor.

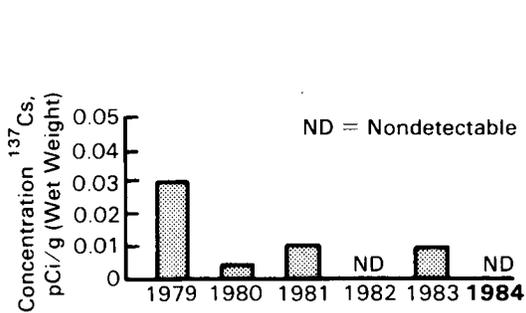
The maximum and average concentrations of  $^{90}\text{Sr}$  in whitefish fillets from samples collected upstream of the site were not quantifiably different than those collected near the 100-D Area. The upstream value was higher than the previous two years of data; and the 100-D values were between those of the previous two years. Individual results for  $^{60}\text{Co}$ ,  $^{90}\text{Sr}$  and  $^{137}\text{Cs}$  for 1984 are shown in Table A.20, Appendix A.

### UPLAND GAME BIRDS

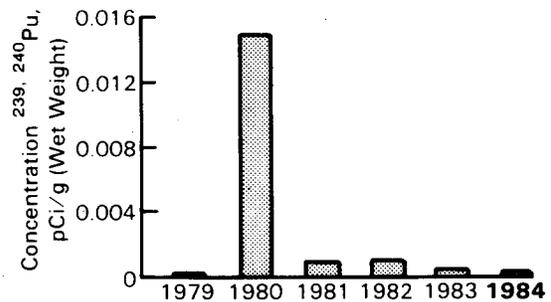
Upland game birds including pheasant and chukar were from the 100, 200 and 300 Areas (Figure 22). Samples of breast meat from each bird were analyzed for  $^{60}\text{Co}$  and  $^{137}\text{Cs}$ . A higher percentage of the birds showed detectable concentrations of  $^{137}\text{Cs}$  than of  $^{60}\text{Co}$ . The median concentrations for  $^{137}\text{Cs}$  in the 100 and 200 Areas are shown in Figure 27 and are within the ranges of the previous years. Median  $^{137}\text{Cs}$  concentrations in the 300 Area were lower than the other areas. Cobalt-60 concentrations were near minimum detectable levels with the maximum sample at 0.03 pCi/g. Maximum and average concentrations for 1984 for both nuclides are shown in Table A.21, Appendix A.



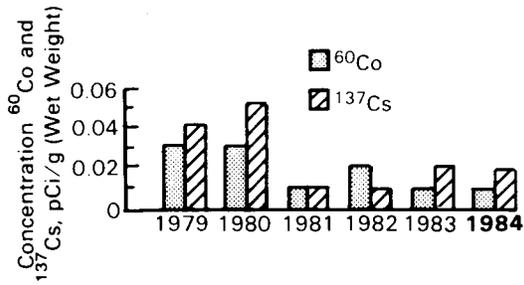
**FIGURE 22.** Wildlife Sampling Areas



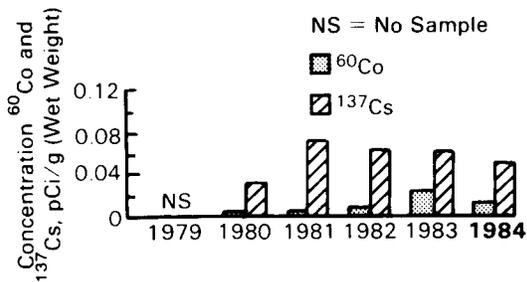
**FIGURE 23.** Median Concentrations of <sup>137</sup>Cs in Deer Muscle



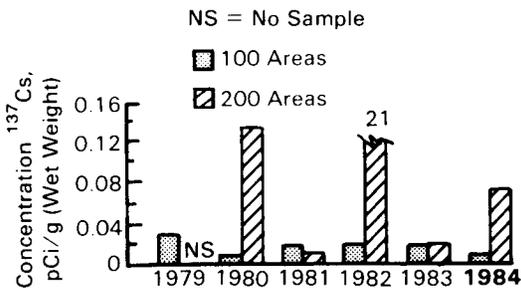
**FIGURE 24.** Median Concentrations of <sup>239,240</sup>Pu in Deer Liver



**FIGURE 25.** Median Concentrations of <sup>60</sup>Co and <sup>137</sup>Cs in Whitefish Muscle



**FIGURE 26.** Median Concentrations of <sup>60</sup>Co and <sup>137</sup>Cs in Bass Muscle



**FIGURE 27.** Median Concentrations of <sup>137</sup>Cs in Game Bird Muscle Samples Collected from the 100 and 200 Areas

### WATERFOWL

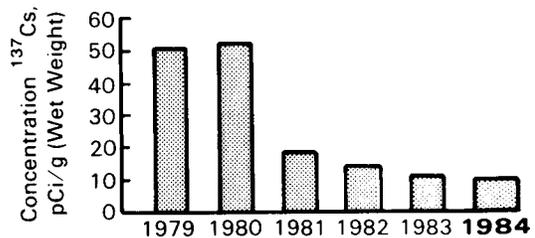
Waterfowl samples (mallard ducks) were collected from B Pond and U Pond in the 200 Areas. An approximately 0.5-kg sample of breast meat from each bird was analyzed for <sup>137</sup>Cs. The results in Figure 28 show decreasing concentrations for the 200 Area ponds over the last several years. Concentrations in samples from the 300 Area

pond in 1984 were about one tenth those in the 200 Areas as shown in Table A.22, Appendix A. Samples have been taken in previous years from other operating areas, along the Columbia River, and from Gable Mountain Pond and are reported in earlier annual reports. Gable Mountain Pond was being renovated in 1984 and no ducks were present. Decommissioning of U Pond began in 1984.

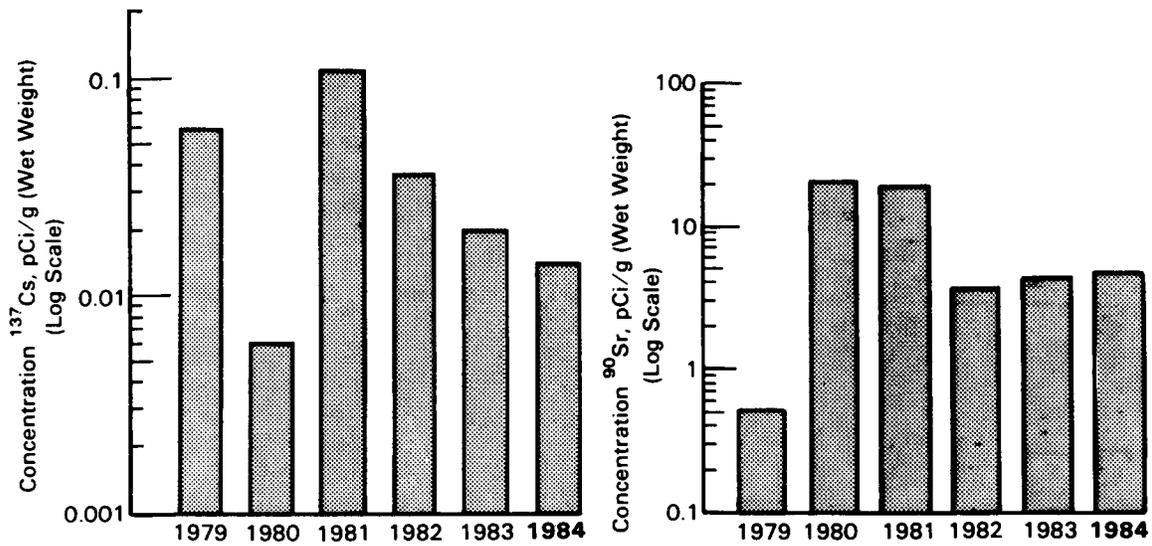
### RABBITS

Cottontail and black-tailed jack rabbits were collected in the 100 and 200 Areas (Figure 22). The samples were analyzed for gamma-emitting radionuclides in muscle, <sup>90</sup>Sr in bone and plutonium in liver. Median concentrations for <sup>90</sup>Sr in bone and <sup>137</sup>Cs in muscle for the last several years are shown in Figures 29 and 30. Median concentrations were within the range of previous years. Maximum and average concentrations for 1984 are shown in Table A.23, Appendix A.

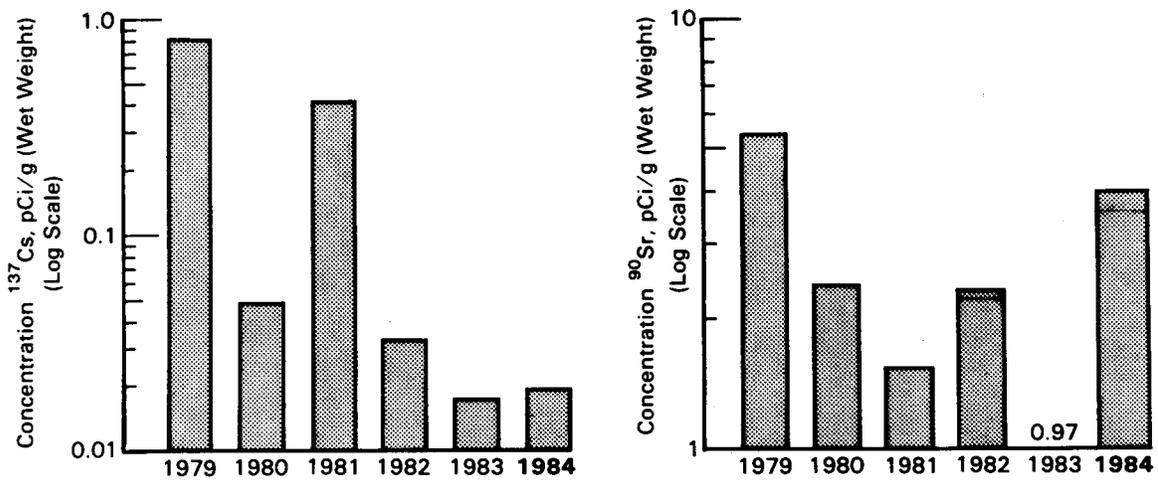
No other gamma-emitting radionuclides of possible Hanford origin were detected in any samples at levels greater than expected from worldwide fallout. Concentrations of <sup>239,240</sup>Pu in liver samples ranged from less-than-detectable to values near the detection limit (0.0006 pCi/g) with only one sample significantly above the detection limit at 0.0012 pCi/g.



**FIGURE 28.** Median Concentrations of <sup>137</sup>Cs in Duck Muscle Samples Collected from 200 Area Ponds



**FIGURE 29.** Median Concentrations of  $^{137}\text{Cs}$  in Muscle and  $^{90}\text{Sr}$  in Bone of Cottontail Rabbits in the 100 Area, 1979 to 1984



**FIGURE 30.** Median Concentrations of  $^{137}\text{Cs}$  in Muscle and  $^{90}\text{Sr}$  in Bone of Jack Rabbits in the 200 Areas, 1979 to 1984

## SOIL AND VEGETATION MONITORING

Surface soil and rangeland vegetation samples were collected at a number of locations onsite as well as offsite. The purpose of sampling was to detect the buildup of radionuclides from the deposition of airborne effluents released from Hanford facilities. Samples were collected at non-agricultural sites so as not to interfere with deposition and buildup processes. Because the radionuclides of interest were present in worldwide fallout or occurred naturally, their presence was expected in all samples.

An assessment of radionuclide contribution from Hanford operations was made by comparing the results of samples collected at downwind locations, primarily to the south and east of the site, with samples collected from distant or generally upwind directions. Based on the samples collected, there was no indication of a significant contribution from Hanford to radionuclide concentrations in soil or vegetation in the offsite environment.

### SAMPLE COLLECTION AND ANALYSIS

Soil and vegetation samples were collected at 15 onsite and 16 offsite locations as shown in Figure 31. The onsite sampling locations were primarily located adjacent to major operating areas where the contribution of radionuclides from operations could be readily assessed. The majority of the offsite samples were collected in a generally downwind direction of the site where any Hanford contribution to radionuclide levels in soil and vegetation would be expected to be most easily detected. Samples were also collected in a generally upwind direction for comparison.

Single samples of surface soil were collected at each location. Each sample consisted of a composite of five "plugs" of soil approximately 2.5-cm deep and 10 cm in diameter obtained within a 100-m<sup>2</sup> area at the sampling site. The composites were dried, sieved to pass through a 2-mm screen, and thoroughly mixed. Aliquots of the composite samples were analyzed.

Samples of perennial vegetation were collected in the immediate vicinity of the soil sampling locations at the same time soil sampling was performed. Vegetation samples included a mixture of rabbitbrush, sagebrush and bitterbrush in rough proportions to the natural abundance of the three plants at the sampling location. No single species of perennial vegetation grows at all of the sampling locations. The vegetation samples were collected by cutting a small amount of the recent growth from a sufficient number of plants in the area to make up an approximately 1-kg sample. The sample was then dried and

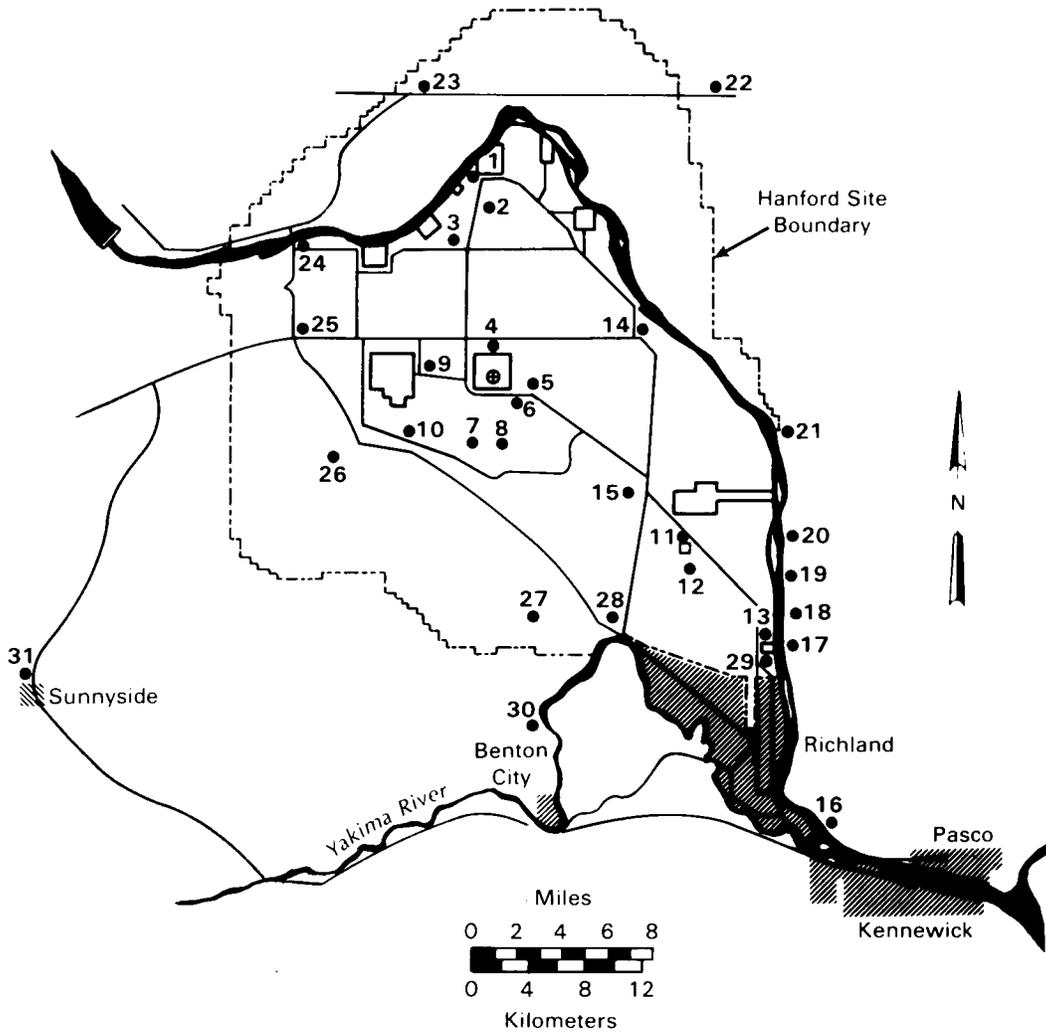
ground and aliquots were taken for analysis. Samples were analyzed for <sup>137</sup>Cs and other gamma-emitting radionuclides, <sup>90</sup>Sr, plutonium and uranium.

### SOIL

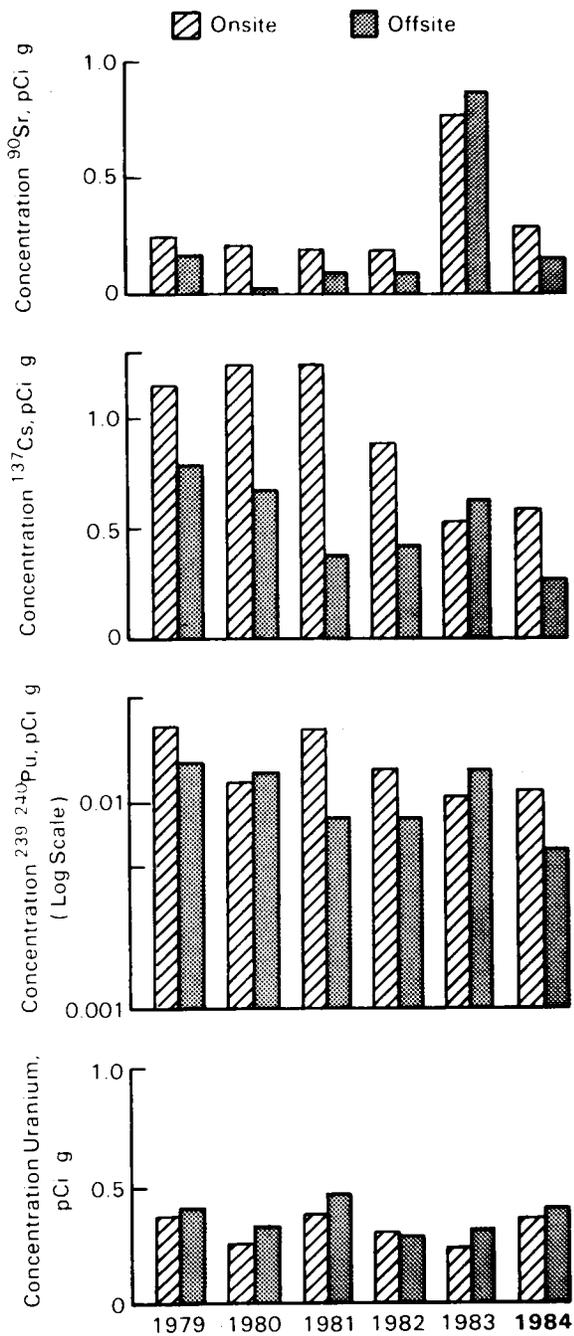
Individual results of soil analyses for samples collected at onsite and offsite locations for 1984 are shown in Table A.24, Appendix A. Although some variability existed between sampling locations, concentrations of three long-lived radionuclides <sup>90</sup>Sr, <sup>137</sup>Cs and <sup>239,240</sup>Pu were similar to those observed in previous years. Sampling locations near the 200 Areas continued to show slightly elevated concentrations for a few radionuclides. Specifically, the 200-ENC sample (location 4, Figure 31) showed elevated levels of <sup>137</sup>Cs and the E of 200W (location 9, Figure 31) sample exhibited elevated levels of <sup>239,240</sup>Pu, with <sup>90</sup>Sr and <sup>137</sup>Cs decreasing at both locations from previous years.

The offsite soil data were similar to data collected during the last several years. The histograms in Figure 32 display <sup>90</sup>Sr, <sup>137</sup>Cs, <sup>239,240</sup>Pu, and uranium median values for all onsite and offsite locations for 1984 and the previous five years. As shown in the figure, radionuclide concentrations tend to be slightly elevated at onsite locations when compared with offsite locations. The only exception is uranium which was found to be slightly elevated in the offsite environs. Uranium is thought to be naturally occurring in the soil at several offsite sampling locations.

Routine soil sampling began in 1971, and Table A.25, Appendix A lists all <sup>239,240</sup>Pu results for



**FIGURE 31.** Soil and Vegetation Sampling Areas (See Tables A.24 and A.26, Appendix A, for location number key)



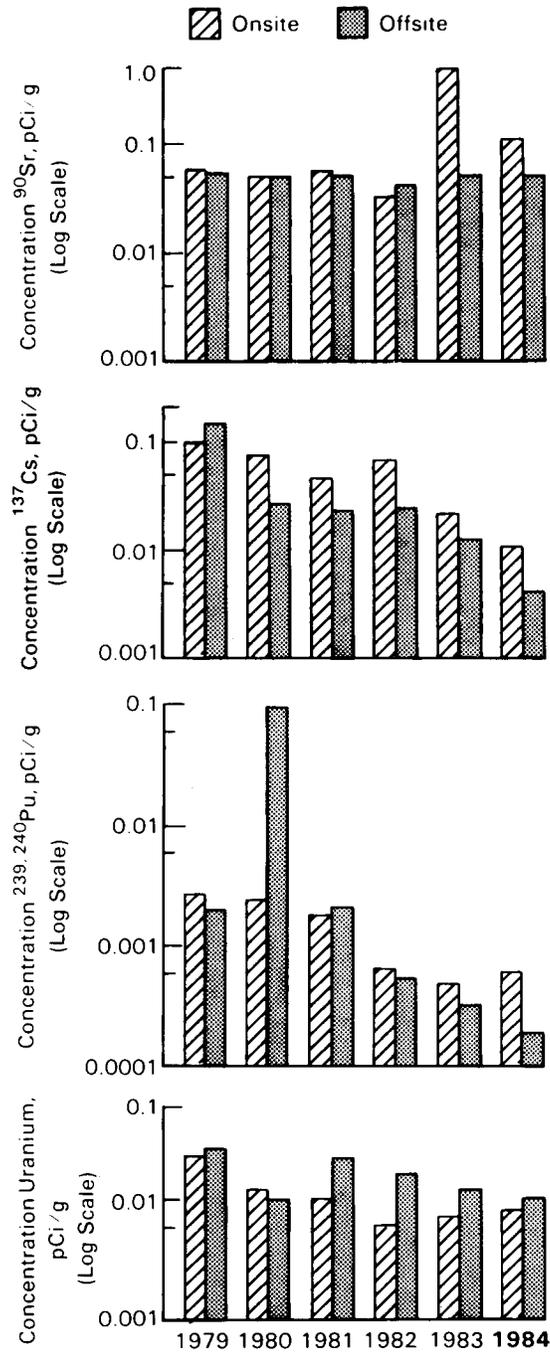
**FIGURE 32.** Median Strontium-90, Cesium-137, Plutonium-239,240 and Uranium Concentrations in Soil at all Onsite and Offsite Locations, 1979 to 1984

samples collected at several onsite and offsite locations. These historical records reveal two important factors: first, in spite of the use of a sampling technique designed to overcome variability, results over the years at a single location are highly variable; second, concentrations are quite low and all sites appear to be stable over time.

## VEGETATION

Individual results of analyses for radionuclides in samples of mature vegetation collected during 1984 at onsite and offsite locations are shown in Table A.26, Appendix A. Trace concentrations of those radionuclides associated with worldwide fallout were measured in all samples collected.

Concentrations of long-lived radionuclides in vegetation samples were similar to those measured at the respective locations in previous years (Figure 33). Concurrent with soil data, concentrations of radionuclides in vegetation in the onsite environs were slightly higher, with the exception of uranium, when compared with offsite data. Similarly, uranium concentrations in vegetation were slightly higher at offsite locations compared to onsite.



**FIGURE 33.** Median Strontium-90, Cesium-137, Plutonium-239,240 and Uranium Concentrations in Vegetation at all Onsite and Offsite Locations, 1979 to 1984

## PENETRATING RADIATION MONITORING

Dose rates from penetrating radiations (primarily gamma-rays) were measured at a number of locations in the Hanford environs during 1984. The measurements were made using thermoluminescent dosimeters (TLDs) to provide estimates of the dose rates from external radiation sources. Naturally occurring sources, including radiations of cosmic origin and natural radioactive materials in the air and ground, as well as fallout from the atmospheric testing of nuclear weapons, resulted in a certain amount of penetrating radiations being recorded at all dosimeter locations. Dosimeters also measured dose rates from exposure to radioactive materials associated with activities at Hanford. Measurements made onsite and offsite were similar to past years. As expected, dose rates near operating facilities were somewhat higher than natural background.

Radiation surveys were conducted at numerous locations on the Hanford Site. Onsite roads, railroads and retired waste disposal sites located outside of operating areas were routinely surveyed during 1984. These surveys were designed to confirm the continued integrity of containment facilities and to identify areas where abnormal levels of radioactivity may have existed. Survey results for 1984 were comparable to past years. No unexpected or abnormal conditions were observed on the site highways or railroads.

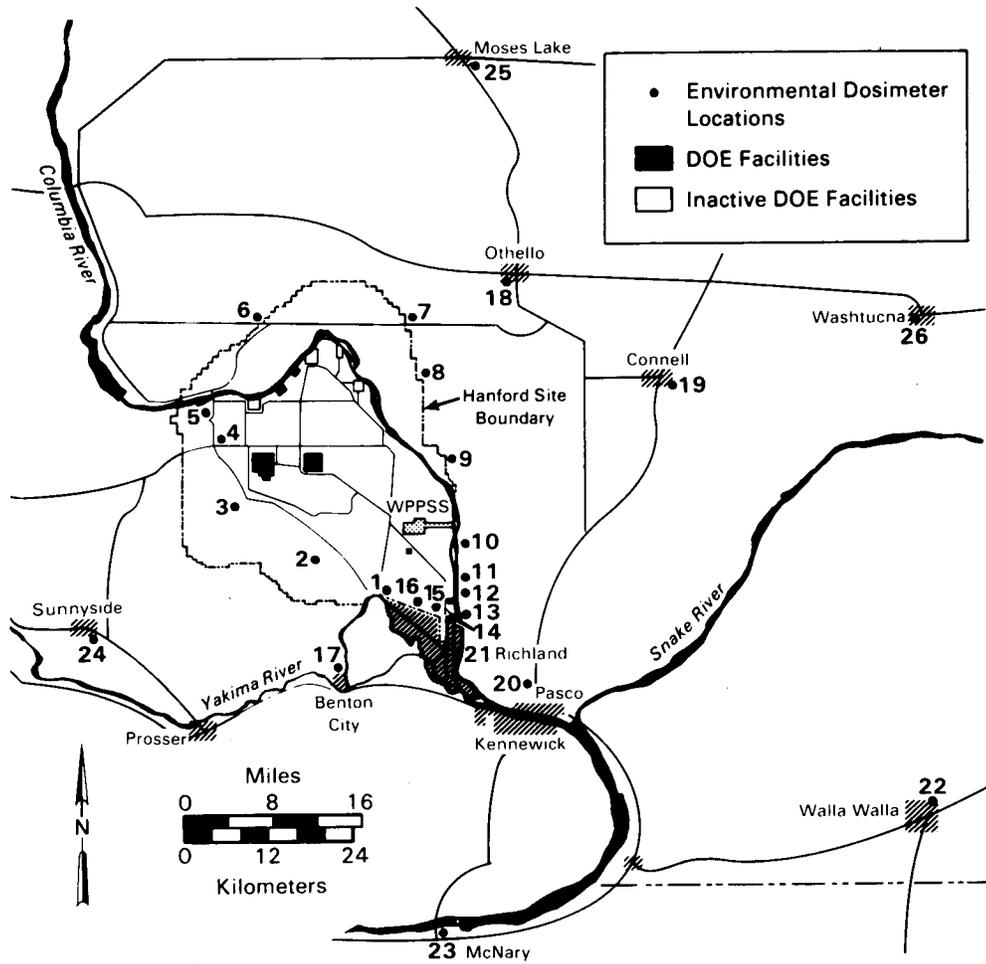
### PENETRATING RADIATION MEASUREMENTS (TLDs)

External radiation measurements were made using environmental TLDs at numerous locations onsite, around the perimeter of the site, in nearby communities, distant communities and along the shoreline of the Columbia River. Environmental radiation dosimeters consisted of five  $\text{CaF}_2:\text{Mn}$  thermoluminescent chips encased in a plastic capsule. The capsule contained a lead/tantalum filter to provide uniform dose response characteristics for penetrating radiations above 60 keV (Fix and Miller 1978). The dosimeters were mounted one meter above ground level and were exchanged every four weeks, with the exception of the shoreline TLDs which were exchanged quarterly. Measured doses are reported in dose equivalent units (mrem) to enable comparison to dose standards and dose equivalents reported elsewhere in this document. The TLDs record radiation exposure from natural and fallout sources as well as any local contribution (NCRP 1975).

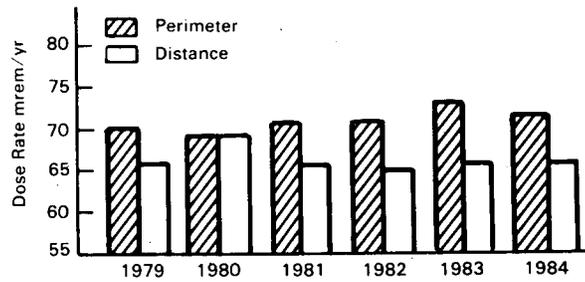
Dosimeters were located at numerous locations in the vicinity of Hanford and at several locations somewhat distant from the site as shown in Figure 34. The dose rates measured at each location during 1984 are given in Table A.27, Appendix A. Most of the offsite dosimeter locations were in or near areas that could have been inhabited

continuously. Dose measurements at these locations are reported in units of mrem/yr. Results were similar to those observed in previous years for the respective locations. The background dose rate, calculated from the annual average dose rates observed at distant locations, was similar to past years at 66 mrem/yr (0.008 mrem/h). Figure 35 shows average annual dose rates measured at perimeter and distant locations during the past five years. The figure illustrates the natural year-to-year variability of penetrating radiations in the environs at both near and distant locations. The figure also demonstrates that dose rates at perimeter stations generally averaged several mrem/yr higher than the distant locations. The possibility of a historic release of radioactive material (prior to 1974) as a cause for the observed differences in dose rate is not substantiated by soil and vegetation sampling data provided in this and previous annual reports. The differences may be due to natural geographic variations in terrestrial radiation.

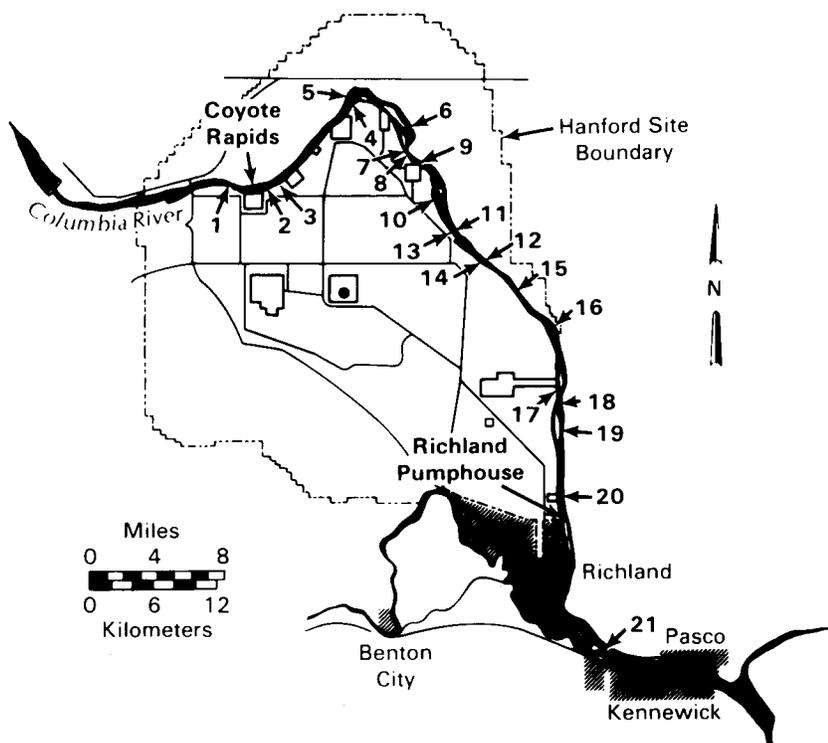
Dosimeters were submerged in the Columbia River at Coyote Rapids and at the Richland pumphouse (Figure 36) to provide an estimate of penetrating dose rates that could be received by a person immersed in the river. Results of the measurements, shown in Table A.28, Appendix A, were less than the background dose rate of 0.008 mrem/h measured on land. The average



**FIGURE 34.** Environmental Dosimeter Locations at the Site Perimeter, Nearby Communities and Distant Communities (See Table A.27, Appendix A, for location number key)



**FIGURE 35.** Annual Average External Dose Rates at Perimeter and Distant Locations, 1979 to 1984



**FIGURE 36.** Environmental Dosimeter Locations Along the Hanford Reach of the Columbia River (See Table A.30, Appendix A, for location number key)

dose rates at the Coyote Rapids and Richland pumphouse locations were 0.005 mrem/h and 0.004 mrem/h, respectively, during 1984. As expected, these dose rates have remained low and relatively constant over the years.

Dosimeters were placed at several publicly accessible locations near the perimeter of operating areas on the Hanford Site as shown in Figure 37. These locations included the shoreline of the Columbia River near 100-N Area, parking lots near the west perimeter of the 300 Area, and the parking lot near the visitors center at the 400 Area (FFTF). Results of these measurements for 1984 are shown in Table A.29, Appendix A. Results are reported as mrem/h (instead of mrem/yr) because the locations are not continuously occupied by the same person. Dose rates near the 100-N Area on the river shoreline were slightly elevated but similar to those observed in previous years. The maximum dose rate recorded was 0.050 mrem/h while the average varied between 0.011 and 0.030 mrem/h. Dose rates at

publicly accessible locations along the west perimeter of the 300 Area were elevated slightly compared to normal background levels of 0.008 mrem/h. The highest dose rate measured was 0.020 mrem/h at a location near a research facility housing a radioactive steam generator presently under study. The average dose rate at the other 300 Area perimeter location near a publicly accessible area was found to be at background levels (0.008 mrem/h). Dose rates near the visitors center at the 400 Area (FFTF) were at background levels, indicating no additional penetrating dose rate could be attributed to FFTF activities during 1984 at this location.

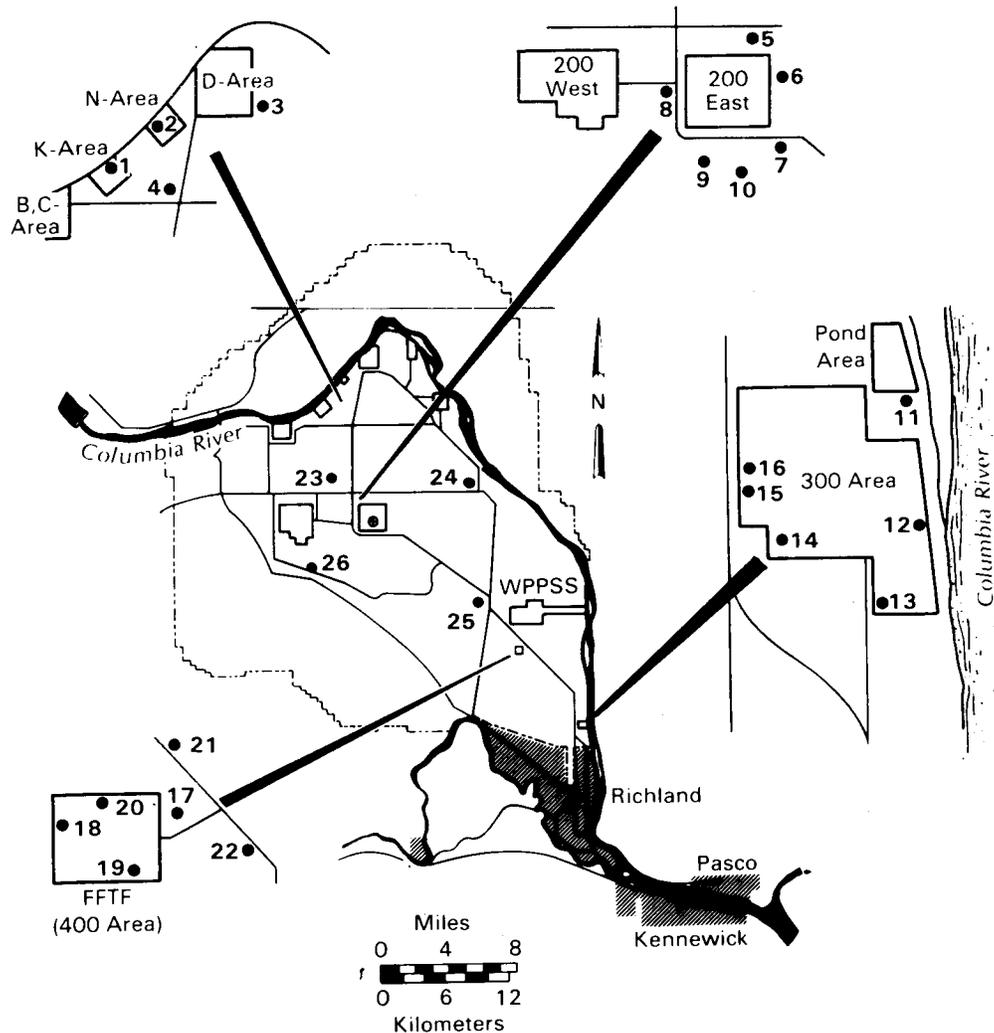
Cooling water containing radioactive materials was discharged to the Columbia River during reactor operations at Hanford from 1944 to 1972. These radionuclides were diluted and dispersed in the river. Low levels of residual radioactivity (primarily  $^{60}\text{Co}$  and  $^{154}\text{Eu}$ ) can still be measured at several locations along the shorelines and on islands in the Hanford reach of the river. Radiation dose rates from these radionuclides were

**Figure removed as per DOE guidance.**

**FIGURE 37.** Environmental Dosimeter Location at Publicly Accessible Locations Onsite (See Table A.29, Appendix A, for location number key)

the subject of an extensive radiological survey of the Hanford reach of the river performed in 1979 (Sula 1980). In 1980, based upon findings of the survey, dosimeters were located in areas along the river, shown in Figure 36, where dose rates due to the residual radioactivity deposits were determined to be slightly elevated with respect to background levels. Table A.30, Appendix A, provides results of measurements at these locations during 1984. Dose rates measured during 1984 were similar to those observed in recent years. Dose rates along the river are expected to gradually decrease at a rate commensurate with the radioactive half-lives of the radionuclides present. The half-life of  $^{60}\text{Co}$  is 5.3 years and  $^{154}\text{Eu}$  is 8.2 years.

Onsite external penetrating radiation was measured at the locations shown in Figure 39. The results of these measurements are given in Table A.31, Appendix A. Dose rates above background were observed at several locations onsite during 1984. The elevated levels observed near 100-N were attributed to short-lived airborne noble gases as well as direct radiations due to reactor operations and waste handling and storage facilities. Dose rates at one of the 300 Area locations (location 16 of Figure 38) were slightly elevated during 1984. This location is near the steam generator examination facility which accounts for the elevated levels. The 400 Area dose rates were observed to be at normal ambient levels except at 400 N (location 20, Figure 38), which lies near a



**FIGURE 38.** Environmental Dosimeter Locations on the Hanford Site (See Table A.31, Appendix A, for location number key)

railroad spur where parked railroad tank cars containing liquid waste account for the slightly higher levels. Dose rates around the 200 Areas were within the expected background levels.

### RADIATION SURVEYS

Onsite roads, railroads and radioactive waste disposal sites located outside of operating areas were routinely surveyed during 1984 to detect abnormal levels of radioactivity. The frequency of the surveys on specific routes for roads and railroads was based on the use and potential for contamination. The majority of the waste sites were surveyed on a semiannual basis during 1984. Specific routes and frequencies for surveys conducted during 1984 were defined in the master schedule (Blumer et al. 1983).

Roads, shown in Figure 39, were surveyed routinely using four scintillation detectors positioned approximately 0.5m above the ground evenly spaced across the width of a vehicle. No

abnormal conditions were observed on the site roadways surveyed during 1984.

Railroad routes, also shown in Figure 39, were surveyed using two scintillation detectors mounted approximately 0.3 m directly above the tracks on a small rail car. Railroad surveys conducted during 1984 did not reveal any unexpected conditions on the site railways.

Inactive waste disposal sites outside of operating area perimeter fences were surveyed during 1984 with portable instruments to detect changes in levels of external radioactivity. Sites also were visually inspected with respect to general physical conditions. In general, radiation surveys conducted during 1984 showed levels comparable to those observed in the past. A few minor cave-ins were observed on two waste disposal sites. These were promptly reported to the responsible contractor for appropriate corrective action.

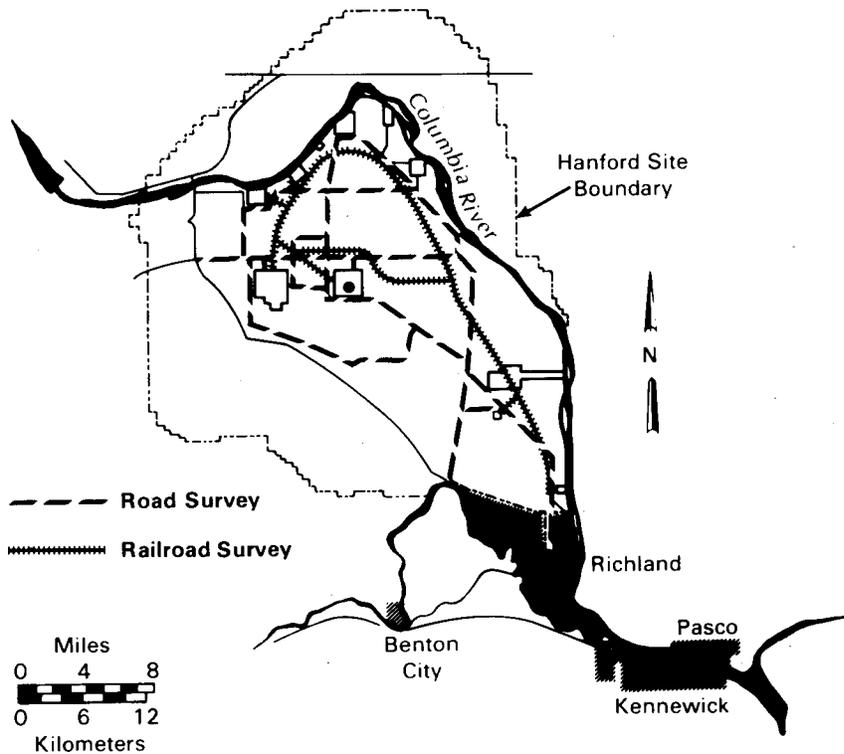


FIGURE 39. Road and Railroad Survey Routes

## NONRADIOLOGICAL MONITORING

Nonradiological monitoring on the Hanford Site has historically emphasized air and Columbia River water sampling. Oxides of nitrogen ( $\text{NO}_x$ ) are routinely released from fossil-fueled steam plants and chemical processing plants located onsite. Air data collected by the Hanford Environmental Health Foundation (HEHF) confirmed minimal nonradiological impact in the Hanford environs for 1984.

The Hanford reach of the Columbia River has been designated Class A, or Excellent, by the Washington State Department of Ecology. This designation requires that industrial uses of the river be compatible with all other uses of the water, including drinking water, recreation, and wildlife. Waste water from Hanford activities is discharged at eight points along the Hanford reach of the Columbia River, each regulated under an existing National Pollutant Discharge Elimination System (NPDES) permit issued by the EPA. In addition, measurements of several Columbia River water quality parameters were conducted routinely during 1984 both upstream and downstream of the Hanford Site to monitor any effects on the river that may be attributable to Hanford discharges and to determine compliance with the Class A designation requirements. The measurements indicated that Hanford operations had minimal, if any, impact on the quality of the Columbia River water.

### AIR

Nonradiological pollutants in routine gaseous emissions from chemical processes and fossil-fueled steam plants at Hanford consisted primarily of the oxides of nitrogen ( $\text{NO}_x$ ). The Hanford Environmental Health Foundation continued to operate a nine station network for monitoring nitrogen dioxide ( $\text{NO}_2$ ) concentrations in the Hanford environs. Nitrogen dioxide concentrations for 1984 were consistent with previous years data and did not exceed EPA and local limits.

#### Sample Collection and Analysis

The  $\text{NO}_x$  sampling locations were selected in an effort to adequately characterize onsite as well as potential offsite impacts of PUREX  $\text{NO}_x$  emissions. The sample locations are shown on the map in Figure 40 and identified in Table 3.

The  $\text{NO}_x$  sampling unit consisted of bubbler assemblies containing absorbing solution operated by a sequential sampling pump. The pumps were set to pull an air flow rate of 200 ml/min and were operated to sequence on a 24-hour basis. Thus, all sample results were midnight-to-midnight, 24-hour integrated averages.

#### Results

As shown in Table 3,  $\text{NO}_2$  data collected by the network in 1984 indicated a maximum observed average  $\text{NO}_2$  concentration per station of less than 0.008 parts per million (ppm). The applic-

able national ambient air standard for  $\text{NO}_2$  is 0.05 ppm as an annual arithmetic mean (National Primary and Secondary Ambient Air Quality Standards 1973).

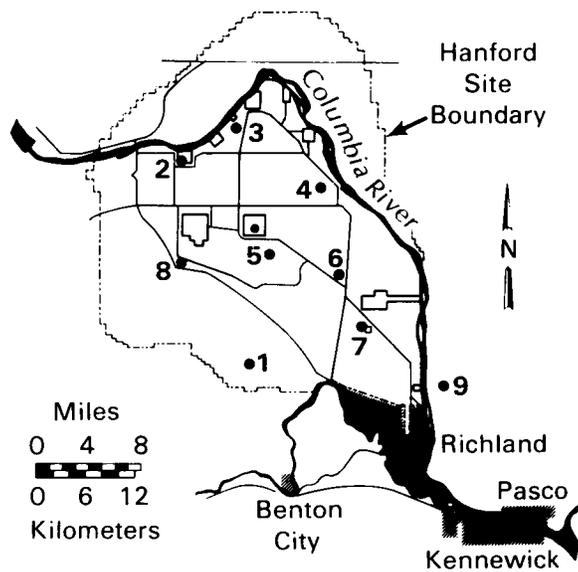
### COLUMBIA RIVER

Nonradioactive waste water is discharged at eight points along the Hanford reach of the Columbia River. These discharges consist of backwash water from water intake screens, cooling water, water storage tank overflow, and fish laboratory waste water. Each discharge point is identified in a National Pollutant Discharge Elimination System (NPDES) permit issued by the EPA. Effluents from each of these outfalls were routinely monitored and reported by the operating contractors as required by the NPDES permit.

Measurements of several Columbia River water quality parameters were conducted routinely during 1984 both upstream and downstream of the Hanford Site to monitor any effects on the river that may be attributable to Hanford discharges and to determine compliance with the Class A designation requirements.

#### Sample Collection and Analysis

Grab samples of Columbia River water were collected monthly at the Vernita Bridge (upstream of Hanford) and at Richland (downstream) and analyzed to indicate the general water quality changes along the Hanford reach of the river. Samples were delivered to HEHF for analyses



**FIGURE 40.** Nitrogen Dioxide (NO<sub>2</sub>) Air Sampling Locations (see Table 3 for location number key)

**TABLE 3.** Ambient Nitrogen Dioxide (NO<sub>2</sub>) Concentrations in the Hanford Environs for 1984

Location	Map Location <sup>(a)</sup>	No. 24-hour Integrated Samples	Annual Average <sup>(b)</sup> ppm NO <sub>2</sub>	% Samples <Detection Limit (0.003 ppm NO <sub>2</sub> )	High 24-hour Average ppm NO <sub>2</sub>
ALE	1	297	<0.005 ± 0.006	14.1	0.024
100-B	2	180	<0.004 ± 0.004	36.7	0.015
100-D	3	256	<0.004 ± 0.004	33.6	0.016
Hanford Townsite	4	273	<0.005 ± 0.006	14.7	0.025
Army Barracks	5	260	<0.005 ± 0.004	12.3	0.015
Wye Barricade	6	303	<0.008 ± 0.008	2.6	0.029
400 Area <sup>(c)</sup>	7	128	<0.004 ± 0.004	41.4	0.011
Highway 240 <sup>(d)</sup>	8	185	<0.004 ± 0.004	30.8	0.011
Sullivan Barn	9	272	<0.005 ± 0.004	16.5	0.015

(a) Locations are identified in Figure 41.

(b) Annual averages ± two standard deviation.

(c) Based on data collected through the second week of June.

(d) Based on data collected through the first week of August.

which included biological oxygen demand (BOD), coliform bacteria, pH and nitrate.

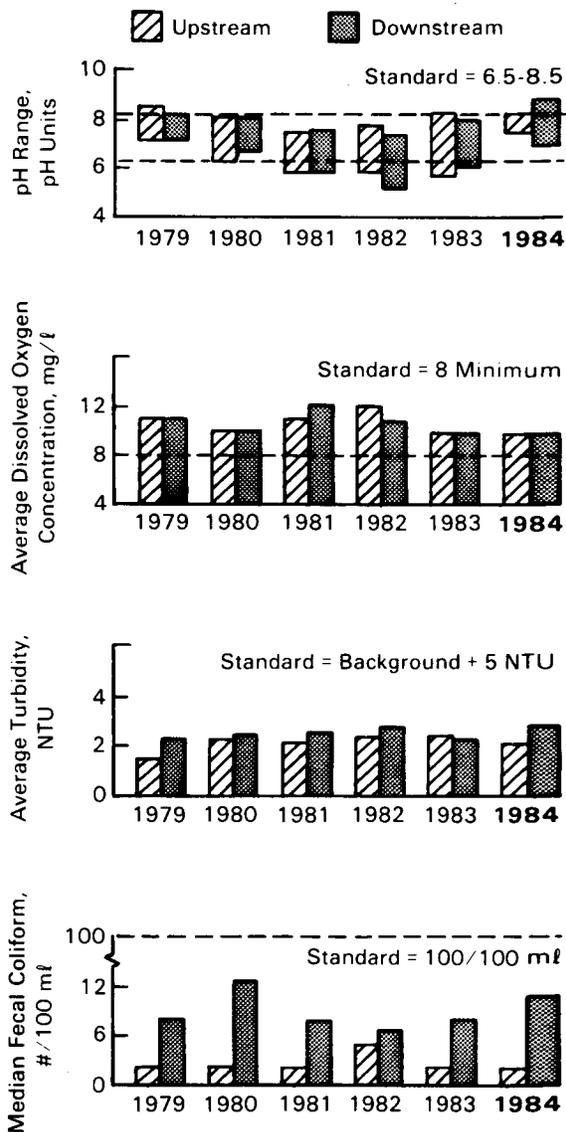
Water quality measurements of the Columbia River were also performed by the United States Geological Survey (USGS) at the same upstream and downstream locations. The USGS samples consisted of river cross-section composites collected bimonthly at the Vernita Bridge and quarterly at Richland. Analyses were performed at the USGS laboratory in Denver, Colorado for numerous physical, biological, and chemical constituents. The USGS was also contracted to provide continuous temperature monitoring of the river upstream and downstream and flow-rate measurements upstream of the site.

**Results**

Figure 41 illustrates sampling results for constituents for which state water quality regulations exist. With one exception (pH 9.1 at downstream location), pH values upstream and downstream were in close agreement and within the acceptable range during 1984. The median fecal coliform concentration during 1984 was slightly higher at the downstream location, but both upstream and downstream concentrations were well below the standard. Average turbidity and dissolved oxygen concentrations were similar upstream and downstream and did not exceed the standard. Concentrations of these water quality variables during 1984 were consistent with measurements of previous years.

Average monthly river flow and periods of N Reactor operation are shown in Figure 42. No substantial difference existed between upstream and downstream temperatures, and monthly averages remained within the standard during 1984. Due to equipment failure, several months of data are missing from the downstream location. While the highest downstream temperatures coincided with periods of low river flow and N Reactor operation, upstream temperatures exhibited the same trend. This suggests that heat contributed from N Reactor effluents was, at best, a small fraction of the temperature increases observed. Natural heating by the sun, therefore, appeared to be the major cause of water temperature increases along the Hanford reach.

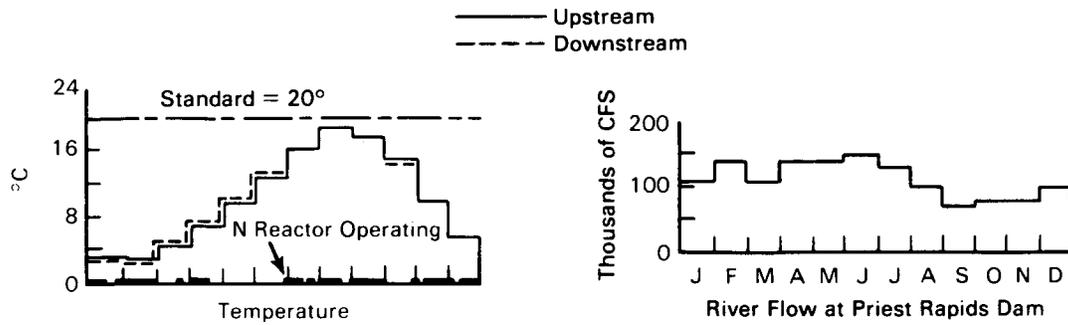
Data collected by both PNL and the USGS are summarized in Table A.32, Appendix A. Data include a number of variables for which state



**FIGURE 41. Columbia River Water Quality**

standards do not exist. Results of USGS analyses that duplicate onsite analyses were generally comparable. None of the analytical results indicated a significant deterioration in water quality at the downstream sampling locations.

The NPDES-permitted discharge locations and the parameters routinely measured are included in Table 7. In two instances during 1984, temperature maximums were exceeded at two of the discharges. At one 100-N Area discharge, the concentration of 1,1,1-trichloroethane exceeded the NPDES notification level. All violations were documented with separate unusual occurrence reports.



**FIGURE 42.** Columbia River Temperature and Flow Rates for 1984

**TABLE 4.** Measurements for NPDES Permitted Discharges at Hanford<sup>(a)</sup>

Measurement	Location		
	100-K Area (2 Discharges)	100-N Area (5 Discharges)	300 Area (1 Discharge)
Flow Rate	X	X	X
Suspended Solids	X	X	X
Temperature	X	X	---
pH	X	X	X
Chlorine	X	X	---
Oil and Grease	---(b)	X	---
Heat Discharged	---	X	---
Settleable Solids	---	---	X
Iron	---	X	---
Ammonia	---	X	---
Chromium	---	X	---

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

(b) Dashed line indicates no measurement required.

## GROUND-WATER MONITORING

Large volumes of process cooling water and low-level radioactive liquid wastes have been released since 1943 to the ground through cribs, ditches, and ponds. Liquid wastes discharged to the ground percolate downward and laterally and eventually enter the unconfined ground water underlying the Hanford Site. As the radionuclides and other contaminants move downward with the waste water, their concentrations are reduced by ion exchange, diffusion, radioactive decay, and dilution in the ground water.

Ground water is sampled at a large number of locations on the Hanford Site. In addition, studies are conducted to provide additional information to characterize further the ground-water system, refine the hydrologic models, and determine the impact of site operations on the environment. Results for 1984 indicated that the tritium and nitrate plumes continued to move slowly toward the Columbia River. All tritium results were within applicable concentration guides. Complete results from the Ground-Water Surveillance Program will be reported in a separate annual report entitled, *Ground-Water Surveillance at the Hanford Site for CY 1984 (PNL-5408)*.

### GEOLOGY AND HYDROLOGY

General features of the geology and hydrology of the site are discussed under "Description of the Hanford Site." Ground water within the unconfined aquifer beneath the site is influenced by artificial recharge from liquid waste disposal cribs, ditches, and ponds in and adjacent to the 200 Areas. Those soluble contaminants in liquid effluents that reach the ground water are restricted to the unconfined aquifer. Thus, the unconfined aquifer is the most thoroughly monitored and studied aquifer beneath the site.

Percolating waste water in proximity to the 200 Area has created localized ground-water mounds that have slightly raised the water table. The disposal of large amounts of waste water can influence the direction of flow of the ground water. However, the general direction of all flow was eastward to the Columbia River.

Disposal at other operating areas also contributed to the ground-water flow beneath the Hanford Site. Smaller amounts of waste water have been disposed of through ground facilities at the various 100 Areas and at the 300 Area. The FFTF Site (400 Area) contributes very little to the ground water, however, was one of the few onsite locations where ground water was used as a drinking water source.

#### Sample Collection and Analysis

More than 300 wells were used to gather ground-water samples from the unconfined aquifer in

1984. Most of the wells were 6 or 8 in. in diameter with steel casings. Normally they were screened or the casings were perforated. During 1984, the Ground-Water Surveillance Program collected about 1,500 samples and performed more than 4,000 analyses. Rockwell and UNC collected additional samples for special purposes. Most routine samples were collected on a quarterly basis; others were obtained monthly, semi-annually, or annually. The method of sample collection varied, but the majority of the monitoring wells contain permanently mounted submersible pumps. Bailers were used to dip water samples from wells incapable of producing water by pumping. Samples were collected just below the water table because that has been demonstrated to be the location of maximum concentration for most contaminants found in the ground water at Hanford (Eddy, Myers, and Raymond, 1978).

Samples collected during routine monitoring were analyzed for a number of radioactive and nonradioactive constituents. Both  $^3\text{H}$  and nitrate ion were measured most frequently. Samples from selected wells also were analyzed, for uranium,  $^{90}\text{Sr}$ ,  $^{60}\text{Co}$ ,  $^{106}\text{Ru}$ ,  $^{131}\text{I}$ ,  $^{137}\text{Cs}$ ,  $^{22}\text{Na}$ ,  $^{65}\text{Zn}$ . Gross beta activity was measured in well water from the 300 Area and certain wells in the 400 Area and 100-H Area. Some samples from the 200 Areas are monitored for gross alpha activity. The nonradioactive constituents monitored in various wells include: calcium, magnesium, sodium, carbonates, bicarbonates, potassium, boron, chloride, sulfate, chromium, and fluoride. Other

measurements were made such as pH, conductance, and dissolved solids.

### Results

Because tritium enters the ground-water system as part of the water molecule, it moves with the water and is unaffected by the geologic conditions that may affect other radionuclides. Tritium provides a good indicator of the position of the contaminated ground-water plume beneath the Hanford Site. Figure 43 represents the distribution of tritium in the unconfined aquifer for 1984.

The main tritium plume has moved away from the 200 Areas in a southeasterly direction and has separated into at least three individual plumes as the leading edge approaches the Columbia River. The smaller plumes adjacent to the 100 and 300 Areas represent current and past operations.

The movement of the tritium plume has reached the river adjacent to the Hanford Townsite as shown by Figure 43. Ground water from the unconfined aquifer enters the Columbia River through subsurface flow and springs that emanate from the riverbank as reported by McCormack and Carlile (1984), Figure 44 indicates historical tritium data for a well located adjacent to the Columbia River near the Hanford Townsite as shown in the map inset. The increase in average annual concentrations plotted in the figure illustrate the movement of the main tritium plume over the past 18 years at that location. The average concentration for the same well during 1984 was 236,700 pCi/l. The total amount of tritium entering the river in this area, during 1984, was calculated to be about 450 Ci, based on the average concentrations of tritium in wells near the

river and flow rate of ground water moving into the river. Tritium concentrations measured in wells near the springs were in the range of approximately 11,000 to 250,000 pCi/l and averaged 172,000 pCi/l over CY 1984. The 250,000 pCi/l of tritium probably represents the maximum concentration that could have occurred in riverbank springs in this area. Except for some small zones around the 100 Areas, ground water from the Hanford Townsite area represented the highest probable tritium concentration entering the Columbia River. The DOE Concentration Guide is 3,000,000 pCi/l.

Despite the fact that tritium enters the Columbia River near the Hanford Townsite, the impact to the river was low. The average annual flow rate from the unconfined aquifer into this section of the river has been estimated to be approximately 85 l/sec (3 cfs) (Prater et al. 1984). This was based on the ground-water model developed for the Hanford Site. The average Columbia River flow rate at Priest Rapids Dam was approximately 3,200,000 l/sec (112,500 cfs). Ground water entering the Columbia River from the Hanford Site was eventually diluted by a large factor because of the difference between the river and ground-water flow rates. (See results in "Surface-Water Monitoring" section)

Figure 46 shows the concentration and distribution of nitrate in the ground water beneath the Site. Elevated concentrations occurred near the 100, 200, and 300 Areas. The nitrate found in the ground water originated from various current and past practices. The applicable concentration guide is 45 ppm (as NO<sub>3</sub>).

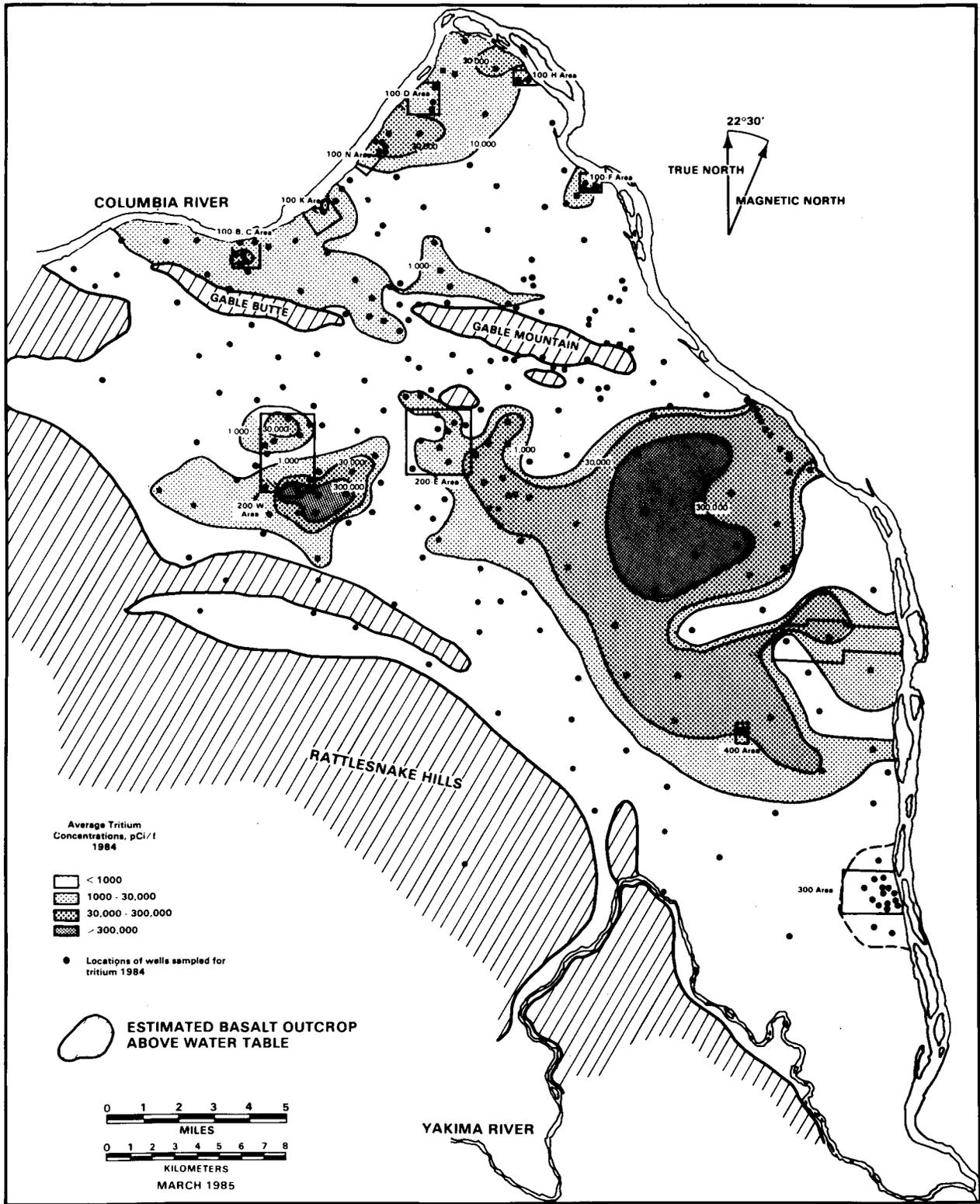
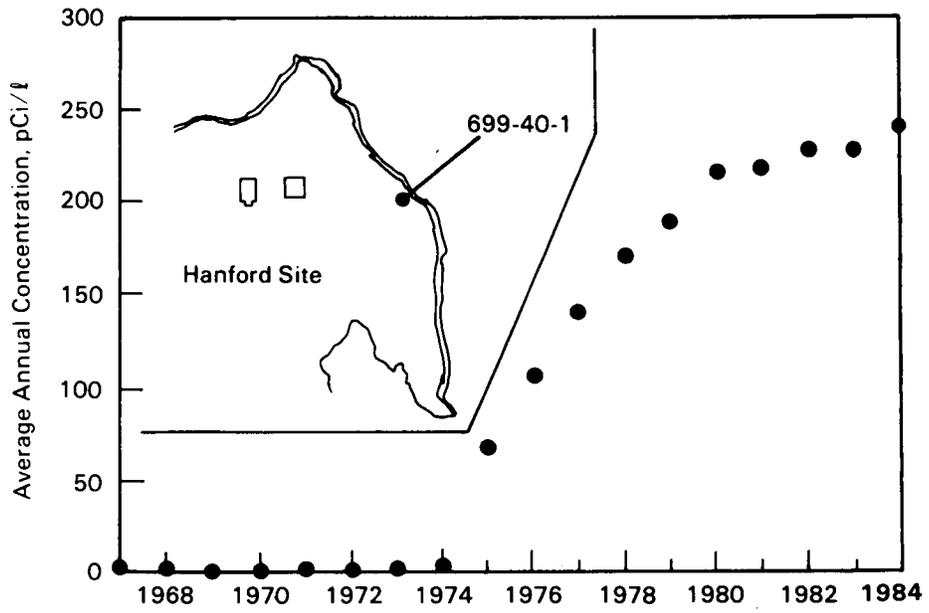
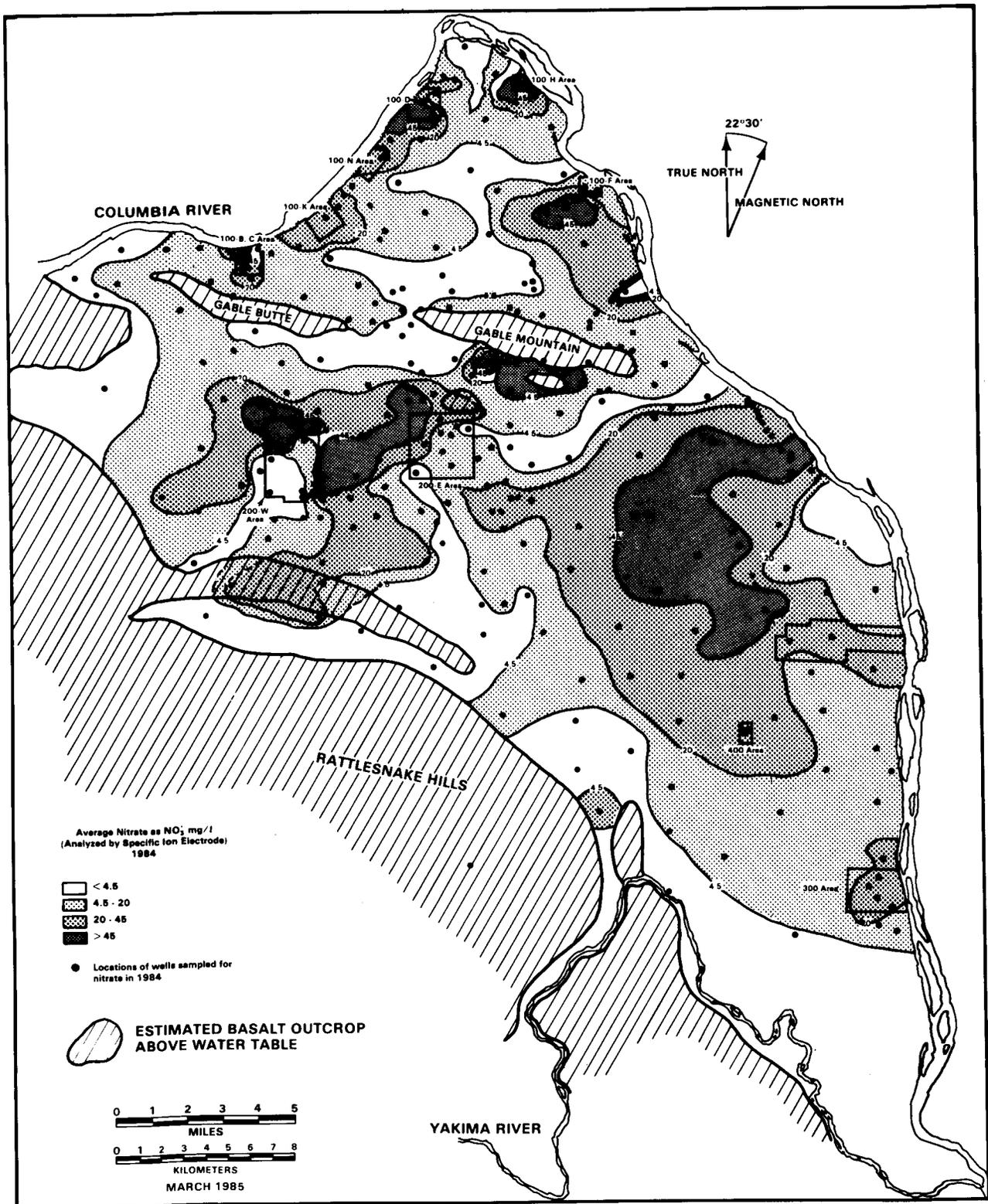


FIGURE 43. Distribution of Tritium in the Unconfined Aquifer for 1984



**FIGURE 44.** Concentration History for Tritium in Well 699-40-1



**FIGURE 45.** Distribution of Nitrate in the Unconfined Aquifer for 1984

## QUALITY ASSURANCE

**A comprehensive quality assurance program was maintained to ensure that the data collected were representative of actual concentrations in the environment. First, extensive environmental data were obtained to eliminate an unrealistic reliance on only a few results. Second, newly collected data were continually compared with both recent results and historical data for each location and each environmental medium to ensure that deviations from previous conditions were identified and promptly evaluated. Third, samples at all locations were collected using well-established and documented procedures to ensure consistency in sample collection. Fourth, the quality of the data was verified by a continuing program of analytical laboratory quality control, participation in interlaboratory cross-checks, replicate sampling and analysis, and splitting samples with other recognized laboratories. This program ensures that the monitoring data can be used to evaluate accurately the environmental impacts from Hanford operations.**

### **ANALYTICAL LABORATORY QUALITY ASSURANCE**

The majority of the routine radioanalyses for the Hanford Environmental Monitoring Program were performed under subcontract by the United States Testing Company, Inc., (UST) Richland, Washington. This laboratory maintained an internal quality assurance program that involved routine calibration of counting instruments, daily source and background counts, routine yield determinations of radiochemical procedures, replicate analyses to check precision, and analyses of reagents to ensure purity of chemicals. The accuracy of radionuclide determination was ensured through the use of standards traceable to the National Bureau of Standards, when available. The laboratory also participated in the DOE Quality Assessment Program (QAP) and the Environmental Protection Agency's (EPA) Laboratory Intercomparison Studies Program. In these programs, samples of different environmental media (water, milk, air filters, soil, foodstuffs and tissue ash) containing one or more radionuclides in known amounts were prepared and distributed to the participating laboratories. After the samples were analyzed, the results were forwarded to DOE and EPA for comparison with known values and with the results from other laboratories. These programs enabled the laboratory to regularly evaluate the accuracy of its analyses and take corrective action where needed. Summaries of the UST results in the DOE and EPA programs are indicated in Tables 5 and 6.

Interlaboratory comparison of the TLD results was provided by participation in the International Environmental Dosimeter Projects sponsored

jointly by the Department of Energy, the Nuclear Regulatory Commission and the Environmental Protection Agency. Results of the Seventh International Environmental Dosimeter Intercomparison Project are provided in Table 7.

Special quality assurance studies were conducted to evaluate the accuracy of analytical procedures not covered by the routine QA programs. In 1984 an evaluation of low-level tritium measurements in Columbia River water was performed by splitting samples with five laboratories. The results of this study are shown in Table 8. The study confirmed that the tritium levels measured by UST are an accurate measure of tritium concentrations in the Columbia River. Duplicate carbon dioxide samples were collected at two locations and the duplicate sent to the University of Miami for a  $^{14}\text{C}$  analysis. Both results were 1.3 pCi/m<sup>3</sup> which compares well with the 1.3 and 1.4 pCi/m<sup>3</sup> reported by PNL. An exchange of compressed air samples was made with Reynolds Electrical and Engineering Company (REECO) at the Nevada Test Site for analysis of  $^{85}\text{Kr}$ . The REECO and UST analysis of the samples compared well. A summary of these results and the replicate analyses performed are shown in Tables 9 and 10.

### **SAMPLE COLLECTION QUALITY ASSURANCE**

Of primary importance in the operation of an environmental monitoring program is the collection of representative samples. To check on the precision of sampling and analysis, replicate samples were routinely collected. The replicate data provided an estimate of the variability that can be expected from the total sampling and

**TABLE 5. Environmental Protection Agency Laboratory Intercomparison Program Results for 1984**

Sample Media	Radionuclides	Number Analyzed	Number of Analyses Within $3\sigma$ Control Limits
Water	Gross Alpha, Gross Beta, $^{51}\text{Cr}$ , $^{60}\text{Co}$ , $^{65}\text{Zn}$ , $^{106}\text{Ru}$ , $^{134}\text{Cs}$ , $^{137}\text{Cs}$ , $^{131}\text{I}$	33	26 <sup>(a)</sup>
Water	$^{238}\text{Pu}$ , $^{239}\text{Pu}$ , $^{226}\text{Ra}$ , $^{238}\text{U}$	12	9 <sup>(b)</sup>
Water	$^{89}\text{Sr}$ , $^{90}\text{Sr}$	6	6
Water	$^3\text{H}$	6	6
Milk	$^{89}\text{Sr}$ , $^{90}\text{Sr}$ , $^{131}\text{I}$ , $^{137}\text{Cs}$	9	7 <sup>(c)</sup>
Food	$^{89}\text{Sr}$ , $^{90}\text{Sr}$ , $^{131}\text{I}$ , $^{137}\text{Cs}$	8	8
Air Filters	Gross Alpha, Gross Beta, $^{40}\text{Sr}$ , $^{137}\text{Cs}$	12	9 <sup>(d)</sup>

- (a) Thirty-two results were within control limits after correction of transcription errors.  
 (b) Ten results were within control limits after one reanalysis.  
 (c) Eight results were within control limits after two reanalyses.  
 (d) Twelve results were within control limits after correction of errors.

**TABLE 6. DOE Quality Assessment Program Results for 1984**

Sample Media	Radionuclides	Number Analyzed	Number of Analyses Within $3\sigma$ Control Limits
Air Filters	$^7\text{Be}$ , $^{54}\text{Mn}$ , $^{60}\text{Co}$ , $^{90}\text{Sr}$ , $^{137}\text{Cs}$ , $^{234}\text{U}$ , $^{238}\text{U}$ , $^{239}\text{Pu}$ , $^{241}\text{Am}$	14	13 <sup>(a)</sup>
Soil	$^{40}\text{K}$ , $^{60}\text{Co}$ , $^{90}\text{Sr}$ , $^{137}\text{Cs}$ , $^{234}\text{U}$ , $^{238}\text{U}$ , $^{238}\text{Pu}$ , $^{241}\text{Am}$	13	10
Vegetation	$^{40}\text{K}$ , $^{60}\text{Co}$ , $^{90}\text{Sr}$ , $^{137}\text{Cs}$ , $^{238}\text{Pu}$	10	8
Tissue	$^{40}\text{K}$ , $^{90}\text{Sr}$ , $^{137}\text{Cs}$ , $^{239}\text{Pu}$ , $^{234}\text{U}$ , $^{238}\text{U}$	6	6
Water	$^3\text{H}$ , $^{54}\text{Mn}$ , $^{60}\text{Co}$ , $^{90}\text{Sr}$ , $^{137}\text{Cs}$ , $^{234}\text{U}$ , $^{238}\text{U}$ , $^{238}\text{Pu}$ , $^{239}\text{Pu}$	14	13 <sup>(b)</sup>

- (a) Fourteen were within control limits after correction of a transcription error.  
 (b) Fourteen were within control limits after one reanalysis.

**TABLE 7. Results of 7th International TLD Intercomparison**

Type Exposure	Expected	Exposure mR	
		Participant Average	PNL
<sup>137</sup> Cs Gamma Source	75.0 ± 3.8	73.0 ± 11.1	77 ± 3.0
<sup>60</sup> Co Gamma Source	79.9 ± 4.0	77.9 ± 13.8	80 ± 4.0
Field Exposure	75.8 ± 6.0	75.1 ± 14.9	68 ± 5.0

**TABLE 8. Columbia River Split Sample Analyzed for Tritium**

Laboratory	Concentration, pCi/l		
	Replicate 1	Replicate 2	Replicate 3
U.S. Testing	299 ± 10.6	285 ± 11.2	—*
University of Miami	294 ± 17.2	271 ± 20.4	290 ± 21.0
State of Oregon	215 ± 122	205 ± 122	258 ± 122
State of Washington	247 ± 213	294 ± 214	352 ± 215
EPA—Las Vegas	267 ± 8	237 ± 8	248 ± 8

\* Sample lost during enrichment

**TABLE 9. Krypton-85 Comparative Measurements (pCi/m<sup>3</sup>)**

Sample Type or Location	Laboratory	
	UST	REECO
200 ESE	2900 ± 370	2700 ± 31
Compressed Air	21.6 ± 6	24.7 ± 5.3

**TABLE 10. Replicate <sup>85</sup>Kr Sample Results (pCi/m<sup>3</sup>)**

Date	Replicates	
	Record ± 2σ	Replicate ± 2σ
1-84	256 ± 34	255 ± 33
3-84	200 ± 26	240 ± 31
4-84	96 ± 14	98 ± 13
7-84	163 ± 22	221 ± 29
9-84	117 ± 17	95 ± 13
11-84	24 ± 1	20 ± 4

analysis process. Summaries of data for replicates of air filters, milk, soil and water are provided in Table 11 through 14. The results demonstrate that the variability in results due to sampling can greatly exceed the analytical errors. The gross alpha and beta measurements in air show that side-by-side air samples can have a wide variation. The coefficient of variation for the gross alpha based on the analysis of replicates was 52% and the gross beta was 29%. The range between replicates for all of the samples was in the expected range and was acceptable to accurately characterize the concentrations of radio-nuclides in the environment. To evaluate the accuracy and precision of the TLD measurements, 3 pairs of TLDs were exposed to known levels of radiation each month and analyzed with the routine environmental TLDs. A summary of the 1984 results is shown in Table 15. An average bias of approximately 2% was observed between the known and measured exposures.

#### DOSE CALCULATIONS QUALITY ASSURANCE

Assurance of the quality of dose calculations was provided in several ways. First, comparisons were made against past calculated doses and significant differences were verified. Second, all computed doses were double checked by the originator and by an independent third party who also checked all input data and assumptions used in the calculation. Third, information necessary to perform all of the calculations was fully documented (see Appendix F, Dose Calculations and Effluents).

**TABLE 11. Evaluation of Replicate Air Samples Analyzed for Gross Beta and Gross Alpha**

Analysis	Number of Replicates	Mean Range Between Replicates pCi/m <sup>3</sup>	Coefficient of Variation of Measurements
Beta	21	.008	29%
Alpha	20	.0005	52%

**TABLE 12. Replicate Soil Sample Results**

Radionuclide	Concentration, pCi/g (dry weight)		
	Record ± 2σ	Replicate ± 2σ	Replicate ± 2σ
<sup>137</sup> Cs	.68 ± .04	.23 ± .03	.31 ± .03
	1.0 ± .06	1.00 ± .07	1.10 ± .06
<sup>60</sup> Co	-.03 ± .03	.02 ± .02	.02 ± .02
	.03 ± .03	.05 ± .03	-.04 ± .03
<sup>90</sup> Sr	.31 ± .04	.16 ± .01	.14 ± .01
	.25 ± .05	.16 ± .02	.17 ± .03
U	.65 ± .10	.31 ± .08	.26 ± .07
	.50 ± .13	.43 ± .11	.81 ± .22
<sup>239,240</sup> Pu	.019 ± .002	.021 ± .003	.010 ± .002
	.014 ± .002	.005 ± .003	.006 ± .002

**TABLE 13. Replicate Milk Samples Concentration, pCi/l**

Radio-nuclide	Date	Record	Replicate ± 2σ	Replicate ± 2σ
<sup>90</sup> Sr	4-10-84	2.0 ± 0.6	1.0 ± 1.6	1.2 ± 1.5
	10-23-84	1.0 ± 0.5	0.9 ± 0.4	0.8 ± 0.4
<sup>137</sup> Cs	4-10-84	-1.8 ± 5.3	-13.0 ± 5.6	2.5 ± 4.5
	10-23-84	4.9 ± 3.4	4.9 ± 4.1	-0.1 ± 6.2
<sup>3</sup> H	4-10-84	360 ± 200	65 ± 190	310 ± 200
	10-23-84	210 ± 200	20 ± 190	140 ± 200

**TABLE 14. Replicate Water Sample Results**

Analysis or Radionuclide	Date	Concentration, pCi/l	
		Record ± 2σ	Replicate ± 2σ
Beta	4-10-84	1.4 ± 1.9	1.7 ± 2.2
	9-25-84	1.8 ± 1.8	1.2 ± 1.5
Alpha	4-10-84	.57 ± .44	.62 ± .41
	9-25-84	1.00 ± .49	.46 ± .39
<sup>137</sup> Cs	4-10-84	.18 ± .86	-.34 ± .89
	9-25-84	1.20 ± .72	.38 ± .63
<sup>60</sup> Co	4-10-84	-.69 ± 1.61	.34 ± .39
	9-25-84	-.74 ± 1.10	.60 ± .54
<sup>90</sup> Sr	4-10-84	.18 ± .09	.22 ± .09
	9-25-84	.21 ± .12	.20 ± .08
U	4-10-84	.32 ± .09	.37 ± .10
	9-25-84	.49 ± 0.0	.51 ± 0.0
<sup>3</sup> H	4-10-84	183 ± 10	118 ± 12
	9-25-84	221 ± 14	263 ± 14

**TABLE 15. Comparison of Replicate TLD Results with Known Exposures**

Month	Bias, % <sup>(a)</sup>		
	High <sup>(b)</sup>	Medium	Low
January	0.0	-1.9	-5.7
February	4.0	1.4	3.2
March	2.2	-1.4	0.0
April	0.6	0.0	0.3
May	1.3	3.2	5.6
June	13.5	12.5	7.6
July	— <sup>(c)</sup>	—	—
August	-6.0	-3.2	-7.7
September	2.4	0.4	1.3
October	2.1	2.3	1.8
November	-0.8	1.4	-1.1
December	2.6	1.1	0.8
Average Bias, %	2.0	1.4	2.0

(a) Average of two observed values minus expected value.

(b) Relative levels of exposure (between 14 and 27 mR)

(c) No sample

## EFFLUENTS, WASTE DISPOSAL, AND UNUSUAL OCCURRENCES

**The operating contractors at Hanford have the responsibility to control, monitor, sample and report effluents released from their facilities. This section briefly summarizes the planned and unplanned releases of effluents at Hanford during 1984 as reported by the operating contractors.**

### EFFLUENTS AND WASTE DISPOSAL

Planned releases of radioactive and nonradioactive materials to the environment occurred either as airborne (gases or particles) or liquid effluents, or as solid wastes. Formal reporting of effluent data was the responsibility of the operating contractors. Information included within this section was obtained from the individual contractors responsible for operating various facilities. Radioactive discharges to the environment were reported to the DOE Effluent Information System. Nonradioactive discharges to the Columbia River were reported to EPA through the National Pollutant Discharge Elimination System (NPDES).

#### Airborne Releases

Radioactive and nonradioactive effluents discharged to the atmosphere during 1984 are summarized in Tables F.18 and F.19, Appendix F. The tables are subdivided according to the major operating areas and include all releases reported by the respective contractors. Radioactive materials discharged to the atmosphere consisted mainly of fission and activation products normally associated with Hanford operations. Nonradioactive airborne releases consisted primarily of emissions from fossil-fueled steam plants; oxides of nitrogen from fuel fabrication, the UO<sub>3</sub> Plant and PUREX; and organic liquids evaporated from laboratories.

#### Liquid Releases

Liquid wastes generated at Hanford were handled in several ways. They were stored, converted to solids, discharged to ground through cribs, ditches or ponds, or discharged directly to the Columbia River. Radioactive and nonradioactive effluents discharged to ground disposal facilities during 1984 are summarized in Tables F.20 and F.21, Appendix F, respectively.

Radioactive liquids discharged to the Columbia River from operating facilities during 1984 are listed in Table F.22, Appendix F. The discharges

reported are from liquid effluent systems in the 100 Areas, including seepage into the river from the 1301-N/1325-N Liquid Waste Disposal Facilities. Not included as releases to the Columbia River are the quantities of <sup>3</sup>H and <sup>129</sup>I that may have entered the Columbia River through springs from the unconfined aquifer. Nonradioactive liquids released to the Columbia River were monitored according to the individual requirements of each NPDES permitted discharge point.

#### Solid Waste Disposal

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 <sup>233</sup>U or transuranics were packaged and buried separate from other wastes for possible retrieval at a future date. Table F.23, Appendix F lists the quantities of radionuclides buried during 1984.

Nonradioactive solid wastes buried in a sanitary landfill near the 200 Areas included general refuse, asbestos and waste chemicals. The quantities of nonradioactive solid wastes buried during 1984 are included in Table F.23, Appendix F.

### ENVIRONMENTALLY RELATED UNUSUAL OCCURRENCES

Unusual occurrences were reported to DOE by onsite contractors during 1984. Several involved the release of radioactive or nonradioactive pollutants to the environment. Generally, the pollutants were either dispersed naturally, stabilized in existing waste disposal sites, or controlled and cleaned up with no permanent environmental impact reported. In some cases, particularly where the contaminants may have reached the ground water, the environmental impact is under continuing observation and evaluation.

Complete summaries, including the event description and corrective actions taken, are available for review in the public reading room at the Hanford Science Center, Richland, Washington.

## COMPARISON OF MEASURED AND CALCULATED RESULTS

A major activity of the environmental monitoring program was to measure radiation levels and radionuclide concentrations in the environment for use in determining the radiological impact of Hanford operations. The quantities of radionuclides released to the environment were usually small and it was not always possible to measure radioactivity attributable to Hanford operations. For dose calculation purposes, environmental concentrations of radionuclides in air, water and other media were calculated based on the quantities released in various effluents. To verify that the calculated environmental concentrations used in the dose models were reasonable, the concentrations of radionuclides measured in the Columbia River were compared with calculated values, and measured air concentrations were compared with calculated air concentrations. The measured and calculated concentrations of radionuclides in air and water compared well. The calculated concentrations used for radiological dose assessment were verified as reasonable estimates.

Table 16 lists the major nuclides contributing to the radiological dose impact from the Hanford liquid effluents and compares the calculated concentrations with the measured upstream and downstream concentrations. The difference between upstream and downstream is an estimate of the contribution from the Hanford operations. For  $^{60}\text{Co}$ ,  $^{89}\text{Sr}$ , and  $^{90}\text{Sr}$ , the monitored increases in concentration agreed well with the calculated values. For  $^{137}\text{Cs}$  and  $^{239}\text{Pu}$ , the measured contributions from Hanford effluents were too low to be distinguished from background levels. This was confirmed by the low calculated concentrations. The measured average concentration of  $^{131}\text{I}$  was lower than calculated; however, a number of the individual measurements were greater than the calculated average. Tritium, uranium and  $^{129}\text{I}$  are nuclides

that are associated with groundwater. The calculated concentration of tritium from 100 N releases was much less than the monitored downstream concentration, indicating tritium was being added to the river from groundwater seepage. Uranium and  $^{129}\text{I}$  do not have monitored effluents and the source of the measured concentrations was assumed to be groundwater seepage into the river.

The comparison of radionuclides in air was made by calculating the concentrations at the offsite monitoring location (Ringold) nearest to the PUREX stack and comparing these with the measured offsite concentrations. The 1984 average dispersion (X/Q) values were used for these calculations. The comparisons are shown in Table 17. The six radionuclides emitted from PUREX

Table 16. Monitored and Calculated Columbia River Concentrations

Radionuclide	N Reactor Release (Ci)	Calculated Downstream Conc. pCi/l	Monitoring Results (pCi/l)	
			Upstream	Downstream
$^3\text{H}$	140	1.4	130	170
$^{60}\text{Co}$	1.3	0.01	0.003	0.012
$^{89}\text{Sr}$	0.9	0.01	0.14	0.15
$^{90}\text{Sr}$	7.2	0.07	0.14	0.17
$^{131}\text{I}$	4.4	0.04	<.0008	0.02
$^{137}\text{Cs}$	0.3	0.003	0.029	0.023
$^{239},^{240}\text{Pu}$	0.000054	0.000000047	.00033	0.00017

**Table 17. Monitoring and Calculated Air Concentrations**

Radionuclide	PUREX Released (Ci)	Calculated Perimeter Concentration pCi/m <sup>3</sup>	Monitoring Results (pCi/m <sup>3</sup> )		
			Onsite	Perimeter	Distant
<sup>3</sup> H	200	0.26	2.2	1.9	1.6
<sup>14</sup> C	3	0.004	1.3	1.3	1.3
<sup>85</sup> Kr	400,000	520	590	75	27
<sup>90</sup> Sr	0.02	0.00003	0.0002	0.0001	<0.0001
<sup>137</sup> Cs	0.04	0.0001	0.0004	<0.0002	<0.000009
<sup>239,240</sup> Pu	0.007	0.000010	0.000007	0.000003	0.000002

and listed in Table 17 were also present in the environment from worldwide fallout. For all nuclides, except <sup>85</sup>Kr and <sup>239,240</sup>Pu, the contributions from Hanford effluents were not distinguishable within the precisions of the monitoring measurements. The calculated <sup>85</sup>Kr perimeter concentration of 520 pCi/m<sup>3</sup> falls between the average onsite concentration of 590 pCi/m<sup>3</sup> and the average perimeter level of 75 pCi/m<sup>3</sup>. The background level of <sup>85</sup>Kr was about 20 pCi/m<sup>3</sup>. The calculated <sup>239,240</sup>Pu perimeter concentration

was 10 aCi/m<sup>3</sup> which compared with the average onsite concentration of 7 aCi/m<sup>3</sup> and perimeter concentration of 3 aCi/m<sup>3</sup>.

The measured and calculated concentrations of radionuclides in air and water compared well. The calculated concentrations used in the dose models were verified as being reasonable estimates of radionuclide concentrations in the environment attributable to the Hanford operations.

## RADIOLOGICAL IMPACT FROM HANFORD OPERATIONS

An assessment of potential radiological impact from Hanford operations during 1984 indicated that radiation doses to the public were well below all applicable regulatory limits and were substantially less than doses potentially received from common sources of radiation. The calculated fifty-year whole body cumulative dose received by a hypothetical maximally exposed individual was about 2 mrem. The calculated fifty-year whole body cumulative dose to the surrounding population was about 5 man-rem. The average per capita whole body dose was estimated at 0.01 mrem per person. These doses can be compared to the approximate 100 mrem and 34,000 man-rem doses received annually by an average individual and the surrounding population, respectively, as a result of naturally occurring radiations in our environment. The assessment of potential radiation doses due to residual radionuclides from past Hanford operations also identified no significant impacts on the public. Measured and calculated doses were well below applicable radiation dose standards.

### RADIOLOGICAL IMPACT FROM 1984 OPERATIONS

Operations at Hanford during 1984 released radioactive materials to the environment as airborne and liquid effluents. Also, certain Hanford facilities were potential sources of direct radiation exposure. Radiological impacts were assessed to determine compliance with pertinent regulations as required by DOE Order 5484.1 (USDOE 1981b).

The radiological impact of 1984 Hanford operations was assessed in terms of the following:

- the maximum dose rate in a publicly accessible location on or within the site boundary (i.e., the "fence-post" dose rate),
- the dose to a hypothetical maximally exposed individual at an offsite location,
- the whole body dose to the population residing within an 80-km radius of one or more of the onsite operating areas.

To the extent possible, these radiological impact assessments were based on the direct measurement of dose rates or of radionuclide concentrations in the environment. The "fence-post" dose rate during 1984 was based on external radiation measurements made near the operating areas. However, the quantities of radionuclide releases associated with 1984 operations were in most cases too small to be measured once dispersed in the offsite environment. A few nuclides could be detected in the Columbia River and in the air at locations on the perimeter of the site. A comparison of the measured and calculated concen-

trations of radionuclides at these locations was discussed in the previous chapter. The potential offsite doses were estimated by using computerized models that predicted concentrations of radioactive materials in the environment from effluent releases. These models are described in Appendix F, and the reported Hanford effluents for 1984 are shown in Tables F.18 through F.23. The radiation doses estimated by these models were quite small and well below the sensitivity of direct measurement. Although the uncertainty associated with these calculations has not been specified, it is relatively large since maximum values are selected for dispersion, uptake, and consumption factors in the models, the doses calculated using these models should be viewed as conservative estimates (i.e., over-estimates) of the potential dose impact from 1984 Hanford operations.

### MAXIMUM "FENCE-POST" DOSE RATE

The "fence-post" dose rate provides a measure of the maximum external radiation dose rate that existed in publicly accessible locations on or near the site during 1984. The "fence-post" dose rate was based on measurements made by fixed environmental dosimeters placed at locations of expected maximum dose rates and does not represent a dose actually received by any member of the public. "Fence-post" dose rates were measured in the vicinity of the 100-N, 300 and 400 (FFTF) operating areas as described in the "Penetrating Radiation Monitoring" section of this report.

Near the 100-N Area, the Columbia River provides access to within a few hundred meters of

the N Reactor and its associated facilities. Measurements made at the 100-N Area shoreline (Table A.26, Appendix A) were consistently above background. The highest average dose rate observed along the shoreline during 1984 was 0.03 mrem/h, or about four times the dose rate normally observed at offsite locations (0.008 mrem/h).

Access to the 400 Area was possible at the Visitors Information Center located southeast of the FFTF reactor building. Penetrating dose rate measurements in the vicinity of this area during 1984 (Table A.26, Appendix A) did not indicate any identifiable dose rates above normal background levels.

Dose rates along the perimeter of the 300 Area were slightly elevated at locations accessible to the public during 1984 (Table A.26, Appendix A). The highest average dose rate was 0.018 mrem/h. The average dose rate at the other 300 Area perimeter location accessible to the public was 0.008 mrem/h.

The reporting of maximum "fence-post" dose rates is required by DOE Order 5484.1. The incurrence of any environmental radiological impact at these locations in terms of dose received by the public should not be interpreted as actual exposure. There was no evidence of recurring or protracted usage by any member of the public at any of these.

#### **MAXIMALLY EXPOSED INDIVIDUAL DOSE**

The maximally exposed individual (MI) doses were those calculated to be potentially received by a hypothetical individual whose location and characteristics were chosen to maximize the combined doses from all realistically available exposure pathways. The particular characteristics of the MI were based on many factors such as the total amount and composition of effluents and the dispersion of effluents released to the air or Columbia River. The following exposure pathways were included in the calculation of the potential MI dose based on 1984 operations; inhalation and submersion in airborne effluents; consumption of foodstuffs contaminated by effluents deposited on the ground from airborne materials and irrigation with Columbia River water; direct exposure to radionuclides

deposited on the ground; use of drinking water obtained from the Columbia River; consumption of fish taken from the Columbia River; and direct exposure to radionuclides during Columbia River recreation. The hypothetical MI for 1984 was postulated to be an individual who:

- was a long-term resident in an area approximately 13 km south-southeast of the 300 Area,
- consumed foodstuffs grown in the northwestern part of the Riverview district using Columbia River water for irrigation,
- consumed drinking water obtained from the Columbia River and,
- used the Columbia River extensively for recreational activities including boating, swimming and fishing (including consumption of the fish).

All MI doses were calculated using the effluents shown in Tables F.18 and F.23, Appendix F. Because these effluents included small quantities of long-lived radionuclides that persist in the environment for many years, the MI was appropriately assumed to be a long-term resident. Thyroid doses were calculated for a one-year-old infant in addition to an adult because the potential thyroid dose to an infant is known to be slightly higher than an adult. Other organ doses were appropriately calculated for an adult MI only.

Calculated 50-year cumulative doses for the MI are summarized in Table 18 and include the doses received from exposure to liquid and airborne effluents during 1984 as well as potential exposure beyond 1984 to that fraction of the 1984 effluents estimated to be deposited on the ground from airborne deposition and irrigation with Columbia River water. Appendix F provides detailed information concerning the computer models and details used to calculate the doses in Table 18.

All potential MI doses calculated for 1984 were well below the applicable Radiation Protection Standards in DOE Order 5480.1A. The organ receiving the largest fraction of the standard was the bone (8 mrem). The DOE Radiation Protection Standard for bone is 1500 mrem. The calculated whole body dose in 1984 was 2 mrem as compared to 1 mrem in 1983. These levels are

**TABLE 18. Dose to the Maximally Exposed Individual from 1984 Hanford Operations**

Pathway	50-Year Cumulative Dose, mrem					
	Whole Body	GI(a)	Bone	Lung	Thyroid	
					Adult	Infant
Direct Airborne(b)	<.01	<.01	.02	.02	<.01	<.01
Foodstuffs(c)	2	.2	8	<.01	.7	2
Drinking Water	.01	<.01	.04	<.01	.05	.2
River Recreation(d)	.1	.1	.3	<.01	.06	—
<b>Total</b>	<b>2</b>	<b>.3</b>	<b>8</b>	<b>.02</b>	<b>.8</b>	<b>3</b>

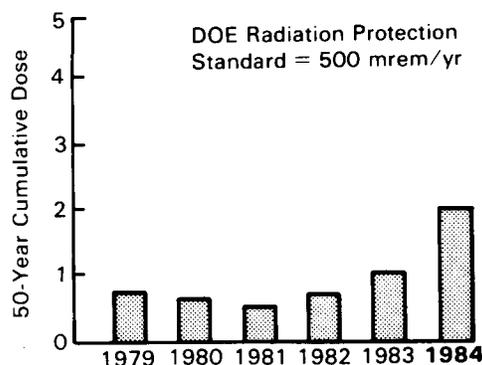
- (a) Gastrointestinal tract (lower large intestine).
- (b) Includes inhalation, submersion, and direct exposure to ground deposition.
- (c) Includes consumption of all foodstuffs contaminated via irrigation water and dry deposition.
- (d) Includes consumption of fish taken from the Columbia River.

well below the DOE Radiation Protection Standard of 500 mrem per year. The whole body and bone doses in 1984 were due almost entirely to the <sup>90</sup>Sr effluent released to the Columbia River at 100-N Area. The increase in the thyroid doses was due to the increase in the emissions of <sup>129</sup>I from the 200 Area.

A comparison of the MI whole body dose impacts attributed to 1984 Hanford operations with estimates for the previous five years is provided in Figure 46. Table 19 shows the calculated doses for all organs for 1984 and the previous five years. All doses are the calculated 50-year cumulative doses that assume long-term residency of the MI.

**POPULATION DOSE**

The regional dose impact from 1984 Hanford operations was estimated by calculating the collective dose to the population residing within an 80-km radius of any of the onsite operating areas. Collective population doses are expressed in units of man-rem. Average individual doses for all pathways were added together and multiplied by the number of people living in the area. Results are shown in Table 20. Site-specific population distributions and other dose calculation information are detailed in Appendix F.



**FIGURE 46. Calculated Maximally Exposed Individual Whole Body Dose, 1979 to 1984**

A comparison of 80-km population doses attributed to 1984 Hanford operations with estimated doses for the five previous years is provided in Table 21 and Figure 47.

The primary pathways contributing to the 1984 whole body population dose were air immersion in the short-lived noble gases from the N Reactor and the consumption of foodstuffs irrigated with water obtained from the Columbia River. The irrigation pathway was the primary source of dose to the bone from <sup>90</sup>Sr. The population dose to the thyroid was due primarily to the consumption of foods containing the long-lived <sup>129</sup>I.

**TABLE 19. Estimated Maximum Exposed Individual Doses Due to Hanford Operations, 1979 to 1984**

Organ	50-Year Cumulative Dose (mrem) <sup>(a)</sup>					
	1979	1980	1981	1982	1983	1984
Whole Body	.7	.6	.5	.7	1	2
GI <sup>(b)</sup>	.2	.1	.06	.07	.2	.3
Bone	3	2	2	2	4	8
Lung	.4	<.01	.01	.02	.01	.02
Thyroid	.8	.2	.2	.2	.2 <sup>(c)</sup>	.8

(a) Total dose to each organ from exposure to all available pathways.

(c) Gastrointestinal Tract (lower large intestine).

(d) Reported as .09 mrem in Price et al. 1984.

**TABLE 20. Dose to the Population from 1984 Hanford Operations**

Pathway	80 km Population 50-Year Cumulative Dose, man-rem				
	Whole Body	GI <sup>(a)</sup>	Bone	Lung	Thyroid
Direct Airborne <sup>(b)</sup>	3	3	4	4	3
Foodstuffs <sup>(c)</sup>	2	.3	7	.06	38
Drinking Water	.5	.09	2	<.01	2
River Recreation <sup>(d)</sup>	.06	.06	.2	.02	.1
<b>Total</b>	<b>5</b>	<b>3</b>	<b>13</b>	<b>4</b>	<b>43</b>

(a) Gastrointestinal tract (lower large intestine).

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

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

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

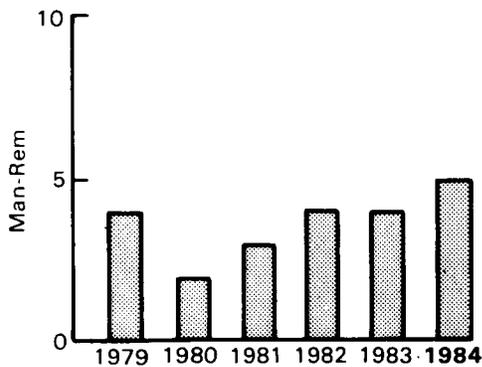
**TABLE 21. Estimated 80-km Population Dose Due to Hanford Operations, 1979 to 1984**

Organ	50-Year Cumulative Dose (man-rem) <sup>(a)</sup>					
	1979	1980	1981	1982	1983	1984
Whole Body	4	2	3	4	4	5
GI <sup>(b)</sup>	3	<1	3	3	3	3
Bone	10	5	5	7	7	13
Lung	5	1	3	4	3	4
Thyroid	12	4	5	7	17 <sup>(c)</sup>	43

(a) Total dose to each organ from exposure to all available pathways.

(c) Gastrointestinal tract (lower large intestine).

(d) Reported as 7 man-rem in Price et al. 1984a; corrected to 17 man-rem in Price et al., 1984b.



**FIGURE 47.** Calculated 80-km Whole Body Population Dose

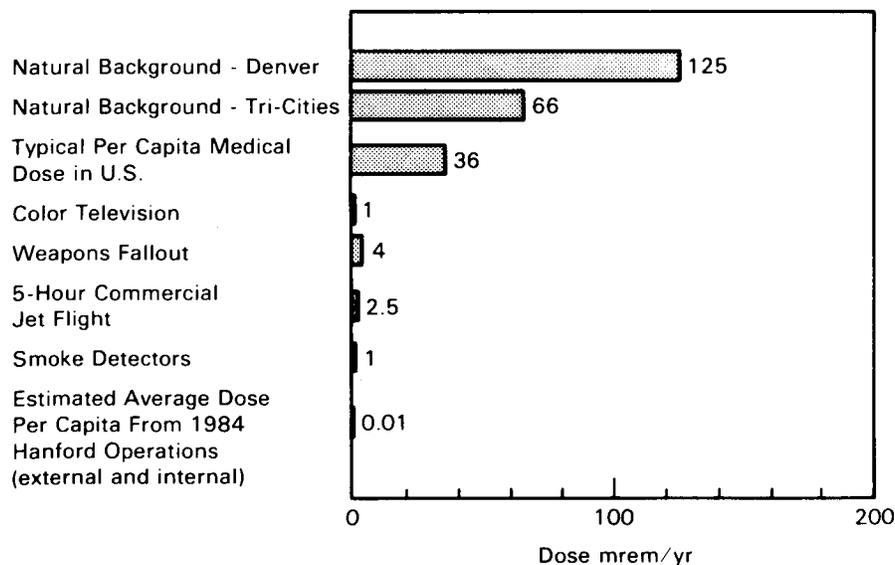
The average “per capita” whole body cumulative dose from the 1984 Hanford operations based on the 80-km population of 340,000 is calculated to be 0.01 mrem/person. This dose estimate can be compared with doses from other routinely encountered sources of radiation such as natural background radiation (Oakley 1972), medical diagnostic procedures (USEPA 1972), and a five-hour commercial jet flight (NCRP 1975). The average doses from these sources and the average per capita whole body cumulative dose from Hanford operations for 1984 are compared in Figure 48. Figure 48 illustrates whole body doses from external sources only. Not

included are doses inside our bodies resulting from exposures to natural and fallout radionuclides. These internal doses are estimated to be about 35 mrem per year. Thus, the total whole body dose received from background sources is about 100 mrem per year. The total whole body dose to the population from background sources is estimated similarly to be 34,000 man-rem.

**IMPACT ON THE COLUMBIA RIVER FROM PAST OPERATIONS**

In the preceding chapters of this report, measured levels of radioactivity in the environment were sometimes attributed to past operations at Hanford. The primary sources of current environmental impacts resulting from past operations were residual radionuclides deposited along the Columbia River shoreline in river sediments, and the seepage of water into the river from the unconfined Hanford aquifer.

Environmental radiation dose rates along the Columbia River shoreline and islands due to residual radionuclides were discussed by Sula (1980). Dose rates along the river were found to be slightly above normal background levels except at a few locations where dose rates were observed to be several times background levels. (See the “Penetrating Radiation” section).



**FIGURE 48.** External Whole Body Doses Received from Various Radiation Sources

For the purpose of evaluating the potential impact of these elevated dose rates on the regional population, a survey of Columbia River recreation was conducted during 1980. The survey area extended from the Vernita Bridge to Columbia Point at the confluence of the Yakima River. Through aerial and ground observations, the survey estimated annual population man-hours spent in recreational activities along the Columbia River. By applying the population shoreline man-hours per year to the measured net dose rates (in excess of background), an estimate of collective population whole body dose per year was obtained. The potential population dose due to exposure to residual radionuclides, derived by this method, was estimated to be approximately 1 man-rem per year.

Increased concentrations in the river were detected for  $^3\text{H}$  and  $\text{U}$ . Increased concentrations of  $^{129}\text{I}$  were detected by using extremely sensitive sampling and analytical techniques. The dose impact from these nuclides entering the river, based on measured differences in river concentrations upstream and downstream of the site (see the "Columbia River Radiological Monitoring" section), was calculated to be only 0.02 mrem whole body dose to an assumed maxi-

imum exposed individual and 2 man-rem of bone dose to the 80 km population of 340,000 people. The per capita bone dose is calculated to be 0.006 mrem.

### IMPACT FROM PUREX OPERATIONS

The PUREX plant began operations in November 1983 and continued in operation throughout 1984. The major emission from PUREX was 400,000 curies of  $^{85}\text{Kr}$ . Even though the curie quantity of this nuclide was large, it was a minor contributor to the radiation dose. The average concentration of  $^{85}\text{Kr}$  at the perimeter monitoring stations was  $75 \text{ pCi/m}^3$  which produced a whole body dose of 0.001 mrem and a skin dose of 0.1 mrem. In 1984 there were 0.0074 Ci of  $^{239,240}\text{Pu}$  in the PUREX airborne emissions. A summary of the MI and population doses from  $^{239,240}\text{Pu}$  is presented in Table 22. Plutonium-239, 240 was a minor contributor to the dose from 1984 Hanford operations with a MI cumulative dose to the whole body of 0.0004 mrem and a bone dose of 0.008 mrem. There was also 0.08 Ci of  $^{241}\text{Pu}$  in the 1984 PUREX emissions. This resulted in doses which were 16% of the  $^{239,240}\text{Pu}$  whole body dose and 20% of the  $^{239,240}\text{Pu}$  bone dose. The lung dose was much smaller, only 2% of the  $^{239,240}\text{Pu}$  lung dose.

TABLE 22. Doses from  $^{239,240}\text{Pu}$  in 1984 PUREX Emissions

Pathway	Maximum Exposed Individual 50-year Cumulative Dose, mrem		
	Whole Body	Lung	Bone
Inhalation	$3.7 \times 10^{-4}$	$6.5 \times 10^{-3}$	$8.0 \times 10^{-3}$
Foodstuffs	$1.4 \times 10^{-6}$	$1.0 \times 10^{-6}$	$3.0 \times 10^{-5}$
Direct Exposure	$1.4 \times 10^{-8}$	$1.4 \times 10^{-8}$	$1.4 \times 10^{-8}$
Total	0.0004	0.0065	0.008
80-km Population 50-Year Cumulative Dose, man-rem			
Pathway	Whole Body	Lung	Bone
Inhalation	$6.6 \times 10^{-2}$	$1.2 \times 10^0$	$1.4 \times 10^0$
Foodstuffs	$8.0 \times 10^{-5}$	$6.0 \times 10^{-5}$	$1.7 \times 10^{-3}$
Direct Exposure	$1.1 \times 10^{-6}$	$1.1 \times 10^{-6}$	$1.1 \times 10^{-6}$
Total	.066	1.2	1.4
Per Capita Dose (mrem)	0.0002	0.0035	0.0041

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**APPENDIX A**  
**DETAILED MONITORING RESULTS FOR 1984**



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

	Composite Group	Sampling Location	Map Location <sup>(a)</sup>		Composite Group	Sampling Location	Map Location <sup>(a)</sup>	
<b>Onsite</b>	100 Area	100 K	1	<b>Perimeter</b>	<b>Northeast Perimeter</b>	Berg Ranch	24	
		100 N	2			Sagehill	25	
		100 D	3			Ringold	26	
			Firestation		4	<b>East Perimeter</b>	Fir Road	27
	200 East Area	S of 200 E	5		Pettett		28	
		E of 200 E	6		<b>Southeast Perimeter</b>	Byers Landing	29	
		200 ESE	7			RRC v64	30	
	North of 200 Areas	Rt 11A, Mi 9	8		<b>Horn Rapids Road</b>	Horn Rapids Rd-Mi 12	31	
		N of 200 E	9			Horn Rapids Rd-Substation	32	
	200 West Area	SW BC Cribs	10		<b>Prosser Barricade</b>	Prosser Barricade	33	
		Army Loop Camp	11			<b>ALE</b>	ALE	34
		GTE Building	12		<b>West Perimeter</b>		Rattlesnake Springs	35
	300 Area	300 Pond	13			Yakima Barricade	36	
		3614-A Bldg.	14			<b>Northwest Perimeter</b>	Vernita Bridge	37
		300 S Gate	15				Wahluke Slope #2	38
		300 SW Gate	16		<b>Nearby Communities</b>		<b>Northwest Communities</b>	Othello
		3705 Bldg.	17			Connell		40
	400 Area	400 E	18			Tri City	Pasco	41
		400 W	19			Benton City	Richland	42
		400 S	20				Benton City	43
		400 N	21		<b>Distant Communities</b>	<b>Outer Northeast</b>	Moses Lake	44
600 Area	Hanford Townsite	22	Washtucna	45				
	Wye Barricade	23	<b>Outer Southeast</b>	Walla Walla		46		
				McNary Dam		47		
			<b>Outer Western</b>	Sunnyside		48		
				Sunnyside Duplicate				

(a) Locations are identified in Figure 3.

TABLE A.2. Airborne Radioactivity in the Hanford Environs for 1984

Concentration Guide(b)	Gross Beta Concentrations(a) pCi/m <sup>3</sup> (10 <sup>-12</sup> μCi/ml)				Gross Alpha Concentrations(a) pCi/m <sup>3</sup> (10 <sup>-12</sup> μCi/ml)			
	100		0.02		0.02		0.02	
Locations(c)	No. of Samples	Maximum	Minimum	Average	No. of Samples	Maximum	Minimum	Average
<b>Onsite</b>								
100 K	26	0.05 ± 0.005	0.01 ± 0.004	0.02 ± 0.004	25	---(d)	---	---
100 N	26	0.04 ± 0.005	<0.004 ± 0.004	0.02 ± 0.004	---	---	---	---
100 D	26	0.06 ± 0.006	0.006 ± 0.004	0.02 ± 0.005	25	0.001 ± 0.0005	<0.0003 ± 0.0003	0.0008 ± 0.0001
100 Fire Station	26	0.05 ± 0.005	0.009 ± 0.002	0.02 ± 0.004	---	---	---	---
Rt 11A, Mi.9	24	0.06 ± 0.005	0.009 ± 0.002	0.02 ± 0.005	25	0.002 ± 0.0002	<0.0002 ± 0.0002	0.0008 ± 0.0002
N of 200 E	26	0.06 ± 0.005	0.01 ± 0.004	0.02 ± 0.005	26	0.002 ± 0.0006	<0.0003 ± 0.0003	0.001 ± 0.0002
E of 200 E	23	0.06 ± 0.005	0.009 ± 0.004	0.02 ± 0.005	23	0.007 ± 0.0006	0.0004 ± 0.0003	0.001 ± 0.0002
200 ESE	25	0.05 ± 0.005	0.007 ± 0.004	0.03 ± 0.005	25	0.002 ± 0.0007	<0.0002 ± 0.0002	0.001 ± 0.0002
S of 200 E	25	0.05 ± 0.005	<0.003 ± 0.004	0.02 ± 0.005	25	0.002 ± 0.0007	0.0005 ± 0.0004	0.001 ± 0.0002
SW of BC Cribs	24	0.05 ± 0.005	0.008 ± 0.004	0.02 ± 0.005	24	0.002 ± 0.0007	<0.0002 ± 0.0002	0.001 ± 0.0001
Army Loop Camp	26	0.05 ± 0.005	0.006 ± 0.004	0.02 ± 0.005	26	0.002 ± 0.0006	0.0004 ± 0.0003	0.0009 ± 0.0002
200 GTE	25	0.07 ± 0.005	0.009 ± 0.004	0.02 ± 0.006	25	0.002 ± 0.0007	<0.0002 ± 0.0003	0.0009 ± 0.0002
3705 Bldg	23	0.08 ± 0.006	<0.004 ± 0.004	0.03 ± 0.007	---	---	---	---
3614A Bldg	25	0.06 ± 0.005	0.01 ± 0.004	0.02 ± 0.005	---	---	---	---
300 SW Gate	25	0.07 ± 0.005	0.007 ± 0.004	0.02 ± 0.006	---	---	---	---
300 S Gate	25	0.09 ± 0.006	0.008 ± 0.004	0.03 ± 0.007	25	0.002 ± 0.0006	0.0005 ± 0.0004	0.001 ± 0.0002
300 Pond	25	0.07 ± 0.006	0.007 ± 0.004	0.03 ± 0.006	24	0.009 ± 0.002	0.0006 ± 0.0004	0.002 ± 0.0007
400 E	24	0.08 ± 0.006	0.008 ± 0.004	0.03 ± 0.007	24	0.002 ± 0.0007	<0.0002 ± 0.0003	0.001 ± 0.0002
400 W	26	0.05 ± 0.005	0.007 ± 0.004	0.02 ± 0.005	26	0.002 ± 0.0007	<0.0004 ± 0.0004	0.001 ± 0.0002
400 S	22	0.05 ± 0.005	0.007 ± 0.004	0.02 ± 0.005	22	0.002 ± 0.0006	0.0005 ± 0.0004	0.001 ± 0.0002
400 N	26	0.07 ± 0.006	<0.004 ± 0.004	0.03 ± 0.006	26	0.002 ± 0.0006	0.0004 ± 0.0003	0.001 ± 0.0002
Hanford	25	0.05 ± 0.005	<0.004 ± 0.005	0.02 ± 0.005	24	0.002 ± 0.0008	0.0004 ± 0.0003	0.0007 ± 0.0002
Wye Barricade	25	0.09 ± 0.01	<0.002 ± 0.004	0.03 ± 0.008	24	0.003 ± 0.001	<0.0004 ± 0.0004	0.001 ± 0.0003
<b>Overall Average</b>				0.02 ± 0.001				0.001 ± 0.00007
<b>Perimeter</b>								
Berg Ranch	25	0.07 ± 0.005	0.01 ± 0.004	0.02 ± 0.005	25	0.002 ± 0.0006	0.0004 ± 0.0003	0.0009 ± 0.0002
Sagehill	25	0.05 ± 0.005	0.01 ± 0.004	0.02 ± 0.004	---	---	---	---
Ringold	23	0.04 ± 0.006	0.008 ± 0.004	0.02 ± 0.003	---	---	---	---
Fir Road	24	0.05 ± 0.005	0.009 ± 0.004	0.02 ± 0.005	---	---	---	---
Pettett	24	0.06 ± 0.005	0.006 ± 0.004	0.03 ± 0.005	24	0.002 ± 0.0008	0.0006 ± 0.0004	0.001 ± 0.0002
Byers Landing	25	0.05 ± 0.005	<0.003 ± 0.004	0.02 ± 0.004	25	0.002 ± 0.0007	0.0005 ± 0.0004	0.001 ± 0.0002
RRC #64	24	0.06 ± 0.005	0.007 ± 0.004	0.02 ± 0.005	24	0.002 ± 0.0006	0.0004 ± 0.0003	0.0009 ± 0.0002
Horn Rapids Rd. Mi. 12	24	0.05 ± 0.005	0.009 ± 0.004	0.02 ± 0.004	24	0.002 ± 0.0006	<0.0003 ± 0.0003	0.0008 ± 0.0001
Horn Rapids Rd. Substation	25	0.05 ± 0.005	0.006 ± 0.004	0.02 ± 0.004	---	---	---	---

TABLE A.2. (Continued)

Concentration Guide(b)	Gross Beta Concentrations(a) pCi/m <sup>3</sup> (10 <sup>-12</sup> μCi/ml)					Gross Alpha Concentrations(a) pCi/m <sup>3</sup> (10 <sup>-12</sup> μCi/ml)						
	No. of Samples	Maximum	Minimum	Average	No. of Samples	Maximum	Minimum	Average	No. of Samples	Maximum	Minimum	Average
<b>Perimeter (continued)</b>												
Prosser Barricade	25	0.05 ± 0.005	0.006 ± 0.004	0.02 ± 0.004	25	0.002 ± 0.0007	0.0004 ± 0.0003	0.001 ± 0.0002				
ALE		0.07 ± 0.005	0.006 ± 0.004	0.02 ± 0.005		---	---	---				
Rattlesnake Springs	25	0.07 ± 0.005	0.01 ± 0.004	0.02 ± 0.005	25	0.002 ± 0.0007	0.0005 ± 0.0004	0.0009 ± 0.0002				
Yakima Barricade	25	0.05 ± 0.005	0.006 ± 0.004	0.02 ± 0.005	25	---	---	---				
Vernita Bridge	25	0.05 ± 0.005	0.005 ± 0.004	0.02 ± 0.005	25	---	---	---				
Wahlake #2	25	0.05 ± 0.005	0.007 ± 0.004	0.02 ± 0.004	25	0.002 ± 0.0006	0.0005 ± 0.0004	0.0009 ± 0.0001				
<b>Overall Average</b>				0.02 ± 0.001				0.001 ± 0.00006				
<b>Nearby Communities</b>												
Othello	25	0.06 ± 0.005	0.009 ± 0.004	0.02 ± 0.005	24	0.002 ± 0.0006	<0.0002 ± 0.0003	0.0009 ± 0.0002				
Connell	25	0.06 ± 0.005	0.01 ± 0.004	0.02 ± 0.004	25	---	---	---				
Pasco	25	0.07 ± 0.006	0.009 ± 0.004	0.02 ± 0.006	25	0.002 ± 0.0006	0.0004 ± 0.0003	0.001 ± 0.0002				
Richland	26	0.08 ± 0.006	0.006 ± 0.004	0.02 ± 0.006	23	0.002 ± 0.0006	<0.0002 ± 0.0002	0.0008 ± 0.0002				
Benton City	23	0.03 ± 0.005	0.006 ± 0.004	0.02 ± 0.003								
<b>Overall Average</b>				0.02 ± 0.002				0.0009 ± 0.0001				
<b>Distant Communities</b>												
Moses Lake	26	0.04 ± 0.005	0.009 ± 0.004	0.02 ± 0.003	26	0.002 ± 0.0006	<0.0001 ± 0.0002	0.0008 ± 0.0002				
Washtucna	26	0.06 ± 0.005	0.008 ± 0.004	0.02 ± 0.004	26	---	---	---				
Walla Walla	26	0.05 ± 0.005	0.008 ± 0.004	0.02 ± 0.004	26	0.001 ± 0.0006	0.0004 ± 0.0003	0.0009 ± 0.0002				
McNary Dam	26	0.05 ± 0.005	<0.004 ± 0.004	0.02 ± 0.006	24	---	---	---				
Sunnyside	24	0.05 ± 0.005	0.009 ± 0.004	0.02 ± 0.004	24	0.002 ± 0.001	0.0006 ± 0.0004	0.001 ± 0.0002				
<b>Overall Average</b>				0.02 ± 0.002				0.001 ± 0.0001				

(a) Maximum and minimum values ± two-sigma counting error. Averages ± two standard error of the calculated mean (95% confidence interval).

(b) From DOE ORDER 5480.1 (Appendix C).

(c) Locations are identified in Figure 3.

(d) Dashed line indicates no analysis was performed.

**TABLE A.3. Selected Airborne Radionuclide Concentrations in the Hanford Environs for 1984**

Radio-nuclide	Composite Group <sup>(a)</sup>	Number of Samples	Concentration, pCi/m <sup>3</sup> (10 <sup>-12</sup> μCi/m <sup>3</sup> ) <sup>(b)</sup>			Concentration Guide, pCi/m <sup>3</sup> <sup>(c)</sup>
			Maximum	Minimum	Average	
<sup>3</sup> H (HTO)	Onsite	176	6.8 ± 2.2	<-1.2 ± 2.5	2.2 ± 0.3	200,000
	Perimeter	139	9.0 ± 4.5	<-0.4 ± 2.3	1.9 ± 0.3	
	Nearby Communities	26	4.2 ± 2.0	<-0.4 ± 2.1	1.5 ± 0.5	
	Distant Communities	26	4.2 ± 2.6	<-0.4 ± 1.0	1.6 ± 0.6	
<sup>14</sup> C(CO <sub>2</sub> )	Onsite	21	1.7 ± 0.1	<0.8 ± 1.3	1.3 ± 0.1	1,000,000
	Perimeter	33	1.5 ± 0.1	0.86 ± 0.6	1.3 ± 0.06	
	Nearby Communities	6	1.4 ± 0.1	1.1 ± 1.0	1.3 ± 1.0	
	Distant Communities	7	1.4 ± 0.1	1.1 ± 1.0	1.3 ± 0.08	
<sup>85</sup> Kr	Onsite	41	4600 ± 590	21 ± 10	590 ± 280	300,000
	Perimeter	22	280 ± 37	19 ± 6	75 ± 26	
	Nearby Communities	— <sup>(d)</sup>	—	—	—	
	Distant Communities	9	47 ± 9	14 ± 5	27 ± 8	
<sup>90</sup> Sr	Onsite	40	0.0008 ± 0.0002	<0.000004 ± 0.00005	0.0002 ± 0.00006	30
	Perimeter	40	0.0009 ± 0.0007	<-0.00006 ± 0.0002	0.0001 ± 0.00006	
	Nearby Communities	15	0.0003 ± 0.0002	<-0.00001 ± 0.0002	0.00009 ± 0.00005	
	Distant Communities	15	0.0004 ± 0.0001	<-0.00007 ± 0.0001	<0.0001 ± 0.00007	
<sup>129</sup> I <sup>(e)</sup>	Onsite	4	0.002 ± 0.0003	0.00001 ± 0.000001	<0.0005 ± 0.0009	20
	Perimeter	2	0.00006 ± 0.000006	0.000004 ± 0.0000004	<0.00003 ± 0.00007	
	Nearby Communities	— <sup>(d)</sup>	—	—	—	
	Distant Communities	2	0.000002 ± 0.0000002	0.0000005 ± 0.00000005	<0.000001 ± 0.000002	
<sup>131</sup> I	Onsite	238	0.014 ± 0.005	<-0.02 ± 0.02	<0.0001 ± 0.0006	100
	Perimeter	104	<0.01 ± 0.01	<-0.03 ± 0.02	<0.00004 ± 0.001	
	Nearby Communities	24	<0.006 ± 0.006	<-0.03 ± 0.01	<-0.0009 ± 0.003	
	Distant Communities	24	<0.01 ± 0.01	<-0.007 ± 0.007	<-0.0001 ± 0.002	
<sup>137</sup> Cs	Onsite	97	0.007 ± 0.003	<-0.002 ± 0.002	0.0004 ± 0.0002	500
	Perimeter	94	0.002 ± 0.001	<-0.002 ± 0.002	<0.0002 ± 0.0002	
	Nearby Communities	36	<0.002 ± 0.003	<-0.003 ± 0.002	<0.00008 ± 0.0004	
	Distant Communities	37	<0.001 ± 0.0007	<-0.002 ± 0.002	<0.000009 ± 0.0003	
U (total)	Onsite	32	0.0004 ± 0.0001	0.00002 ± 0.000009	0.00009 ± 0.00003	2
	Perimeter	24	0.0004 ± 0.0001	<0.000009 ± 0.00001	0.00008 ± 0.00003	
	Nearby Communities	— <sup>(d)</sup>	—	—	—	
	Distant Communities	3	0.0003 ± 0.00009	0.00004 ± 0.00002	<0.0002 ± 0.0002	
<sup>238</sup> Pu	Onsite	41	<0.00002 ± 0.00003	<-0.000004 ± 0.000003	<0.000002 ± 0.000002	0.07
	Perimeter	44	<0.00002 ± 0.00003	<-0.000002 ± 0.000002	<0.0000007 ± 0.000001	
	Nearby Communities	17	<0.00003 ± 0.00006	<-0.000002 ± 0.000002	<0.000002 ± 0.000003	
	Distant Communities	15	<0.000004 ± 0.000006	<-0.000002 ± 0.000002	<0.0000006 ± 0.000001	
<sup>239,240</sup> Pu	Onsite	40	0.00003 ± 0.000007	<-0.0000004 ± 0.000005	0.000007 ± 0.000002	0.06
	Perimeter	40	0.00001 ± 0.000007	<-0.000003 ± 0.000004	0.000003 ± 0.000001	
	Nearby Communities	15	0.000005 ± 0.000003	<-0.000002 ± 0.000002	<0.000001 ± 0.000001	
	Distant Communities	15	<0.000004 ± 0.000004	<0.00 ± 0.000008	0.000002 ± 0.000001	

(a) Onsite, perimeter, nearby communities, and distant sampling locations are identified in Table 2.

(b) Maximum and minimum values ± two sigma counting error. Averages ± two standard error of calculated mean (95% confidence interval).

(c) From DOE Order 5480.1. (Appendix C).

(d) No analysis was performed.

(e) Iodine-129 quarterly sampling initiated in July, 1984.

TABLE A.4. Airborne Radionuclide Concentrations in the 100 Areas

Radio-nuclide	Sample Location	Number of Samples	Concentration, pCi/m <sup>3</sup> (a)				Average 1984 Distant(b)
			Maximum	Minimum	Annual Average		
<sup>3</sup> H (HTO)	K Area	13	5.6 ± 1.9	<0.5 ± 0.9	2.3 ± 0.9		
	N Area	13	4.1 ± 1.6	<0.3 ± 2.0	1.6 ± 0.8		
	D Area	13	3.0 ± 2.6	<0.1 ± 1.1	1.3 ± 0.7		
	Fire Station	13	3.9 ± 1.9	<0.4 ± 2.3	1.7 ± 0.8		
						1.6 ± 0.6	
<sup>14</sup> C (CO <sub>2</sub> )	Fire Station	7	1.7 ± 0.1	1.2 ± 0.1	1.4 ± 0.2	1.3 ± 0.08	
<sup>90</sup> Sr	Composite(c)	5	0.0003 ± 0.00005	<0.00004 ± 0.00004	0.0002 ± 0.0001	<0.0001 ± 0.00007	
<sup>129</sup> I(d)	Fire Station	2	0.00002 ± 0.000002	<0.00001 ± 0.000001	0.00002 ± 0.000009	<0.000001 ± 0.000002	
<sup>131</sup> I	N Area	26	0.012 ± 0.005	<-0.004 ± 0.006	0.003 ± 0.002		
	D Area	26	0.014 ± 0.005	<-0.004 ± 0.005	<0.002 ± 0.002	<-0.001 ± 0.002	
<sup>137</sup> Cs	Composite	13	<0.001 ± 0.001	<-0.001 ± 0.0008	<0.0009 ± 0.0004	<0.00009 ± 0.0003	
U (total)	Composite	4	0.00006 ± 0.00002	<0.00002 ± 0.000009	0.00004 ± 0.00002	0.0002 ± 0.0002	
<sup>239</sup> Pu	Composite	5	0.0000006 ± 0.000002	<0.0000002 ± 0.0000004	<0.0000004 ± 0.000001	<0.0000006 ± 0.000001	
<sup>238,240</sup> Pu	Composite	5	0.000008 ± 0.000006	<0.000002 ± 0.000001	0.000004 ± 0.000003	0.000002 ± 0.000001	
Gross Beta	K Area	26	0.05 ± 0.005	0.01 ± 0.004	0.02 ± 0.004		
	N Area	26	0.04 ± 0.005	<0.004 ± 0.004	0.02 ± 0.004		
	D Area	26	0.06 ± 0.005	0.006 ± 0.004	0.02 ± 0.005		
	Fire Station	26	0.05 ± 0.005	0.009 ± 0.002	0.02 ± 0.004		
					0.02 ± 0.002	0.02 ± 0.002	
Gross Alpha	D Area	25	0.001 ± 0.0005	<0.0003 ± 0.0003	0.0008 ± 0.001	0.001 ± 0.0001	

(a) Maximum and minimum concentrations ±2σ counting error. Averages ± two standard error of the calculated mean (95% confidence level).  
 (b) Distant sampling locations are identified in Table 2.  
 (c) Composites of biweekly samples from the individual sampling locations are identified in Table 2.  
 (d) Values for <sup>129</sup>I are reported for the 3rd and 4th quarter of 1984.

**TABLE A.5. Airborne Radionuclide Concentrations in the 200-E Area**

Radio-nuclide	Sample Location	Number of Samples	Concentration, pCi/m <sup>3</sup> (a)			
			Maximum	Minimum	Annual Average	Average 1984 Distant <sup>(b)</sup>
<sup>3</sup> H (HTO)	S of 200E	13	3.9 ± 2.3	<-0.3 ± 1.8	1.7 ± 0.8	
	E of 200E	12	6.8 ± 2.2	2.0 ± 1.2	4.1 ± 1.0	
	200 ESE	13	6.1 ± 1.6	1.6 ± 1.1	3.4 ± 0.9	
					3.0 ± 0.6	1.6 ± 0.6
<sup>14</sup> C (CO <sub>2</sub> )	200 ESE	7	1.5 ± 0.6	<0.8 ± 1.3	1.2 ± 0.3	1.3 ± 0.08
<sup>85</sup> Kr	S of 200E	11	1200 ± 150	21 ± 10	300 ± 200	
	E of 200E	9	710 ± 92	120 ± 20	330 ± 130	
	200 ESE	11	4600 ± 590	70 ± 10	1500 ± 790	
					740 ± 350	27 ± 8
<sup>90</sup> Sr	Composite <sup>(c)</sup>	5	0.0003 ± 0.00006	0.00006 ± 0.00005	0.0002 ± 0.0001	<0.0001 ± 0.00007
<sup>129</sup> I <sup>(d)</sup>	200 ESE	2	0.002 ± 0.0003	0.0002 ± 0.0003	<0.001 ± 0.002	<0.000001 ± 0.000002
<sup>131</sup> I	S of 200E	17	<0.008 ± 0.008	<-0.009 ± 0.006	<-0.002 ± 0.002	<-0.0001 ± 0.002
	E of 200E	17	<0.006 ± 0.006	<-0.013 ± 0.007	<-0.001 ± 0.003	
	200 ESE	25	<0.005 ± 0.005	<-0.005 ± 0.006	<-0.0004 ± 0.002	
<sup>137</sup> Cs	Composite	12	0.002 ± 0.0008	<-0.0001 ± 0.0006	0.0006 ± 0.0004	<0.000009 ± 0.0003
U (total)	Composite	4	0.00005 ± 0.00002	0.00004 ± 0.00002	0.00005 ± 0.00001	<0.0002 ± 0.0002
<sup>238</sup> Pu	Composite	5	<0.000002 ± 0.000002	<-0.0000003 ± 0.000001	<0.0000009 ± 0.000001	<0.0000006 ± 0.000001
<sup>239,240</sup> Pu	Composite	5	0.00003 ± 0.000007	0.000003 ± 0.000002	0.00001 ± 0.000009	0.000002 ± 0.000001
Gross Beta	S of 200E	25	0.05 ± 0.005	<0.003 ± 0.004	0.02 ± 0.005	
	E of 200E	23	0.06 ± 0.005	0.009 ± 0.004	0.02 ± 0.005	
	200 ESE	25	0.05 ± 0.005	0.007 ± 0.004	0.03 ± 0.005	
					0.02 ± 0.003	0.02 ± 0.002
Gross Alpha	S of 200E	25	0.002 ± 0.0007	0.0005 ± 0.0004	0.001 ± 0.0002	
	E of 200E	23	0.002 ± 0.0006	0.0004 ± 0.0003	0.001 ± 0.0002	
	200 ESE	25	0.002 ± 0.0007	<0.0002 ± 0.0002	0.001 ± 0.0002	
					0.001 ± 0.0001	0.001 ± 0.0001

(a) Maximum and minimum concentrations ±2σ counting error. Averages ± two standard error of the calculated mean (95% confidence level).

(b) Distant sampling locations are identified in Table 2.

(c) Composites of biweekly samples from the individual sampling locations are identified in Table 2.

(d) Values for <sup>129</sup>I are reported for the 3rd and 4th quarter of 1984.

**TABLE A.6. Airborne Radionuclide Concentrations in the 200-W Area**

Radio-nuclide	Sample Location	Number of Samples	Concentration, pCi/m <sup>3</sup> (a)			
			Maximum	Minimum	Annual Average	Average 1984 Distant <sup>(b)</sup>
<sup>3</sup> H (HTO)	SW BC Cribs	12	5.7 ± 2.1	<-0.2 ± 1.6	1.9 ± 1.0	
	GTE Bldg.	13	3.5 ± 1.9	<0.8 ± 0.8	2.2 ± 0.7	
					2.0 ± 0.6	1.6 ± 0.6
<sup>90</sup> Sr	Composite <sup>(c)</sup>	5	0.0004 ± 0.00007	<0.00002 ± 0.00003	<0.0001 ± 0.0002	<0.0001 ± 0.00007
<sup>131</sup> I	All Locations				NRA <sup>(d)</sup>	
<sup>137</sup> Cs	Composite	13	0.0007 ± 0.0004	<-0.0005 ± 0.0009	<0.00003 ± 0.0003	<0.000009 ± 0.0003
U (total)	Composite	4	0.00007 ± 0.00002	0.00003 ± 0.00001	0.00005 ± 0.00002	0.0002 ± 0.0002
<sup>238</sup> Pu	Composite	5	0.000002 ± 0.000001	<0.00 ± 0.00006	<0.000001 ± 0.00001	0.0000006 ± 0.000001
<sup>239,240</sup> Pu	Composite	5	<0.00002 ± 0.00004	<0.000003 ± 0.000004	<0.000009 ± 0.00001	0.000002 ± 0.000001
Gross Beta	SW BC Cribs	24	0.05 ± 0.005	0.008 ± 0.004	<0.02 ± 0.005	
	Army Loop Camp	26	0.05 ± 0.005	0.006 ± 0.004	<0.02 ± 0.005	
	GTE Bldg.	25	0.07 ± 0.005	0.009 ± 0.004	0.02 ± 0.006	
					0.02 ± 0.003	0.02 ± 0.002
Gross Alpha	SW BC Cribs	24	0.002 ± 0.0007	<0.0002 ± 0.0002	0.001 ± 0.0002	
	Army Loop Camp	26	0.002 ± 0.0006	0.0004 ± 0.0003	0.0009 ± 0.0002	
	GTE Bldg.	25	0.002 ± 0.0007	<0.0002 ± 0.0003	0.0009 ± 0.0002	
					0.0009 ± 0.0001	0.001 ± 0.0001

(a) Maximum and minimum concentrations ±2σ counting error. Averages ± two standard error of the calculated mean (95% confidence level).

(b) Distant sampling locations are identified in Table 2.

(c) Composites of biweekly samples from the individual sampling locations are identified in Table 2.

(d) Not routinely analyzed.

**TABLE A.7. Airborne Radionuclide Concentrations North of the 200 Areas**

Radio-nuclide	Sample Location	Number of Samples	Concentration, pCi/m <sup>3</sup> (a)				Average 1984 Distant(b)
			Maximum	Minimum	Annual Average		
<sup>3</sup> H (HTO)	Rt. 11 A, Mi. 9	12	5.9 ± 2.1	<0.6 ± 1.3	2.1 ± 1.1		
	N of 200E	13	5.1 ± 2.1	<1.0 ± 1.3	2.3 ± 0.7		
<sup>90</sup> Sr <sup>131</sup> I	Composite(c)	5	0.0005 ± 0.0001	<0.00007 ± 0.0001	2.2 ± 0.6	1.6 ± 0.6	
	All Locations				<0.0002 ± 0.0002	<0.0001 ± 0.00007	
<sup>137</sup> Cs	Composite	13	<0.001 ± 0.001	<-0.002 ± 0.002	NRA (d)	<0.000009 ± 0.0003	
	Composite	4	0.00005 ± 0.00002	0.00003 ± 0.00002	0.00004 ± 0.00002	<0.0002 ± 0.0002	
U (total)	Composite	5	<0.000002 ± 0.000002	<0.00 ± 0.000002	<0.0000007 ± 0.0000009	0.0000006 ± 0.000001	
<sup>239</sup> Pu	Composite	5	0.00001 ± 0.000004	<0.000002 ± 0.000002	0.000006 ± 0.000004	0.000002 ± 0.000001	
Gross Beta	Rt. 11A, Mi. 9	24	0.06 ± 0.005	0.009 ± 0.004	0.02 ± 0.005		
	N of 200E	26	0.06 ± 0.005	0.01 ± 0.004	0.02 ± 0.005		
Gross Alpha	Rt. 11A, Mi. 9	24	0.002 ± 0.0006	<0.0002 ± 0.0002	0.02 ± 0.004	0.02 ± 0.002	
	N of 200E	26	0.002 ± 0.0006	<0.0003 ± 0.0003	0.0008 ± 0.0002		
					0.001 ± 0.0002		

(a) Maximum and minimum concentrations ±2σ counting error. Averages ± two standard error of the calculated mean (95% confidence level).

(b) Distant sampling locations are identified in Table 2.

(c) Composites of biweekly samples from the individual sampling locations are identified in Table 2.

(d) Not routinely analyzed.

TABLE A.8. Airborne Radionuclide Concentrations in the 300 Area

Radio-nuclide	Sample Location	Number of Samples	Concentration, pCi/m <sup>3</sup> (a)				Average 1984 Distant <sup>(b)</sup>
			Maximum	Minimum	Annual Average	Average 1984 Distant <sup>(b)</sup>	
<sup>85</sup> Kr	300 Pond	10	260 ± 34	24 ± 10	130 ± 48	27 ± 8	
<sup>90</sup> Sr	Composite(c)	5	0.0003 ± 0.00005	<0.000004 ± 0.00005	<0.0001 ± 0.0001	<0.0001 ± 0.00007	
<sup>131</sup> I	300 SW Gate	26	<0.009 ± 0.01	<-0.006 ± 0.006	0.0003 ± 0.002	<-0.0001 ± 0.002	
<sup>137</sup> Cs	Composite	12	0.0006 ± 0.0004	<-0.0007 ± 0.0007	<0.00001 ± <0.0003	<0.000009 ± 0.0003	
U (total)	Composite	4	0.0004 ± 0.0001	0.0001 ± 0.00003	<0.0002 ± 0.0002	<0.0002 ± 0.0002	
<sup>238</sup> Pu	Composite	6	<0.00002 ± 0.00003	<-0.0000004 ± 0.0000008	<0.000005 ± 0.000009	0.0000006 ± 0.000001	
<sup>239,240</sup> Pu	Composite	5	<0.000004 ± 0.000004	<0.0000003 ± 0.0000006	0.000003 ± 0.000002	0.000002 ± 0.000001	
Gross Beta	300 Pond	25	0.07 ± 0.006	0.007 ± 0.004	0.03 ± 0.006	0.02 ± 0.002	
	3614-A Bldg.	25	0.06 ± 0.005	0.01 ± 0.004	0.02 ± 0.005		
	300 S Gate	25	0.09 ± 0.006	0.008 ± 0.004	0.03 ± 0.007		
	300 SW Gate	25	0.07 ± 0.005	0.007 ± 0.004	0.02 ± 0.006		
	3705 Bldg.	23	0.08 ± 0.006	<0.004 ± 0.004	0.03 ± 0.007		
Gross Alpha	300 Pond	24	0.009 ± 0.002	0.0006 ± 0.0004	0.002 ± 0.003	0.02 ± 0.002	
	300 S Gate	25	0.002 ± 0.0006	0.0005 ± 0.0004	0.001 ± 0.0002		
					0.002 ± 0.0004	0.001 ± 0.0001	

(a) Maximum and minimum concentrations ±2σ counting error. Averages ± two standard error of the calculated mean (95% confidence level).

(b) Distant sampling locations are identified in Table 2.

(c) Composites of biweekly samples from the individual sampling locations are identified in Table 2.

TABLE A.9. Airborne Radionuclide Concentrations in the 400 Area

Radio-nuclide	Sample Location	Number of Samples	Concentration, pCi/m <sup>3</sup> (a)				Average 1984 Distant(b)
			Maximum	Minimum	Annual Average		
<sup>3</sup> H (HTO)	400E	12	4.3 ± 2.2	<0.21 ± 1.6	2.6 ± 0.9	1.6 ± 0.6	
<sup>90</sup> Sr	Composite(c)	5	0.0002 ± 0.00006	<0.00003 ± 0.00004	0.0001 ± 0.00009	<0.0001 ± 0.00007	
<sup>131</sup> I	400E	24	<0.004 ± 0.004	<-0.02 ± 0.02	<-0.001 ± 0.003		
	400W	26	<0.005 ± 0.005	<-0.007 ± 0.006	<-0.0003 ± 0.002		
	400S	23	<0.006 ± 0.006	<-0.006 ± 0.007	<0.0006 ± 0.002		
	400N	26	<0.006 ± 0.006	<-0.006 ± 0.0005	0.00007 ± 0.002	<-0.0001 ± 0.002	
<sup>137</sup> Cs	Composite	13	0.0008 ± 0.0005	<-0.0004 ± 0.0005	<0.0002 ± 0.0003	<0.000009 ± 0.00003	
U (total)	Composite	4	0.0002 ± 0.00005	0.00003 ± 0.00001	0.00007 ± 0.00006	0.0002 ± 0.0002	
<sup>238</sup> Pu	Composite	5	<0.000001 ± 0.000001	<0.00 ± 0.00001	<0.0000005 ± 0.000003	<0.0000006 ± 0.000001	
<sup>239,240</sup> Pu	Composite	5	0.000008 ± 0.000003	<0.000001 ± 0.000002	0.000006 ± 0.000004	0.000002 ± 0.000001	
Gross Beta	400E	24	0.08 ± 0.006	0.008 ± 0.004	0.03 ± 0.007	0.02 ± 0.002	
	400N	26	0.05 ± 0.005	0.007 ± 0.004	0.02 ± 0.005		
	400S	22	0.05 ± 0.005	0.007 ± 0.004	0.02 ± 0.005		
	400N	26	0.07 ± 0.005	<0.004 ± 0.004	0.03 ± 0.006		
Gross Alpha	400E	24	0.002 ± 0.0007	<0.0002 ± 0.0003	0.001 ± 0.0002		
	400W	26	0.002 ± 0.0007	<0.0004 ± 0.0004	0.001 ± 0.0002		
	400S	22	0.002 ± 0.0006	0.0005 ± 0.0004	0.001 ± 0.0002		
	400N	26	0.002 ± 0.0006	0.0004 ± 0.0003	0.001 ± 0.0002		
					0.001 ± 0.0001	0.001 ± 0.0001	

(a) Maximum and minimum concentrations ±2σ counting error. Averages ± two standard error of the calculated mean (95% confidence level).

(b) Distant sampling locations are identified in Table 2.

(c) Composites of biweekly samples from the individual sampling locations are identified in Table 2.

TABLE A.10. Airborne Radionuclide Concentrations in the 600 Area

Radio-nuclide	Sample Location	Number of Samples	Concentration, pCi/m <sup>3</sup> (a)				Average 1984 Distant <sup>(b)</sup>
			Maximum	Minimum	Annual Average	Average 1984 Distant <sup>(b)</sup>	
<sup>3</sup> H (HTO)	Hanford	12	5.7 ± 2.7	<0.1 ± 0.2	2.3 ± 1.1		
	Wye Barricade	12	6.0 ± 3.0	<-1.2 ± 2.5	1.6 ± 1.1	1.6 ± 0.6	
<sup>14</sup> C (CO <sub>2</sub> )	Wye Barricade	7	1.6 ± 0.01	1.1 ± 0.1	1.3 ± 0.2	1.3 ± 0.08	
<sup>90</sup> Sr	Hanford	5	0.0008 ± 0.0002	<0.00005 ± 0.0002	0.0004 ± 0.0003		
	Wye Barricade	5	0.0006 ± 0.0002	<0.00002 ± 0.0002	<0.0002 ± 0.0002	<0.0001 ± 0.00007	
<sup>131</sup> I	Hanford				NRA <sup>(c)</sup>		
	Wye Barricade					<-0.0001 ± 0.002	
<sup>137</sup> Cs	Hanford	13	0.007 ± 0.003	<-0.002 ± 0.002	0.0007 ± 0.001		
	Wye Barricade	13	0.003 ± 0.002	<-0.001 ± 0.005	0.0008 ± 0.0007	<0.000009 ± 0.00003	
U (total)	Hanford	4	<0.0002 ± 0.0002	0.00005 ± 0.00003	0.00009 ± 0.00008		
	Wye Barricade	4	0.0002 ± 0.00009	0.00004 ± 0.00003	0.0001 ± 0.00008	<0.0002 ± 0.0002	
<sup>238</sup> Pu	Hanford	5	<0.000006 ± 0.00001	<-0.0000009 ± 0.000003	<0.000002 ± 0.000004		
	Wye Barricade	5	<0.000004 ± 0.000004	<-0.0000004 ± 0.000003	<0.0000004 ± 0.000003	<0.0000006 ± 0.000001	
<sup>238,240</sup> Pu	Hanford	5	0.00001 ± 0.000007	<0.0000009 ± 0.000003	0.000007 ± 0.000006		
	Wye Barricade	5	0.00002 ± 0.000008	<-0.0000004 ± 0.000005	<0.000007 ± 0.000007	0.000002 ± 0.000001	
Gross Beta	Hanford	25	0.05 ± 0.005	<0.004 ± 0.005	0.02 ± 0.005		
	Wye Barricade	25	0.09 ± 0.01	<0.002 ± 0.004	0.03 ± 0.008	0.02 ± 0.002	
Gross Alpha	Hanford	24	0.002 ± 0.0008	0.0004 ± 0.0003	0.0007 ± 0.0002		
	Wye Barricade	24	0.003 ± 0.001	<0.0004 ± 0.0004	0.001 ± 0.0003	0.001 ± 0.0001	

(a) Maximum and minimum concentrations ±2σ counting error. Averages ± two standard error of the calculated mean (95% confidence level).

(b) Distant sampling locations are identified in Table 2.

(c) Not routinely analyzed.

**TABLE A.11. Radionuclide Concentrations in Columbia River Water Upstream from Hanford Operations in 1984**

Radionuclide <sup>(b)</sup>	Number of Samples Collected	Concentration, pCi/l <sup>(a)</sup>			
		Minimum Result	Maximum Result	Average	
<sup>3</sup> H	13	94 ± 9.4	190 ± 14	130 ± 15	
<sup>60</sup> Co	Particulate	21	<-0.0037 ± 0.0069	0.014 ± 0.0068	<0.0012 ± 0.0019
	Dissolved	21	<-0.0040 ± 0.015	<0.014 ± 0.014	0.0033 ± 0.0030
<sup>89</sup> Sr	13	< 0.037 ± 0.090	0.33 ± 0.11	0.14 ± 0.064	
<sup>90</sup> Sr	13	0.073 ± 0.037	0.18 ± 0.042	0.14 ± 0.020	
<sup>95</sup> Zr	Particulate	21	<-0.0054 ± 0.0076	0.0077 ± 0.0049	<0.00025 ± 0.0021
	Dissolved	21	<-0.0081 ± 0.013	0.012 ± 0.011	<0.0023 ± 0.0041
<sup>95</sup> Nb	Particulate	21	<-0.0053 ± 0.0047	0.0034 ± 0.0030	<0.00004 ± 0.0013
	Dissolved	21	<-0.0068 ± 0.0084	0.0093 ± 0.0066	<0.00070 ± 0.0026
<sup>106</sup> Ru	Particulate	21	<-0.029 ± 0.031	0.036 ± 0.031	<-0.0058 ± 0.0097
	Dissolved	21	<-0.058 ± 0.086	0.088 ± 0.074	<0.0057 ± 0.020
<sup>129</sup> I	Dissolved	5	7.5 x 10 <sup>-6</sup> ± 9.6 x 10 <sup>-7</sup>	1.7 x 10 <sup>-5</sup> ± 1.9 x 10 <sup>-6</sup>	1.2 x 10 <sup>-5</sup> ± 3.8 x 10 <sup>-6</sup>
<sup>131</sup> I	Particulate	21	<-0.0061 ± 0.0073	<0.0050 ± 0.0074	<0.00027 ± 0.0018
	Dissolved	21	<-0.010 ± 0.016	<0.010 ± 0.014	<0.00056 ± 0.0040
<sup>137</sup> Cs	Particulate	21	0.0087 ± 0.0029	0.022 ± 0.0053	0.014 ± 0.0017
	Dissolved	21	0.014 ± 0.0077	0.047 ± 0.012	0.029 ± 0.0044
<sup>144</sup> Ce	Particulate	21	<-0.018 ± 0.012	<0.0070 ± 0.0087	<-0.00023 ± 0.0033
	Dissolved	21	<-0.029 ± 0.030	0.021 ± 0.020	<-0.0038 ± 0.0072
U(Natural)	13	0.18 ± 0.00	0.43 ± 0.14	0.33 ± 0.047	
<sup>238</sup> Pu	Particulate	5	<2.0 x 10 <sup>-6</sup> ± 0.00	9. x 10 <sup>-6</sup> ± 4.2 x 10 <sup>-6</sup>	4.2 x 10 <sup>-6</sup> ± 3.2 x 10 <sup>-6</sup>
	Dissolved	5	<4.4 x 10 <sup>-5</sup> ± 5.8 x 10 <sup>-5</sup>	4.6 x 10 <sup>-4</sup> ± 8.0 x 10 <sup>-5</sup>	1.8 x 10 <sup>-4</sup> ± 1.6 x 10 <sup>-4</sup>
<sup>239,240</sup> Pu	Particulate	5	<9.0 x 10 <sup>-6</sup> ± 1.0 x 10 <sup>-5</sup>	5.0 x 10 <sup>-5</sup> ± 6.0 x 10 <sup>-6</sup>	2.7 x 10 <sup>-5</sup> ± 1.6 x 10 <sup>-5</sup>
	Dissolved	5	<1.8 x 10 <sup>-5</sup> ± 3.5 x 10 <sup>-5</sup>	5.0 x 10 <sup>-4</sup> ± 1.8 x 10 <sup>-4</sup>	3.0 x 10 <sup>-4</sup> ± 1.9 x 10 <sup>-4</sup>

(a) Maximum and minimum values ± two sigma counting error. Averages ± two standard error of the calculated mean (95% confidence interval).

(b) Radionuclides measured using the large-volume sampler show the particulate and dissolved fractions separately. Other radionuclides are based on samples collected by the cumulative sampler (see text).

**TABLE A.12. Radionuclide Concentrations in Columbia River Water Downstream from Hanford Operations in 1984**

Radionuclide <sup>(b)</sup>	Number of Samples Collected	Concentration, pCi/l <sup>(a)</sup>			Concentration Guide	
		Minimum Result	Maximum Result	Average		
<sup>3</sup> H	12	130 ± 13	270 ± 14	170 ± 23	3,000,000	
<sup>60</sup> Co	Particulate	23	<0.0012 ± 0.0036	0.022 ± 0.0047	0.0076 ± 0.0025	30,000
	Dissolved	24	<-0.0010 ± 0.0088	0.093 ± 0.012	0.012 ± 0.0077	
<sup>89</sup> Sr	12	<-0.019 ± 0.13	0.36 ± 0.11	0.15 ± 0.082	3,000	
<sup>90</sup> Sr	12	<0.023 ± 0.049	0.26 ± 0.11	0.17 ± 0.041	300	
<sup>95</sup> Zr	Particulate	23	<-0.0033 ± 0.0057	0.0067 ± 0.0044	0.0015 ± 0.0015	60,000
	Dissolved	24	<-0.0080 ± 0.010	0.011 ± 0.011	<0.00053 ± 0.0029	
<sup>95</sup> Nb	Particulate	23	<-0.0042 ± 0.0033	0.0055 ± 0.0031	0.0014 ± 0.0011	100,000
	Dissolved	24	<-0.0052 ± 0.0073	0.0095 ± 0.0082	<0.00040 ± 0.0021	
<sup>106</sup> Ru	Particulate	23	<-0.019 ± 0.028	0.034 ± 0.023	<0.0025 ± 0.0076	10,000
	Dissolved	24	<-0.050 ± 0.051	0.061 ± 0.047	<0.00042 ± 0.016	
<sup>129</sup> I	Dissolved	5	4.4 × 10 <sup>-5</sup> ± 4.9 × 10 <sup>-6</sup>	1.2 × 10 <sup>-4</sup> ± 1.1 × 10 <sup>-5</sup>	7.4 × 10 <sup>-5</sup> ± 2.9 × 10 <sup>-5</sup>	60
<sup>131</sup> I	Particulate	23	<-0.0040 ± 0.0051	0.0060 ± 0.0039	0.0020 ± 0.0016	300
	Dissolved	24	<-0.0018 ± 0.011	0.056 ± 0.011	0.017 ± 0.0070	
<sup>137</sup> Cs	Particulate	23	0.0077 ± 0.0033	0.015 ± 0.0027	0.011 ± 0.0011	20,000
	Dissolved	24	0.013 ± 0.0059	0.032 ± 0.0076	0.023 ± 0.0023	
<sup>144</sup> Ce	Particulate	23	<-0.0051 ± 0.0081	<0.0077 ± 0.010	<0.00096 ± 0.0022	10,000
	Dissolved	24	<-0.019 ± 0.020	0.016 ± 0.015	<-0.0016 ± 0.0048	
U(Natural)	12	0.27 ± 0.00	0.73 ± 0.00	0.45 ± 0.085	600	
<sup>238</sup> Pu	Particulate	5	<1.0 × 10 <sup>-6</sup> ± 0.00	<3.1 × 10 <sup>-6</sup> ± 3.2 × 10 <sup>-6</sup>	2.2 × 10 <sup>-6</sup> ± 1.4 × 10 <sup>-6</sup>	5,000
	Dissolved	5	<2.0 × 10 <sup>-5</sup> ± 0.00	8.5 × 10 <sup>-5</sup> ± 5.6 × 10 <sup>-5</sup>	4.4 × 10 <sup>-5</sup> ± 3.0 × 10 <sup>-5</sup>	
<sup>239,240</sup> Pu	Particulate	5	4.0 × 10 <sup>-6</sup> ± 2.0 × 10 <sup>-6</sup>	2.5 × 10 <sup>-5</sup> ± 6.0 × 10 <sup>-6</sup>	1.8 × 10 <sup>-5</sup> ± 8.3 × 10 <sup>-6</sup>	5,000
	Dissolved	5	<2.6 × 10 <sup>-5</sup> ± 4.1 × 10 <sup>-5</sup>	4.9 × 10 <sup>-4</sup> ± 1.2 × 10 <sup>-4</sup>	<1.5 × 10 <sup>-4</sup> ± 1.8 × 10 <sup>-4</sup>	

(a) Maximum and minimum values ± two sigma counting error. Averages ± two standard error of the calculated mean (95% confidence interval).

(b) Radionuclides measured using the large-volume sampler show the particulate and dissolved fractions separately. Other radionuclides are based on samples collected by the cumulative sampler (see text).

(c) From DOE Order 5450.1 (see Appendix C).

**TABLE A.13. Radionuclide Concentrations in Onsite Ponds in 1984**

Location	Radionuclide	No. Samples Collected	Concentration, pCi/μ(a)		
			Minimum Result	Maximum Result	Average
West Lake	Gross Alpha	4	55 ± 7.2	320 ± 18	180 ± 130
	Gross Beta	4	120 ± 25	400 ± 44	240 ± 130
	<sup>3</sup> H	4	810 ± 210	1100 ± 220	940 ± 170
	<sup>90</sup> Sr	4	0.94 ± 0.080	5.0 ± 0.28	2.3 ± 2.0
	<sup>137</sup> Cs	4	<0.89 ± 4.0	4.4 ± 2.6	<1.8 ± 2.9
Gable Pond	Gross Alpha	4	<0.33 ± 0.34	1.3 ± 0.41	0.72 ± 0.50
	Gross Beta	4	7.2 ± 2.3	37 ± 4.7	17 ± 15
	<sup>3</sup> H	4	<160 ± 190	310 ± 200	220 ± 120
	<sup>90</sup> Sr	4	0.83 ± 0.10	4.8 ± 0.22	2.7 ± 1.9
	<sup>137</sup> Cs	4	5.3 ± 1.6	28 ± 5.7	17 ± 11
B Pond	Gross Alpha	4	<0.30 ± 1.1	0.85 ± 0.34	0.63 ± 0.43
	Gross Beta	4	9.6 ± 2.5	88 ± 7.0	45 ± 38
	<sup>3</sup> H	5	<160 ± 200	12,000 ± 380	5,600 ± 4,500
	<sup>90</sup> Sr	5	1.8 ± 0.16	33 ± 0.70	<8.6 ± 12
	<sup>137</sup> Cs	5	<0.83 ± 2.1	11 ± 3.7	<2.5 ± 4.5
FFTF Pond	Gross Alpha	4	<0.25 ± 1.8	<0.12 ± 1.3	<0.069 ± 0.69
	Gross Beta	4	3.5 ± 0.71	41 ± 12	19 ± 19
	<sup>3</sup> H	4	20,000 ± 450	41,000 ± 630	29,000 ± 9,800
	<sup>137</sup> Cs	4	<1.0 ± 2.8	<1.3 ± 2.7	<0.024 ± 1.6
	<sup>22</sup> Na	4	<2.8 ± 4.6	3.0 ± 2.7	<0.21 ± 3.2

(a) Maximum and minimum values ± two sigma counting error. Averages ± two standard error of the calculated mean (95% confidence interval).

**TABLE A.14. Radionuclides in Milk Samples**

Location(b)	Concentration, pCi/l(a)					
	<sup>131</sup> I			<sup>137</sup> Cs		
	No. of Samples	Maximum	Average	No. of Samples	Maximum	Average
Wahluke East Area Composite	13	<0.1 ± 0.16	<-0.13 ± 0.14	13	5.2 ± 4.3	<-0.47 ± 2.6
Sagemoor Area Composite	26	0.94 ± 0.17	<-0.08 ± 0.11	26	9.9 ± 4.5	2.0 ± 1.8
Riverview Area(c)	12	<0.06 ± 0.14	<-0.092 ± 0.098	12	11 ± 5.4	<2.2 ± 2.6
Benton City Area	13	<0.037 ± 0.18	<-0.12 ± 0.094	13	6.9 ± 4.3	<1.3 ± 2.5
Sunnyside Area	25	<0.22 ± 0.26	<-0.07 ± 0.075	25	10 ± 5.1	<1.7 ± 1.8
Moses Lake Area	13	<0.17 ± 0.21	<-0.5 ± 0.31	13	8.4 ± 4.1	3.0 ± 1.8

Location(b)	<sup>89</sup> Sr			<sup>90</sup> Sr		
	No. of Samples	Maximum	Average	No. of Samples	Maximum	Average
	Wahluke East Area Composite	4	2.1 ± 0.86	<0.56 ± 1.4	4	1.3 ± 0.41
Sagemoor Area Composite		---(d)	---	4	1.7 ± 0.66	1.3 ± 0.46
Benton City Area		---	---	4	2.0 ± 0.64	1.6 ± 0.57
Sunnyside Area	4	<1.4 ± 1.2	0.83 ± 0.76	4	1.1 ± 0.87	0.69 ± 0.59

Location(b)	<sup>3</sup> H			<sup>129</sup> I		
	No. of Samples	Maximum	Average	No. of Samples	Maximum	Average
	Wahluke East Area Composite	13	490 ± 210	240 ± 98	2	0.0068 ± 0.00081
Sagemoor Area Composite	12	470 ± 210	250 ± 85	2	0.0054 ± 0.00057	<0.0032 ± 0.0054
Riverview Area(c)	12	530 ± 260	210 ± 111	2	0.0041 ± 0.00047	<0.0027 ± 0.0037
Benton City Area	13	360 ± 200	200 ± 86	2	0.0043 ± 0.00049	<0.0029 ± 0.0035
Sunnyside Area	12	<240 ± 200	150 ± 81	2	0.0023 ± 0.00017	<0.0015 ± 0.002
Moses Lake Area	13	490 ± 210	230 ± 92	2	0.00069 ± 0.000085	<0.00061 ± 0.0002

(a) Maximum values ± two sigma counting error. Averages ± two standard error of the calculated mean (95% confidence interval).

(b) Refer to Figure 18.

(c) Drinking and irrigation water obtained from the Columbia River.

(d) No sample

**TABLE A.15. Radionuclides in Leafy Vegetables**

Location(b)	Concentration, pCi/g, wet weight(a)					
	<sup>90</sup> Sr			<sup>137</sup> Cs		
	No. of Samples	Maximum	Average	No. of Samples	Maximum	Average
Wahluke East Area	3	0.0069 ± 0.0028	0.0047 ± 0.0036	3	<0.0084 ± 0.012	<0.0016 ± 0.015
Riverview Area(c)	3	0.015 ± 0.0025	0.01 ± 0.0067	3	<0.0059 ± 0.013	<0.000023 ± 0.012
Benton City Area	3	0.028 ± 0.0031	<0.014 ± 0.014	3	0.01 ± 0.009	0.0066 ± 0.0065
Sunnyside Area	3	0.056 ± 0.0086	0.033 ± 0.027	3	<0.01 ± 0.016	<0.0069 ± 0.011
Moses Lake Area	3	0.0072 ± 0.0021	0.0061 ± 0.0024	3	<0.0051 ± 0.014	<-0.0028 ± 0.014

(a) Maximum and minimum concentrations ±2σ counting error. Averages ± two standard error of the calculated mean (95% confidence level).

(b) Refer to Figure 18.

(c) Irrigated with Columbia River water.

TABLE A.16. Radionuclides in Fruit

Fruit/ Location(c)	Concentration, pCi/g, wet weight(a,b)											
	<sup>137</sup> Cs				<sup>90</sup> Sr				<sup>3</sup> H			
	Number of Samples	Maximum	Average	Number of Samples	Maximum	Average	Number of Samples	Maximum	Average	Number of Samples	Maximum	Average
<b>Apples</b>												
Sagemoor Area	3	0.01 ± 0.0052	<0.0018 ± 0.0092	3	<0.0023 ± 0.0012	0.0017 ± 0.0011	3	460 ± 210	0.0017 ± 0.0011	3	270 ± 260	
Cold Creek Area	3	0.00016 ± 0.0076	<-0.0072 ± 0.0096	3	0.0028 ± 0.0011	0.0024 ± 0.0016	3	<111 ± 200	0.0024 ± 0.0016	3	<85 ± 120	
Sunnyside Area	3	<0.0015 ± 0.0063	<-0.0054 ± 0.014	3	<0.0029 ± 0.0016	0.0022 ± 0.0011	3	490 ± 210	0.0022 ± 0.0011	3	310 ± 260	
<b>Cherries</b>												
Sunnyside Area	3	0.0067 ± 0.0069	<-0.003 ± 0.014	3	0.0085 ± 0.0037	0.0058 ± 0.0036	3	<140 ± 200	0.0058 ± 0.0036	3	<44 ± 180	
<b>Grapes</b>												
Sagemoor Area	3	<0.0013 ± 0.0066	<-0.0043 ± 0.011	3	0.0048 ± 0.0014	0.0032 ± 0.0019	3	630 ± 210	0.0032 ± 0.0019	3	510 ± 190	
Cold Creek Area	3	<0.00097 ± 0.0071	<-0.0012 ± 0.0052	3	<0.0022 ± 0.0014	0.0019 ± 0.00088	3	<160 ± 200	0.0019 ± 0.00088	3	510 ± 120	
Sunnyside Area	3	0.0053 ± 0.0051	<0.0014 ± 0.0079	3	<0.0047 ± 0.0035	0.0041 ± 0.0022	3	520 ± 210	0.0041 ± 0.0022	3	360 ± 230	

(a) Except for <sup>3</sup>H, which is given in pCi/l of water.

(b) Maximum values ± two sigma counting error. Averages ± two standard error of the calculated mean (95% confidence interval).

(c) Refer to Figure 18.

**TABLE A.17. Radionuclides in Wheat and Alfalfa**

Type/Location <sup>(b)</sup>	Concentration, pCi/g, dry weight <sup>(a)</sup>					
	<sup>90</sup> Sr			<sup>137</sup> Cs		
	No. of Samples	Maximum	Average	No. of Samples	Maximum	Average
<b>Wheat</b>						
Wahluke East Area	3	0.0096 ± 0.0065	<0.0054 ± 0.009	3	<0.0082 ± 0.012	<0.0042 ± 0.0089
Sagemoor Area	3	0.015 ± 0.012	0.01 ± 0.0078	3	0.0081 ± 0.0074	<0.0023 ± 0.0078
Benton City Area	3	0.0081 ± 0.0019	0.0069 ± 0.0031	3	0.0075 ± 0.0059	<0.0054 ± 0.0054
Sunnyside Area	3	0.01 ± 0.0032	0.0074 ± 0.0042	3	0.015 ± 0.0094	<0.0038 ± 0.014
Moses Lake Area	3	<0.015 ± 0.0052	0.011 ± 0.0059	3	<0.0073 ± 0.0094	<0.0057 ± 0.017
Riverview Area <sup>(c)</sup>	3	0.015 ± 0.0024	0.014 ± 0.003	3	0.012 ± 0.0095	<0.0054 ± 0.0085
<b>Alfalfa</b>						
Wahluke East Area	3	0.084 ± 0.013	0.062 ± 0.029	3	0.034 ± 0.016	<0.016 ± 0.023
Sagemoor Area	3	0.16 ± 0.0066	0.13 ± 0.028	3	<0.0035 ± 0.016	<0.0001 ± 0.011
Benton City Area	3	0.067 ± 0.0052	0.053 ± 0.022	3	0.031 ± 0.02	<0.014 ± 0.024
Sunnyside Area	3	0.12 ± 0.016	0.091 ± 0.034	3	<0.0063 ± 0.012	<0.000073 ± 0.015
Moses Lake Area	3	0.25 ± 0.0089	0.22 ± 0.036	3	0.035 ± 0.016	<0.013 ± 0.027
Riverview Area <sup>(c)</sup>	3	0.13 ± 0.011	0.13 ± 0.0082	3	<0.015 ± 0.017	<0.01 ± 0.01

(a) Maximum values ± two sigma counting error. Averages ± two standard error of the calculated mean (95% confidence interval).

(b) Refer to Figure 18.

(c) Irrigated with Columbia River water.

**TABLE A.18. Radionuclides in Beef, Chickens, and Eggs**

Type/Location <sup>(b)</sup>	Concentration, pCi/g, wet weight <sup>(a)</sup>					
	<sup>90</sup> Sr			<sup>137</sup> Cs		
	No. of Samples	Maximum	Average	No. of Samples	Maximum	Average
<b>Beef</b>						
Sagemoor Area	1	---	<0.0022 ± 0.0023	1	---	<0.0026 ± 0.0059
Riverview Area <sup>(c)</sup>	1	---	<0.0011 ± 0.0014	1	---	0.01 ± 0.0056
<b>Chickens</b>						
Sagemoor Area	2	0.0035 ± 0.0018	<0.0024 ± 0.0038	2	<0.0039 ± 0.007	<-0.003 ± 0.018
Sunnyside Area	1	---	<0.0019 ± 0.0035	1	---	<-0.0023 ± 0.011
<b>Eggs</b>						
Sagemoor Area	2	0.01 ± 0.0027	<0.0062 ± 0.01	2	0.014 ± 0.0043	<0.0071 ± 0.017
Sunnyside Area	1	---	0.0049 ± 0.003	1	---	<-0.0002 ± 0.0034

(a) Maximum values ± two sigma counting error. Averages ± two standard error of the calculated mean (95% confidence interval).

(b) Refer to Figure 18.

(c) Water supplied from the Columbia River.

**TABLE A.19. Cesium-137 in Deer Muscle and Plutonium-239,240 in Deer Liver**

Location	Type	Concentration, pCi/g, wet weight(a)					
		<sup>137</sup> Cs			<sup>239,240</sup> Pu		
		Number of Samples	Maximum	Average	Number of Samples	Maximum	Average
Random (road kills)	Muscle	6	0.007 ± 0.005	<0.0004 ± 0.006	---(b)	---	---
	Liver	---	---	---	6	0.0005 ± 0.0003	0.0002 ± 0.0002

(a) Maximum values ± two sigma counting error. Averages ± two standard error of the calculated mean (95% confidence interval).

(b) Dashed lines indicated no analysis or no calculation.

**TABLE A.20. Radionuclides in Columbia River Fish**

Type	Location(b)	Concentration, pCi/g, wet weight(a)											
		<sup>60</sup> Co				<sup>90</sup> Sr				<sup>137</sup> Cs			
		Number of Samples	Maximum	Average	Number of Samples	Maximum	Average	Number of Samples	Maximum	Average	Number of Samples	Maximum	Average
Whitefish	Upstream of Site Boundary	5	0.02 ± 0.02	0.001 ± 0.01	5	0.02 ± 0.01	0.008 ± 0.008	5	0.03 ± 0.02	0.01 ± 0.02	5	0.03 ± 0.02	0.01 ± 0.02
	100-D Area Vicinity	10	0.06 ± 0.05	0.02 ± 0.01	10	0.01 ± 0.01	0.006 ± 0.003	10	0.03 ± 0.01	0.02 ± 0.01	10	0.03 ± 0.01	0.02 ± 0.01
Bass	100F Sloughs	5	0.02 ± 0.01	0.004 ± 0.01	5	0.003 ± 0.003	0.002 ± 0.001	5	0.10 ± 0.02	0.06 ± 0.02	5	0.10 ± 0.02	0.06 ± 0.02

(a) Maximum values ± two sigma counting error. Averages ± two standard error of the calculated mean (95% confidence interval).

(b) Refer to Figure 22.

**TABLE A.21. Cobalt-60 and Cesium-137 in Muscle Tissue of Upland Gamebirds**

Location <sup>(b)</sup>	Concentration, pCi/g, wet weight <sup>(a)</sup>					
	<sup>60</sup> Co			<sup>137</sup> Cs		
	Number of Samples	Maximum	Average	Number of Samples	Maximum	Average
<b>100 Areas</b>						
Pheasant	10	0.02 ± 0.008	0.003 ± 0.008	10	0.09 ± 0.02	0.02 ± 0.02
<b>200 Areas</b>						
Chukar	3	0.01 ± 0.01	0.007 ± 0.01	3	0.09 ± 0.02	0.07 ± 0.03
<b>300 Area</b>						
Pheasant	3	0.03 ± 0.01	0.01 ± 0.02	3	0.02 ± 0.007	0.01 ± 0.02

(a) Maximum values ± two sigma counting error. Averages ± two standard error of the calculated mean (95% confidence interval).

(b) Refer to Figure 22.

**TABLE A.22. Cesium-137 in Muscle Tissue of Mallard Ducks**

Location <sup>(b)</sup>	Number of Samples	Concentration, pCi/g, wet weight <sup>(a)</sup>		
		Maximum	Minimum	Average
<b>200 Area</b>				
B Pond	20	13 ± 0.1	0.1 ± 0.02	3.4 ± 1.9
U Pond	2	67 ± 0.3	5.5 ± 0.8	<36 ± 77
<b>300 Area</b>				
Pond	3	0.7 ± 0.03	0.06 ± 0.01	<0.3 ± 0.4

(a) Maximum and minimum values ± two sigma counting error. Average ± two standard error of the calculated mean (95% confidence interval)

(b) Refer to Figure 22.

**TABLE A.23. Strontium-90 and Cesium-137 in Bone and Muscle Tissue of Rabbits**

Concentration, pCi/g. wet weight <sup>(a)</sup>						
Location <sup>(b)</sup>	<sup>90</sup> Sr (Bone)			<sup>137</sup> Cs (Muscle)		
	Number of Samples	Maximum	Average	Number of Samples	Maximum	Average
<b>100 Areas</b>						
Cottontail	6	55 ± 41	<16 ± 17	6	<0.027 ± .031	0.014 ± .013
<b>200 Areas</b>						
Jack Rabbit	16	15 ± 11	6.9 ± 2.7	8	0.035 ± .028	0.019 ± .01

(a) Maximum values ± two sigma counting error. Averages ± two standard error of the calculated mean (95% confidence interval).

(b) Refer to Figure 22.

**TABLE A.24. Radionuclides in Soil<sup>(a)</sup>**

Location	Map Location(c)	Concentration, pCi/g, dry weight <sup>(b)</sup>				
		<sup>90</sup> Sr	<sup>137</sup> Cs	<sup>239,240</sup> Pu		U (Total)
<b>Onsite</b>						
1 mile NE of N Area	1	0.29 ± 0.017	0.7 ± 0.048	0.015 ± 0.0018	0.42 ± 0.11	
1 mile E of N Area	2	0.22 ± 0.012	0.67 ± 0.045	0.016 ± 0.0027	0.32 ± 0.088	
100 Area Fire Station	3	0.45 ± 0.024	0.98 ± 0.059	0.021 ± 0.0017	0.45 ± 0.12	
200 ENC	4	0.20 ± 0.19	21.0 ± 0.23	0.033 ± 0.0044	0.36 ± 0.098	
E of 200 E	5	0.73 ± 0.048	1.4 ± 0.057	0.012 ± 0.0015	0.32 ± 0.082	
200 ESE	6	0.44 ± 0.058	0.53 ± 0.038	0.0091 ± 0.0017	0.37 ± 0.07	
SW of BC Cribs	7	0.12 ± 0.05	0.064 ± 0.022	0.0034 ± 0.0019	1.0 ± 0.15	
S of 200 E	8	0.5 ± 0.1	0.14 ± 0.02	0.0056 ± 0.0031	0.46 ± 0.22	
E of 200 W	9	0.33 ± 0.022	0.58 ± 0.041	0.074 ± 0.0041	0.53 ± 0.29	
2 miles S of 200 W	10	0.14 ± 0.023	0.17 ± 0.029	0.0036 ± 0.0019	0.34 ± 0.092	
NE of FTF	11	0.18 ± 0.021	0.12 ± 0.024	0.0021 ± 0.0007	0.3 ± 0.082	
SE of FTF	12	<0.032 ± 0.054	0.08 ± 0.019	0.0087 ± 0.0011	0.27 ± 0.073	
N of 300 Area	13	0.58 ± 0.029	0.43 ± 0.038	0.0062 ± 0.0029	0.76 ± 0.2	
Hanford Townsite	14	0.31 ± 0.029	0.91 ± 0.053	0.016 ± 0.0027	0.34 ± 0.093	
Wye Barricade	15	0.31 ± 0.044	0.68 ± 0.04	0.014 ± 0.0023	0.65 ± 0.1	
<b>Overall Average</b>		0.32 ± 0.1	1.9 ± 2.8	0.016 ± 0.0093	0.46 ± 0.11	
<b>Offsite</b>						
Riverview	16	0.039 ± 0.012	0.077 ± 0.048	<0.0018 ± 0.0018	0.32 ± 0.085	
Byers Landing	17	0.064 ± 0.0076	0.2 ± 0.031	0.0066 ± 0.0040	0.43 ± 0.11	
Sagemore	18	0.25 ± 0.046	1.0 ± 0.064	0.019 ± 0.0021	0.50 ± 0.13	
Taylor Flats #2	19	0.042 ± 0.0082	0.084 ± 0.031	0.0014 ± 0.00046	1.0 ± 0.26	
W End Fir Road	20	0.14 ± 0.015	0.12 ± 0.031	0.0022 ± 0.0015	0.54 ± 0.14	
Ringold	21	0.24 ± 0.014	0.44 ± 0.044	0.0074 ± 0.0012	0.78 ± 0.21	
Berg Ranch	22	0.2 ± 0.019	0.49 ± 0.046	0.0097 ± 0.0015	0.41 ± 0.11	
Wahluke #2	23	0.16 ± 0.017	0.29 ± 0.028	0.0061 ± 0.0029	0.43 ± 0.12	
Vernita Bridge	24	0.17 ± 0.015	0.26 ± 0.034	0.0060 ± 0.0024	0.92 ± 0.26	
Yakima Barricade	25	0.13 ± 0.017	0.10 ± 0.027	0.0016 ± 0.0010	0.21 ± 0.056	
Rattlesnake Springs	26	0.075 ± 0.0088	0.14 ± 0.031	0.0032 ± 0.0016	0.26 ± 0.069	
ALE	27	0.36 ± 0.039	0.55 ± 0.043	0.0091 ± 0.0014	0.25 ± 0.067	
Prosser Barricade	28	0.36 ± 0.022	0.15 ± 0.025	0.0039 ± 0.0016	0.36 ± 0.064	
S of 300 Area	29	0.35 ± 0.015	1.1 ± 0.058	0.022 ± 0.0023	1.0 ± 0.29	
Benton City	30	0.36 ± 0.031	0.53 ± 0.043	0.0099 ± 0.0015	0.91 ± 0.24	
Sunnyside	31	0.31 ± 0.029	1.5 ± 0.071	0.025 ± 0.0026	0.26 ± 0.071	
<b>Overall Average</b>		0.20 ± 0.059	0.44 ± 0.21	0.0084 ± 0.0037	0.54 ± 0.15	

(a) Single samples were obtained at each location.

(b) Individual results ± two sigma counting error.

(c) Locations are identified in Figure 23.

**TABLE A.25. Plutonium-239,240 Concentration in Soil at Selected Locations, 1971 to 1984<sup>(a)</sup>**

	Concentration, pCi/g, dry weight <sup>(b)</sup>		
	200 ESE	E of 200 W	Sunnyside Area
1971	0.017 <sup>(c)</sup>	--- <sup>(d)</sup>	---
1972	0.023	---	---
1973	0.036	---	---
1974	0.017	---	---
1975	0.014	---	---
	0.022	---	---
	0.013	---	---
	0.017	---	---
	0.016	0.031	---
1976	0.014	0.076	---
1977	0.0062 ± 0.0023	0.17 ± 0.017	0.0038 ± 0.0015
1978	0.020 ± 0.0037	0.56 ± 0.02	0.0080 ± 0.0029
1979	0.029 ± 0.0019	0.83 ± 0.022	0.025 ± 0.0035
1980	---	0.63 ± 0.016	0.014 ± 0.0025
1981	0.026 ± 0.004	0.42 ± 0.0075	0.013 ± 0.0014
1982	0.023 ± 0.0041	0.78 ± 0.016	0.0092 ± 0.0019
	---	---	0.013 ± 0.005
	---	---	0.0050 ± 0.0013
1983	0.028 ± 0.0054	0.83 ± 0.027	0.026 ± 0.0045
1984	0.0091 ± 0.0017	0.074 ± 0.0041	0.025 ± 0.0026

	Concentration, pCi/g, dry weight <sup>(b)</sup>		
	Byers Area	Riverview Area	Benton City Area
1971	0.012	0.011	0.018
	---	0.011	0.018
1972	0.006	0.008	0.023
	0.003	---	---
1973	0.0052	0.022	0.012
	0.003	---	---
1974	0.0056	0.002	0.037
	0.023	---	---
1975	---	---	---
1976	0.0029	---	---
1977	0.0055 ± 0.0017	0.0040 ± 0.0029	0.0081 ± 0.002
1978	0.00044 ± 0.0037	0.017 ± 0.0034	0.0099 ± 0.002
1979	0.018 ± 0.0027	0.017 ± 0.0028	0.016 ± 0.0014
1980	---	0.016 ± 0.0018	0.020 ± 0.003
1981	0.0049 ± 0.00097	0.011 ± 0.0012	0.021 ± 0.0022
1982	0.0015 ± 0.0009	0.0064 ± 0.0019	0.024 ± 0.0032
1983	0.012 ± 0.0021	0.021 ± 0.005	0.015 ± 0.0017
1984	0.0066 ± 0.004	0.0018 ± 0.0018	0.0099 ± 0.0015

(a) Single samples were collected at each location.

(b) Individual results ± two sigma counting error.

(c) No error estimates were calculated for samples analyzed prior to 1977.

(d) No sample.

**TABLE A.26. Radionuclides in Vegetation<sup>(a)</sup>**

Location	Map Location <sup>(c)</sup>	Concentration, pCi/g, dry weight <sup>(b)</sup>			
		<sup>90</sup> Sr	<sup>137</sup> Cs	<sup>238,240</sup> Pu	U (Total)
<b>Onsite</b>					
1 mile NE of N Area	1	0.069 ± 0.0067	<-0.0097 ± 0.014	<0.0005 ± 0.0005	0.0077 ± 0.0034
1 mile E of N Area	2	0.12 ± 0.012	<-0.0032 ± 0.013	<0.00012 ± 0.0003	0.0061 ± 0.003
100 Area Fire Station	3	0.1 ± 0.011	0.015 ± 0.012	<0.00012 ± 0.00025	0.0067 ± 0.0033
200 ENC	4	0.39 ± 0.015	0.24 ± 0.021	0.00042 ± 0.00022	0.0092 ± 0.0037
E of 200 E	5	0.2 ± 0.026	0.069 ± 0.013	0.00074 ± 0.00066	0.0066 ± 0.0042
200 ESE	6	0.19 ± 0.013	0.079 ± 0.016	0.00093 ± 0.00066	0.0052 ± 0.004
SW of BC Cribs	7	0.11 ± 0.034	0.018 ± 0.013	<0.00053 ± 0.00061	0.017 ± 0.0077
S of 200 E	8	1.1 ± 0.066	0.022 ± 0.011	0.00044 ± 0.00037	0.011 ± 0.0054
E of 200 W	9	0.13 ± 0.02	0.055 ± 0.016	0.0065 ± 0.0018	0.016 ± 0.0065
2 miles S of 200 W	10	0.19 ± 0.0065	<0.01 ± 0.012	<0.0001 ± 0.0002	0.015 ± 0.0058
NE of FFTF	11	0.022 ± 0.0064	<0.0064 ± 0.011	<0.00036 ± 0.00038	0.014 ± 0.0055
SE of FFTF	12	0.088 ± 0.009	<-0.0095 ± 0.014	0.00083 ± 0.00063	0.0058 ± 0.0027
N of 300 Area	13	0.023 ± 0.0043	0.011 ± 0.0089	0.0022 ± 0.0011	0.012 ± 0.0046
Hanford Townsite	14	0.043 ± 0.0059	<0.01 ± 0.02	0.00055 ± 0.00035	0.0032 ± 0.0022
Wye Barricade	15	0.016 ± 0.0074	<-0.0037 ± 0.011	<0.00078 ± 0.00088	0.0045 ± 0.0036
<b>Overall Average</b>		<b>0.19 ± 0.14</b>	<b>0.034 ± 0.033</b>	<b>0.001 ± 0.00085</b>	<b>0.0093 ± 0.0026</b>
<b>Offsite</b>					
Riverview	16	0.015 ± 0.01	<-0.00014 ± 0.014	<0.00013 ± 0.00017	0.021 ± 0.0076
Byers Landing	17	0.018 ± 0.0075	0.024 ± 0.012	<-0.00012 ± 0.00014	0.022 ± 0.0078
Sagemore	18	0.067 ± 0.012	<0.003 ± 0.012	<0.00012 ± 0.00014	0.012 ± 0.005
Taylor Flats #2	19	0.063 ± 0.01	0.016 ± 0.013	<-0.00011 ± 0.00013	0.011 ± 0.0044
W End Fir Road	20	0.047 ± 0.016	<-0.095 ± 0.012	<0.0004 ± 0.00048	0.036 ± 0.012
Ringold	21	0.051 ± 0.01	<-0.00077 ± 0.013	<-0.000065 ± 0.00028	0.025 ± 0.0085
Berg Ranch	22	0.092 ± 0.026	0.027 ± 0.011	0.00080 ± 0.00059	0.017 ± 0.0066
Wahluke #2	23	0.046 ± 0.013	<-0.012 ± 0.012	<0.00017 ± 0.00031	0.0088 ± 0.0039
Vernita Bridge	24	0.072 ± 0.011	<-0.0054 ± 0.01	0.00035 ± 0.00025	0.01 ± 0.0045
Yakima Barricade	25	0.022 ± 0.0033	<0.00 ± 0.013	<0.00027 ± 0.00044	0.0037 ± 0.002
Rattlesnake Springs	26	0.087 ± 0.01	<0.0054 ± 0.013	<0.00022 ± 0.00022	0.0042 ± 0.0022
ALE	27	0.082 ± 0.0069	<-0.0006 ± 0.012	0.00074 ± 0.00063	0.0057 ± 0.0025
Prosser Barricade	28	0.12 ± 0.0085	<0.012 ± 0.012	<0.00017 ± 0.00031	0.0042 ± 0.0023
S of 300 Area	29	0.047 ± 0.0055	<0.0032 ± 0.013	<0.00036 ± 0.00067	0.014 ± 0.0053
Benton City	30	0.055 ± 0.016	<0.0041 ± 0.011	<-0.00015 ± 0.00025	0.014 ± 0.0056
Sunnyside	31	0.037 ± 0.0083	0.018 ± 0.012	0.00031 ± 0.00025	<0.0013 ± 0.0014
<b>Overall Average</b>		<b>0.057 ± 0.014</b>	<b>0.0078 ± 0.0055</b>	<b>0.00022 ± 0.00017</b>	<b>0.013 ± 0.0049</b>

- (a) Single samples were obtained at each location.  
 (b) Individual results ± two sigma counting error.  
 (c) Locations are identified in Figure 23.

**TABLE A.27. Environmental Dosimeter Measurements - Perimeter and Community Locations**

Location	Map Location(b)	No of Samples	Dose Rate, mrem/yr(a)		
			Maximum	Minimum	Average(c)
<b>Perimeter Stations</b>					
Prosser Barricade	1	11	80	62	69 ± 3
ALE	2	10	77	66	73 ± 3
Rattlesnake Springs	3	12	95	66	73 ± 4
Yakima Barricade	4	12	120	69	80 ± 7
Vernita Bridge	5	13	120	62	80 ± 10
Wahluke #2	6	13	99	66	80 ± 6
Berg Ranch	7	13	120	66	77 ± 7
Sagehill	8	13	80	58	69 ± 4
Ringold	9	13	95	58	69 ± 6
Fir Road	10	13	84	58	69 ± 5
Pettett	11	13	84	55	66 ± 4
Sagemoor	12	13	88	58	73 ± 4
Byer's Landing	13	13	88	66	69 ± 4
RRC #64	14	13	73	55	66 ± 3
Horn Rapids Rd - Mi 12	15	11	88	55	69 ± 6
Horn Rapids Rd - Substation	16	11	77	55	62 ± 4
Range of annual averages 66-80 mrem/yr					
<b>Nearby Communities</b>					
Benton City	17	11	58	40	51 ± 3
Othello	18	13	69	44	58 ± 4
Connell	19	13	91	51	62 ± 6
Pasco	20	13	73	58	62 ± 3
Richland	21	13	69	58	66 ± 3
Range of annual averages 51-66 mrem/yr					
<b>Distant Communities</b>					
Walla Walla	22	13	84	47	66 ± 5
McNary	23	13	80	66	73 ± 3
Sunnyside	24	11	69	47	58 ± 4
Moses Lake	25	11	80	31	58 ± 7
Washtucna	26	6	95	58	73 ± 12
Range of annual averages 58-73 mrem/yr					

(a) Monthly integrated readings in mR were converted to annual dose equivalent rates.

(b) Locations are identified in Figure 35.

(c) Averages ± two standard error of the calculated mean (95% confidence level).

**TABLE A.28. Immersion Dose Rates in the Columbia River**

Location <sup>(b)</sup>	Number of Measurements	Dose Rate, mrem/h <sup>(a)</sup>		
		Maximum	Minimum	Average <sup>(c)</sup>
Coyote Rapids	3	0.006	0.005	0.005 ± 0.001
Richland Pumphouse	7	0.005	0.003	0.004 ± 0.0007

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

(b) Locations are identified in Figure 37.

(c) Averages ± two standard error of calculated mean (95% confidence level).

**TABLE A.29. Environmental Dosimeter Measurements at Publicly Accessible Onsite Locations**

Location	Map Location <sup>(b)</sup>	No of Measurements	Dose Rate, mrem/h <sup>(a)</sup>		
			Maximum	Minimum	Average <sup>(c)</sup>
<b>100-N Area Shoreline</b>					
100-N Trench Springs	1	5	0.016	0.013	0.014 ± 0.001
Below 100-N Main Stack	2	13	0.040	0.017	0.023 ± 0.004
Upstream Tip 100-N Berm	3	13	0.034	0.010	0.011 ± 0.001
Downstream 100-N Outfall	4	12	0.050	0.020	0.030 ± 0.005
<b>300 Area Perimeter Fence</b>					
377-S Fence	5	12	0.020	0.016	0.018 ± 0.001
3705 West Fence	6	12	0.008	0.007	0.008 ± 0.0002
<b>400 Area (FFTF) Perimeter Fence</b>					
400 East	7	12	0.009	0.007	0.008 ± 0.0003

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

(b) Locations are identified in Figure 38.

(c) Averages ± two standard error of the calculated mean (95% confidence level).

**TABLE A.30. Environmental Dosimeter Measurements along the Hanford Reach of the Columbia River**

Location	Map Location <sup>(b)</sup>	No of Measurements	Dose Rate, mrem/h <sup>(a)</sup>		
			Maximum	Minimum	Average <sup>(c)</sup>
Upriver 100-B Area	1	4	0.008	0.007	0.008 ± 0.0004
Below 100-B Retention Basin	2	4	0.018	0.016	0.017 ± 0.001
Above 100-K Boat Ramp	3	4	0.008	0.008	0.008 ± 0.0002
Downriver 100-D	4	4	0.034	0.010	0.011 ± 0.001
Downriver opposite 100-D	5	4	0.008	0.007	0.008 ± 0.0004
Lower end Locke Island	6	4	0.008	0.008	0.008 ± 0.0003
White Bluffs Slough	7	4	0.015	0.012	0.014 ± 0.0002
White Bluffs Ferry Landing	8	4	0.008	0.008	0.008 ± 0.0002
Below 100-F	9	4	0.008	0.008	0.008 ± 0.0004
100F Floodplain	10	4	0.016	0.015	0.015 ± 0.001
Hanford powerline crossing	11	4	0.010	0.008	0.009 ± 0.001
Hanford ferry landing	12	4	0.008	0.007	0.007 ± 0.001
Hanford Peninsula	13	4	0.014	0.012	0.013 ± 0.001
Hanford railroad track	14	4	0.013	0.011	0.012 ± 0.001
Savage Island Slough	15	4	0.011	0.010	0.010 ± 0.0004
Ringold Island	16	4	0.009	0.008	0.009 ± 0.0005
Powerline crossing	17	4	0.010	0.009	0.010 ± 0.001
North end Wooded Island	18	4	0.008	0.007	0.007 ± 0.001
South end Wooded Island	19	4	0.010	0.009	0.010 ± 0.0003
Island Near 300 Area	20	4	0.012	0.009	0.011 ± 0.001
Below Bateman Island	21	4	0.010	0.010	0.010 ± 0.0005

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

(b) Locations are identified in Figure 37.

(c) Averages ± two standard error of the calculated mean (95% confidence level).

**TABLE A.31. Onsite External Penetrating Dose Measurements**

Location	Map Location <sup>(b)</sup>	No. of Measurements	Dose Rate, mrem/h <sup>(a)</sup>		
			Maximum	Minimum	Average <sup>(c)</sup>
<b>100 Area</b>					
100 K	1	13	0.013	0.005	0.008 ± 0.001
100 N	2	13	0.014	0.008	0.010 ± 0.001
100 D	3	13	0.015	0.006	0.009 ± 0.001
100 Area Fire Station	4	12	0.014	0.005	0.008 ± 0.001
<b>200 Area</b>					
N of 200 E	5	12	0.010	0.008	0.009 ± 0.001
E of 200 E	6	12	0.010	0.008	0.010 ± 0.001
200 ESE	7	12	0.010	0.008	0.010 ± 0.0004
GTE Building	8	12	0.012	0.006	0.007 ± 0.001
SW of 200-BC Cribs	9	12	0.012	0.007	0.008 ± 0.001
S of 200 E	10	11	0.012	0.008	0.009 ± 0.001
<b>300 Area</b>					
300 Pond	11	12	0.009	0.008	0.008 ± 0.0003
3614 A Building	12	12	0.008	0.007	0.008 ± 0.0002
300 S Gate	13	12	0.009	0.007	0.008 ± 0.0004
300 SW Gate	14	12	0.008	0.007	0.008 ± 0.0002
3705 West Fence	15	12	0.015	0.013	0.013 ± 0.0004
377 Building South Fence	16	12	0.020	0.016	0.018 ± 0.001
<b>400 Area</b>					
400 E	17	12	0.009	0.007	0.008 ± 0.0003
400 W	18	12	0.009	0.006	0.007 ± 0.0005
400 S	19	12	0.009	0.007	0.008 ± 0.0004
400 N	20	12	0.013	0.010	0.011 ± 0.001
FFTF North	21	12	0.012	0.007	0.008 ± 0.001
FFTF Southeast	22	12	0.010	0.007	0.008 ± 0.001
<b>600 Area</b>					
Rt. 11A Mi 9	23	12	0.010	0.007	0.008 ± 0.001
Hanford	24	13	0.010	0.003	0.008 ± 0.001
Wye Barricade	25	13	0.012	0.008	0.009 ± 0.001
Army Loop Camp	26	12	0.010	0.008	0.008 ± 0.0004

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

(b) Locations are identified in Figure 39.

(c) Averages ± two standard error of the mean (95% confidence level).

TABLE A.32. Columbia River Water Quality Data

Analysis	Units	Vernita Bridge (Upstream)				Richland (Downstream)				
		No. of Samples	Maximum	Minimum	Annual Average(a)	No. of Samples	Maximum	Minimum	Annual Average(a)	State Standard(b)
<b>Environmental Surveillance Sampling Program</b>										
pH	pH units	13	8.5	7.7	NA	13	9.1	7.2	NA	6.5 - 8.5
Fecal coliform	#/100 ml	13	25	2	2(d)	13	95	2	11(d)	100
Total coliform	#/100 ml	13	540	2	49(d)	13	920	2	49(d)	
Biological Oxygen Demand	mg/l	13	8.7	1.5	2.9 ± 1.1	13	6.2	1.2	2.4 ± 0.77	
Nitrate	mg/l	13	0.80	0.040	0.17 ± 0.11	13	0.38	0.050	0.17 ± 0.064	
<b>USGS Sampling Program(e)</b>										
Temperature(f)	°C	351	19.3	2.5	10.7 ± 5.8	286	—(g)	2.6	—	20 (maximum)
Dissolved Oxygen	mg/l	5	12.4	9.5	11 ± 0.54	4	12.3	9.4	11 ± 0.64	8 (minimum)
Turbidity	NTU(c)	6	2.5	1.8	2.2 ± 0.10	4	3.7	2.6	3.0 ± 0.25	5 + background
pH	pH units	6	7.9	7.4	NA	4	8.2	7.3	NA	6.5 - 8.5
Fecal coliform	#/100 ml	5	3,000	<1	<1(d)	4	4,000	<1	2,500(d)	100
Suspended solids, 105°C	mg/l	6	15	1	6.8 ± 2.1	4	16	6	9.5 ± 2.4	
Dissolved solids, 180°C	mg/l	6	98	73	85 ± 4.0	4	91	74	83 ± 4.0	
Specific conductance	µmhos	6	160	122	146 ± 6.0	4	158	122	144 ± 8.5	
Hardness, as CaCO <sub>3</sub>	mg/l	6	78	58	69 ± 2.8	4	76	61	70 ± 3.2	
Phosphorus, total	mg/l	6	0.040	0.020	0.037 ± 0.0042	4	0.030	0.010	0.20 ± 0.0058	
Chloride, dissolved	mg/l	6	3.3	1.0	1.6 ± 0.35	4	2.3	1.2	1.7 ± 0.26	
Chromium, dissolved	mg/l	4	<1	<1	<1	4	20	<10		
Nitrogen, Kjeldahl	mg/l	6	0.60	0.20	0.28 ± 0.065	4	0.30	<0.20		
Total Organic Carbon	mg/l	4	6.9	3.2	5.1 ± 0.76	4	6.6	1.5	3.2 ± 1.2	
Iron, dissolved	mg/l	4	31	11	1.9 ± 4	4	37	11	19 ± 6	
Ammonia, dissolved (as N)	mg/l	6	0.180	0.010	0.06 ± 0.03	4	0.050	0.010	0.03 ± 0.009	

(a) Average values ± two standard error of the calculated mean (95% confidence interval).

(b) See Appendix C.

(c) Nephelometric Turbidity Units.

(d) Annual median.

(e) Provisional data subject to revision.

(f) Each value represents a daily average.

(g) missing data

N/A = Not Applicable.



## **APPENDIX B**

### **REFERENCE GUIDE**

- **Glossary**
- **Acronyms and Abbreviations**
- **Miscellaneous Abbreviations**
- **Conversion Table**
- **Table of Unit Prefixes**



## GLOSSARY

**Absorbed Dose** - The amount of energy deposited by radiation in a given amount of material. Absorbed dose is measured in units of "rads." (See dose equivalent.)

**Activation Product** - A material made radioactive by exposure to neutron radiation in a nuclear reactor.

**Aquifer** - An underground formation through which ground water can easily percolate.

**Unconfined Aquifer** - Contains ground water that is not confined or under pressure from relatively impermeable rocks. The pressure in 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.

**Confined Aquifer** - Bounded above and below by impermeable layers of rock. Ground water in the confined aquifer is under pressure.

**Alpha Particle** - A positively charged particle emitted by certain radioactive materials. Alpha particles can be stopped by a sheet of paper or very thin layers of other materials, including skin.

**Beta Particle** - A negatively charged particle emitted from an atom during radioactive decay. A beta particle can be stopped by an inch of wood or a thin sheet of aluminum.

**Background Radiation** - The radioactivity in the environment including cosmic rays from space and radiation that exists elsewhere - in the air, in the earth, and in man-made materials that surround us. In the United States most people receive 100 to 250 millirems of background radiation per year.

**Concentration Guides** - The concentration of a given radionuclide in air or water that could be inhaled or consumed continuously without exceeding the radiation protection standard.

**Controlled Area** - An area that has controlled access to protect individuals from exposure to radiation or radioactive materials.

**Cosmic Radiation** - High energy sub-atomic particles from outer space, which bombard the Earth's atmosphere. Cosmic radiation is part of natural background radiation.

**Cumulative Dose Equivalent** - The total dose one could receive in a period of 50 years following release of the radionuclides to the environment including the dose that could incur as a result of residual radionuclides remaining in the environment beyond the year of release.

**Counting Error** - The variability caused by the inherent random nature of radioactive disintegration and the detection process.

**Detection Level** - The smallest amount of radioactivity that can be detected by a particular radiation counting instrument.

**Dose Equivalent** - A modification in the calculation of an absorbed dose which reveals the biological effects of all radiations by adopting a common scale. The unit of dose equivalent is the rem. A mrem is one-thousandth of a rem.

**Dosimeter** - A device, such as a TLD, which can be worn and used to measure the external radiation dosage a person receives over a period of time.

**Effluent** - A liquid or gaseous stream that flows or is discharged from a source; in environmental monitoring, a liquid or gas discharged as waste, such as contaminated water or air from a factory.

**Effluent Monitoring** - Sampling or measuring specific liquid or gaseous effluent streams for the presence of pollutants.

**Environmental Monitoring Program** - Conducted by PNL for DOE. This program is responsible for monitoring the levels of radiation and radionuclides in the environment attributable to Hanford Operations and assessing potential impacts.

**Exposure** - Subjecting a target (usually living tissue) to radiation.

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

**"Fence-post" Dose Rate** - The dose calculated at the rate of highest exposure or, in other words, at the boundary of Hanford Site.

**Fission** - The splitting or breaking apart of a heavy atom into two new atoms. When a heavy atom, such as uranium, is split, large amounts of energy and one or more neutrons are released.

**Fission Products** - The atoms formed when uranium is split in a nuclear reactor. Fission products are usually radioactive.

**Ground Water** - A subsurface body of water that saturates the soil and slowly flows through the soil in a downhill direction.

**Ground-Water Surveillance Program** - Conducted by PNL for DOE and funded separately from the Environmental Monitoring Program. This program describes the concentration of various constituents in the ground water and assesses their potential impact on the environment.

**Half-life** - The length of time in which any radioactive substance will lose one-half of its radioactivity. The half-life may vary in length from a fraction of a second to thousands of years.

**Log Scale** - A technique used to reduce the size of the vertical axis of a graph.

**Maximum Exposed Individual** - A hypothetical individual who remains in an uncontrolled area and would, when all potential routes of exposure from a facility's operations are considered, receive the greatest dose equivalent.

**Isotope** - Different forms of the same chemical element which are distinguished by having different numbers of neutrons in the nucleus. A single element may have many isotopes. For example, the three isotopes of hydrogen are protium, deuterium, and tritium.

**Long-lived Isotope** - A radionuclide that decays at such a slow rate that a quantity of it will exist for an extended period (half-life is greater than 3 years).

**Short-lived Isotope** - A radionuclide that decays so rapidly that a given quantity is transformed almost completely into decay products within a short period (half-life of a day or less).

**Mean** - The average value of a series of measurements.

**Median** - The middle value in a set of results arranged in order from lowest to highest.

**Minimum Detectable Concentration** - The smallest amount or concentration of a radioactive element that can be detected in a sample.

**Offsite Locations** - Sampling and measurement locations outside the Hanford Site boundary.

**Onsite Locations** - Sampling and measurement locations within the Hanford Site boundary.

**Outfall** - The end of a drain or pipe that carries waste water or other effluents into a ditch, pond, or river.

**Millirem (mrem)** - A unit of radiation dosage equal to one-thousandth of a rem. An individual member of the public can receive up to 500 millirems per year according to DOE standards. This limit does not include radiation received for medical treatment or the 100 to 250 millirems people receive annually from background radiation.

**Plume** - The distribution of a pollutant after being released from a stack or pipe either in air or water.

**Plutonium** - A heavy, radioactive, man-made metallic element. Its most important isotope is fissionable plutonium-239, produced by irradiation of uranium-238. Routine analysis cannot distinguish between the <sup>239</sup>Pu and <sup>240</sup>Pu isotopes, hence, the term <sup>239,240</sup>Pu.

**Primary Cooling Loop** - A closed system of piping which provides cooling water to the reactor. Heat energy is transferred to the secondary loop through a heat exchanger.

**Radiation** - Refers to the process of emitting energy in the form of rays or particles thrown off by disintegrating atoms; may consist of alpha, beta, or gamma radiation.

**Alpha Radiation** - The least penetrating type of radiation. Alpha radiation can be stopped by a sheet of paper or outer dead layer of skin.

**Beta Radiation** - Emitted from a nucleus during fission. Beta radiation can be stopped by an inch of wood or a thin sheet of aluminum.

**Internal Radiation** - Radiation originating from a source within the body as a result of the inhalation, ingestion, or implantation of natural or man-made radionuclides in body tissues.

**External Radiation** - Radiation originating from a source outside the body, such as cosmic radiation or natural and man-made radionuclides.

**Gamma Radiation** - A form of electromagnetic, high energy radiation emitted from a nucleus. Gamma rays are essentially the same as x-rays and require heavy shieldings, such as concrete or steel to be stopped.

**Radioactivity** - A property of matter possessed by some elements, such as uranium, of spontaneously emitting alpha, beta or gamma rays.

**Radioisotope** - A radioactive isotope of a specified element. Carbon-14 is a radioisotope of carbon. Tritium is the only radioisotope of hydrogen.

**Radionuclide** - A radioactive nuclide. There are several hundred known nuclides, both man-made and naturally occurring; nuclides are characterized by the number of neutrons and protons in an atom's nucleus.

**REM** - An acronym for Roentgen Equivalent Man; a unit of radiation exposure that indicates the potential impact on human cells.

**Spent Fuel** - Nuclear fuel that contains uranium, activation products, fission products, and plutonium following exposure in a nuclear reactor. Spent fuel is processed in the PUREX plant.

**Standard Deviation** - The range of calculated uncertainty expected from repeated measurements of a sample.

**Standard Error of the Mean** - The calculated uncertainty of a mean value. When the standard error is doubled, it is referred to as the 95% confidence interval.

**Thermoluminescent dosimeters (TLD)** - A material that, after being exposed to radiation, luminesces upon being heated. The amount of light emitted is proportional to the amount of radiation (dose) to which it was exposed.

**Uncontrolled Area** - An area on or near a nuclear facility that is not restricted to public access.

**Uranium (U)** - A very heavy, radioactive, metallic element. Nuclear fuel contains uranium.

**Whole Body Dose** - A radiation dose commitment that involves exposure of the entire body.

**Windrose** - A star-shaped diagram showing how often winds of various speeds blow in different directions. Usually based on yearly averages.

**X/Q (Chi over Que)** - A dispersion factor calculated with an atmospheric dispersion model from average annual meteorological data. It is used to estimate the average annual air concentration from the total airborne release of each radionuclide. The resulting estimates of average annual air concentrations at specific locations from the source are used to calculate potential doses.

## ACRONYMS AND ABBREVIATIONS

<b>ALE</b>	Arid Land Ecology (Reserve)	<b>PUREX</b>	Plutonium and Uranium Extraction Plant
<b>APHA</b>	America Public Health Association	<b>RHO</b>	Rockwell-Hanford Operation
<b>BMI</b>	Battelle Memorial Institute	<b>UNC</b>	UNC Nuclear Industries
<b>BWIP</b>	Basalt Waste Isolation Program	<b>UO<sub>3</sub> Plant</b>	Uranium Oxide Plant
<b>DOE</b>	Department of Energy	<b>UO</b>	Unusual Occurrence
<b>EML</b>	Environmental Measurements Laboratory	<b>UST</b>	United States Testing Company, Inc.
<b>EPA</b>	Environmental Protection Agency	<b>USGS</b>	United States Geological Survey
<b>ERDA</b>	Energy Research and Development Administration	<b>WHC</b>	Westinghouse Hanford Company
<b>FFTF</b>	Fast Flux Test Facility	<b>WPPSS</b>	Washington Public Power Supply System
<b>FRC</b>	Federal Radiation Council		
<b>HEDL</b>	Hanford Engineering Development Laboratory	$\alpha$	alpha
<b>HEHF</b>	Hanford Environmental Health Foundation	$\beta$	beta
<b>ICRP</b>	International Commission on Radiological Protection	$\gamma$	gamma
<b>NCRP</b>	National Council on Radiation Protection	$\sigma$	standard deviation
<b>NERP</b>	National Environmental Research Park	<b>ALARA</b>	as low as reasonably achievable
<b>NPDES</b>	National Pollutant Discharge Elimination System	<b>BOD</b>	biological oxygen demand
<b>O&amp;EP</b>	Occupational and Environmental Protection	<b>DL</b>	detection level
<b>PNL</b>	Pacific Northwest Laboratory	<b>CFS</b>	cubic feet per second
<b>PSD</b>	Prevention of Significant Deterioration	<b>DL</b>	detection level
		<b>HTO</b>	tritiated water vapor
		<b>MDC</b>	minimum detectable concentrations
		<b>MI</b>	maximum individual
		<b>NTU</b>	nephelometric turbidity units
		<b>TLD</b>	thermoluminescent dosimeter
		<b>TRU</b>	transuranic
		<b>VCP</b>	vitrified clay pipe

## MISCELLANEOUS ABBREVIATIONS

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

Length	
Symbol	Name
f	feet
km	kilometer ( $10^3$ m)
m	meter (m)
cm	centimeter ( $10^{-2}$ m)
mm	millimeter ( $10^{-3}$ m)
$\mu$ m	micrometer ( $10^{-6}$ m)

Area	
Symbol	Name
ha	hectare (10,000 m <sup>2</sup> )

Volume	
Symbol	Name
cm <sup>3</sup>	cubic centimeter
l	liter
ml	millileter ( $10^{-3}$ l)
m <sup>3</sup>	cubic meter
ppm	parts per million

Mass	
Symbol	Name
g	gram
kg	kilogram ( $10^3$ g)
$\mu$ g	microgram ( $10^{-6}$ g)
ng	nanogram ( $10^{-9}$ g)
MT	metric ton ( $10^3$ kg)

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

## CONVERSION TABLE

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>	<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
in.	2.54	cm	cm	0.394	in.
ft	0.305	m	m	3.28	ft
mi	1.61	km	km	0.621	mi
lb	0.454	kg	kg	2.205	lb
liq qt	0.946	ℓ	ℓ	1.057	liq qt
ft <sup>2</sup>	0.093	m <sup>2</sup>	m <sup>2</sup>	10.76	ft <sup>2</sup>
ha	2.47	acres	acres	0.405	ha
mi <sup>2</sup>	2.59	km <sup>2</sup>	km <sup>2</sup>	0.386	mi <sup>2</sup>
ft <sup>3</sup>	0.028	m <sup>3</sup>	m <sup>3</sup>	35.7	ft <sup>3</sup>
mCi/mi <sup>2</sup>	0.386	mCi/km <sup>2</sup>	mCi/km <sup>2</sup>	2.59	mCi/mi <sup>2</sup>
d/m	0.450	pCi	pCi	2.22	d/m
nCi	.001	pCi	pCi	1000	nCi
pCi/ℓ	10 <sup>-9</sup>	μCi/ml	μCi/ml	10 <sup>9</sup>	pCi/ℓ
pCi/m <sup>3</sup>	10 <sup>-12</sup>	μCi/cm <sup>3</sup>	μCi/cm <sup>3</sup>	10 <sup>12</sup>	pCi/m <sup>3</sup>
mCi/km <sup>2</sup>	1.0	nCi/m <sup>2</sup>	nCi/m <sup>2</sup>	1.0	mCi/km <sup>2</sup>

### Table of Unit Prefixes

<u>Factor</u>	<u>Prefix</u>	<u>Symbol</u>
10 <sup>3</sup>	kilo	k
10 <sup>2</sup>	hecto	h
10 <sup>1</sup>	deka	da
10 <sup>-1</sup>	deci	d
10 <sup>-2</sup>	centi	c
10 <sup>-3</sup>	milli	m
10 <sup>-6</sup>	micro	μ
10 <sup>-9</sup>	nano	n
10 <sup>-12</sup>	pico	p
10 <sup>-15</sup>	femto	f
10 <sup>-18</sup>	atto	a

**APPENDIX C**  
**APPLICABLE STANDARDS AND PERMITS**



## APPENDIX C

### APPLICABLE STANDARDS AND PERMITS

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 1984 are listed in the following tables. The state of Washington has promulgated water quality standards for the Columbia River (Washington State Department of Ecology 1982). Of interest to Hanford operations is the designation of the Hanford reach of the Columbia River as Class A excellent. This designation requires that the water be usable for substantially all needs including drinking water, recreation, and wildlife. Class A water standards are summarized in Table C.1.

Environmental radiation protection standards are published in DOE ORDER 5480.1 *Environmental Protection, Safety, and Health Protection Program for DOE Operations* (USDOE 1981).

These standards (shown in Table C.2) are based on guidelines originally recommended by the Federal Radiation Council (FRC) and other scientific groups such as the International Commission on Radiological Protection (ICRP) and the National Commission on Radiation Protection and Measurements (NCRP). The standards govern exposures to ionizing radiation from DOE operations. DOE ORDER 5480.1A also lists radionuclide concentration guides for air and water. Several of the concentration guides for air and water are listed in Table C.3.

Permits required for regulated releases to water and air have been issued by the EPA under the National Pollution Discharge Elimination System of the Clean Water Acts and the Prevention of Significant Deterioration requirements of the Clean Air Act. Permits for collecting wildlife for environmental sampling are issued by the Washington State Department of Game and the U.S. Fish and Wildlife Service. Current permits are listed in Table C.5.

**TABLE C.1.** Washington State Water Quality Standards for the Hanford Reach of the Columbia River

Parameter	Permissible Levels
Fecal coliform organism	1) $\leq 100$ organisms/100 ml (median) 2) $\leq 10\%$ of samples may exceed 200 organisms/100 ml
Dissolved oxygen	$> 8$ mg/l
Temperature	1) $\leq 20^\circ\text{C}$ ( $68^\circ\text{F}$ ) due to human activities 2) When natural conditions exceed $20^\circ\text{C}$ , no temperature increase of greater than $0.3^\circ\text{C}$ allowed. 3) Increases not to exceed $34/(T - 9)$ , where T = highest existing temperature in $^\circ\text{C}$ outside of dilution zone
pH	1) 6.5 to 8.5 range 2) $< 0.5$ unit induced variation
Turbidity	$\leq 5$ NTU <sup>(a)</sup> over background turbidity
Toxic, radioactive, or deleterious materials	Concentrations shall be below those of public health significance, or which cause acute or chronic toxic conditions to the aquatic biota, or which may adversely affect any water use.
Aesthetic value	Shall not be impaired by the presence of materials or their effects, excluding those of natural origin, which offend the senses of sight, smell, touch or taste.

(a) NTU = Nephelometric Turbidity Units—Standard Candle.

Copies of these regulations may be obtained from the following organizations:

State of Washington,  
Department of Ecology  
Olympia, WA 98504

U.S. Environmental Protection Agency  
Region 10  
1200 Sixth Avenue  
Seattle, WA 98101

U.S. Department of Energy  
Richland Operations Office  
Richland, WA 99352

**TABLE C.2. DOE Radiation Protection Standards for External and Internal Exposure**

Type of Exposure	Annual Dose Equivalent or Dose Commitment, millirem <sup>(a)</sup>	
	Based on Dose to Individuals at Points of Maximum Probable Exposure	Based on an Average Dose to a Suitable Sample of the Exposed Population <sup>(b)</sup>
Whole body, gonads, or bone marrow	500	170
Other Organs	1500	500

(a) In keeping with DOE policy on lowest practicable exposure, exposures to the public shall be limited to as small a fraction of the respective annual dose limits as is reasonably achievable.

(b) See paragraph 5.4, Federal Radiation Council Report No. 1, for discussion on concept of suitable sample of exposed population.

**TABLE C.3. DOE Order 5480.1A Radionuclide Concentration Guides**

Radionuclide	Water	Air
	pCi/l ( $10^{-9}$ $\mu$ Ci/ml)	pCi/m <sup>3</sup> ( $10^{-12}$ $\mu$ Ci/ml)
Gross Alpha	30	0.02
Gross Beta	3,000	100
<sup>3</sup> H	3,000,000	200,000
<sup>14</sup> C (CO <sub>2</sub> )	NS <sup>(a)</sup>	1,000,000
<sup>51</sup> Cr	2,000,000	80,000
<sup>54</sup> Mn	100,000	1,000
<sup>60</sup> Co	30,000	300
<sup>65</sup> Zn	100,000	2,000
<sup>85</sup> Kr	NS	300,000
<sup>89</sup> Sr	3,000	300
<sup>90</sup> Sr	300	30
<sup>95</sup> ZrNb	60,000	1,000
<sup>106</sup> Ru	10,000	200
<sup>129</sup> I	60	20
<sup>131</sup> I	300	100
<sup>137</sup> Cs	20,000	500
<sup>140</sup> BaLa	20,000	1,000
<sup>144</sup> Ce	10,000	200
<sup>238</sup> Pu	5,000	0.07
<sup>239</sup> Pu	5,000	0.06
Uranium (total)	600	2

(a) NS indicates no standard

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**TABLE C.4. Benton-Franklin-Walla Walla Counties Air Pollution Control Authority Ambient Air Quality Standards<sup>(a)</sup>**

Parameters	Type of Standard <sup>(b)</sup>	Sampling Period	Permissible Levels
NO <sub>2</sub>	Secondary and primary	Annual average	100 µg/m <sup>3</sup>

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(a) Benton-Franklin-Walla Walla Air Pollution Control Authority 1980.

(b) Primary ambient air quality national standards define levels of air quality to protect the public health. Secondary standards define levels of air quality to protect the public welfare from any known or anticipated adverse effects of a pollutant.

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**TABLE C.5. 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. Expires December 31, 1985.

**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<sub>x</sub> to the atmosphere from the Purex Plant and the Uranium Oxide Plant. No expiration date.

**Wildlife Sampling Permits**

Scientific Study or Collection Permit No. 011 WM-008-84 issued to Pacific Northwest Laboratory, by Washington State Department of Game, covers the collection of wildlife, including fish, for environmental monitoring purposes. Renewed annually.

Federal Fish and Wildlife Permit No. 671877, issued to Pacific Northwest Laboratory by U.S. Fish and Wildlife.

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**APPENDIX D**  
**ANALYTICAL PROCEDURES AND**  
**SAMPLING SUMMARY**



## APPENDIX D

### ANALYTICAL PROCEDURES AND SAMPLING SUMMARY

#### RADIOLOGICAL SAMPLES

All routine environmental surveillance samples are analyzed according to detailed, written analytical procedures that are described in general terms below. Minimum detectable concentrations for the various medium/analysis combinations and other analytical information is shown in Table D.1.

#### Air Samples

**Alpha-, Beta-, and Gamma-Emitting Radionuclides** are measured by a direct count of the glass fiber filter; alpha on a low-background gas flow proportional counter, beta on a gas flow proportional counter, and gamma on a Ge(Li) detector with a multichannel pulse height analyzer.

**Strontium-90** is determined by leaching the glass fiber filters with nitric acid, scavenging with barium chromate, precipitating as a carbonate, transferring to a stainless steel planchet, and counting with a low-background gas flow proportional counter.

**Uranium** is leached from the glass fiber filters with nitric acid and extracted as tetrapropyl ammonium uranyl trinitrate followed by back extraction into water. A portion of the water extract is fused with sodium and lithium fluoride and analyzed with a fluorometer.

**Plutonium** is leached from the glass fiber filters with fuming 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 HTO is determined by collecting the water vapor with silica gel. The water vapor is removed by heat and vacuum and collected in a freeze trap. The tritium content of the water vapor is determined with a liquid scintillation spectrometer.

**Iodine-131** is collected on activated charcoal which is then counted on a Ge(Li) detector with a multichannel pulse height analyzer.

**Carbon-14** is collected as carbon dioxide gas trapped in soda lime. The carbon dioxide is released from the soda lime sample with acid and injected into a "Benzene Synthesizer" instrument. The carbon dioxide is quantitatively converted to benzene through a series of catalyzed reactions. The benzene product is mixed with scintillator fluid and counted on a low temperature liquid scintillation counter.

**Krypton-85** is removed from the air sample and purified using a specially constructed cryogenic chromatography instrument. The sample is passed through a series of cold traps. The purified krypton is mixed with scintillation fluid and counted on a low temperature liquid scintillation counter.

#### Water Samples

**Beta-Emitting Radionuclides** are measured by a direct count of dried residue with a gas flow proportional counter.

**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.

**Gamma-Emitting Radionuclides** are determined by a direct count of 500 ml of sample concentrate using a Ge(Li) detector with a multichannel pulse height analyzer.

**Strontium-90** in large-volume water samples is precipitated with fuming nitric acid, scavenged with barium chromate, precipitated as a carbonate, transferred to a stainless steel planchet, and counted with a low-background gas flow proportional counter. After a 15-day period the yttrium-90 daughter is separated and then counted with a proportional counter.

**Tritium** samples are either counted directly with a liquid scintillation spectrometer or the sample is enriched by alkaline electrolysis and then counted with a liquid scintillation spectrometer.

**Filter-Resin Samples** are analyzed for gamma-emitting radionuclides using a Ge(Li) detector with a multichannel gamma-ray spectrometer. Aliquots of the samples are analyzed by neutron activation analysis for  $^{129}\text{I}$  and by chemical separation and alpha spectrometry for plutonium.

#### **Milk**

**Gamma-Emitting Radionuclides** are measured by a direct count of the sample on a Ge(Li) detector with a multichannel pulse height analyzer.

**Tritium** in water distilled from milk is counted directly with a liquid scintillation spectrometer.

**Iodine-129** is separated from milk with an anion exchange resin, purified, and analyzed by the neutron activation method.

**Iodine-131** is removed from milk with an anion exchange resin. The iodine is eluted with sodium hypochlorite, precipitated as palladium iodide and beta-counted with a low-background gas flow proportional counter.

**Strontium-89,90** is removed from milk with a cation resin, eluted with sodium chloride, precipitated as a carbonate, and transferred to a stainless steel planchet for counting with a low-background gas flow proportional counter.

#### **Foodstuffs**

**Gamma-Emitting Radionuclides** are determined by a direct count of the sample on a Ge(Li) detector with a multichannel pulse height analyzer.

**Tritium** in water distilled from farm produce is counted directly with a liquid scintillation spectrometer.

**Plutonium** is determined as in air filter samples after drying, ashing in a furnace, and treating with nitric acid prior to the anion exchange step.

**Uranium** is determined as in water samples after drying, ashing in a furnace, and treating with nitric acid prior to the ether extraction step.

**Strontium-90** is determined as in air samples after drying, ashing in a furnace, and treating with nitric acid prior to the fuming nitric acid step.

#### **Vegetation and Wildlife**

**Uranium, Plutonium, Strontium, and Gamma-Emitting Radionuclides** are determined using the procedures described for farm produce.

#### **Soil**

**Gamma-Emitting Radionuclides** are analyzed by placing the sample into a marinelli beaker and counting on a Ge(Li) detector with a multichannel pulse height analyzer.

**Plutonium and Strontium-89,90** are determined after the soil is dried, mixed thoroughly, leached with nitric acids, and then precipitated as strontium oxalate. The sample is then precipitated as a carbonate, transferred to a planchet and counted as with water samples.

After removal of strontium from the sample, plutonium is co-precipitated 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 and analyzed by a method similar to the procedure described for air filter samples.

**Uranium** analysis is conducted after the sample is dried, ashed in a furnace, and leached with hot nitric acid. Uranium is extracted from the acid leachate as tetrapropyl ammonium uranyl trinitrate and then extracted back into water. A portion of the water extract is fused with sodium and lithium fluoride and analyzed with a fluorometer.

#### **NONRADIOLOGICAL SAMPLES**

Water samples collected to monitor water quality of the Columbia River are analyzed according to standard methods. The most applicable methods recommended by the American Public Health Association in their publication *Standard Methods for the Examination of Water and Wastewater (APHA 1975)* are used for most onsite analyses. Supplemental USGS samples are analyzed according to approved USGS standard methods.

**TABLE D.1. Radiological Monitoring Sampling Summary**

Medium Sampled	Type of Analysis	Frequency of Analysis	Approximate Sample Size	Count Time	Minimum Detectable Concentration (MDC)	Analysis Aliquot Size	Collected Offsite/Onsite
Air	Gross Beta	biweekly	850 m <sup>3</sup>	40 min	0.003 pCi/m <sup>3</sup>	850 m <sup>3</sup>	offsite/onsite
	Gross Alpha	biweekly	850 m <sup>3</sup>	50 min	0.001 pCi/m <sup>3</sup>	850 m <sup>3</sup>	offsite/onsite
	<sup>131</sup> I	biweekly	850 m <sup>3</sup>	100 min	0.01 pCi/m <sup>3</sup>	850 m <sup>3</sup>	offsite/onsite
	HTO <sup>(a)</sup>	monthly	10 m <sup>3</sup>	150 min	0.3 pCi/ml	5.0 ml	offsite/onsite
	<sup>14</sup> C <sup>(b)</sup>	bimonthly	40 m <sup>3</sup>	150 min	1.0 pCi/m <sup>3</sup>	10 g of carbon	offsite/onsite
	<sup>86</sup> Kr <sup>(c)</sup>	monthly	0.3 m <sup>3</sup>	150 min	2.0 pCi/m <sup>3</sup>	0.3 m <sup>3</sup>	offsite/onsite
	Gamma Scan ( <sup>137</sup> Cs)	monthly comp.	1700 m <sup>3</sup> per station	50 min	0.01 pCi/m <sup>3</sup>	1700-7700 m <sup>3</sup>	offsite/onsite
	<sup>88</sup> Sr	quarterly comp	5100 m <sup>3</sup> per station	100 min	0.01 pCi/m <sup>3</sup>	2,000-10,000 m <sup>3</sup>	offsite/onsite
	<sup>90</sup> Sr	quarterly comp	5100 m <sup>3</sup> per station	100 min	0.001 pCi/m <sup>3</sup>	2,000-10,000 m <sup>3</sup>	offsite/onsite
	<sup>238</sup> Pu	quarterly comp	5100 m <sup>3</sup> per station	1000 min	1 x 10 <sup>-4</sup> pCi/m <sup>3</sup>	2,000-10,000 m <sup>3</sup>	offsite/onsite
	<sup>239</sup> Pu	quarterly comp	5100 m <sup>3</sup> per station	1000 min	0.09 pCi/m <sup>3</sup>	2,000-10,000 m <sup>3</sup>	offsite/onsite
	U	quarterly comp	5100 m <sup>3</sup> per station	NA <sup>(d)</sup>	0.01 pCi/m <sup>3</sup>	2,000-10,000 m <sup>3</sup>	offsite/onsite
	<sup>129</sup> I <sup>(d)</sup>	quarterly	850 m <sup>3</sup> per station	NA	1 x 10 <sup>-5</sup> pCi/m <sup>3</sup>	850 m <sup>3</sup>	offsite/onsite
	River water	Gross Beta	monthly comp	40 l	20 min	4.0 pCi/l	500 ml
Gross Alpha		monthly comp	40 l	50 min	4.0 pCi/l	500 ml	offsite
<sup>3</sup> H (enriched)		monthly comp	40 l	450 min	50 pCi/l	150 ml	offsite
<sup>88</sup> Sr		monthly comp	40 l	100 min	0.6 pCi/l	10 l	offsite
<sup>90</sup> Sr		monthly comp	40 l	100 min	0.06 pCi/l	4-10 l	offsite
U		monthly comp	40 l	NA	0.5 pCi/l	100-1000 ml	offsite
Gamma Scan ( <sup>137</sup> Cs)		monthly comp	40 l	50 min	8.0 pCi/l	4-10 l	offsite
River Water (Resin & Particulate)	Gamma Scan ( <sup>137</sup> Cs)	biweekly	1000 l	1000 min	0.01 pCi/l	250-500 l	offsite/onsite
	<sup>90</sup> Sr	quarterly comp	6000 l	100 min.	0.01 pCi/l	1500-3000 l	offsite/onsite
	Pu <sup>129</sup> I	quarterly comp	6000 l	24-72 hrs.	1 x 10 <sup>-4</sup> pCi/l	1500-3000 l	offsite/onsite
		quarterly comp	6000 l	NA	1 x 10 <sup>-6</sup> pCi/l	1500-3000 l	offsite/onsite
Surface Water	Gross Beta	quarterly	10 l	20 min	40 pCi/l	500 ml	onsite
	Gross Alpha	quarterly	10 l	50 min	4.0 pCi/l	500 ml	onsite
	<sup>3</sup> H	quarterly	10 l	150 min	300 pCi/l	5 ml	onsite
	<sup>90</sup> Sr	quarterly	10 l	100 min	0.06 pCi/l	4-10 l	onsite
	Gamma Scan ( <sup>137</sup> Cs)	quarterly	10 l	50 min	8.0 pCi/l	4-10 l	onsite
Milk	<sup>131</sup> I <sup>(e)</sup>	biweekly	10 l	100 min	0.5 pCi/l	4 l	offsite
	<sup>129</sup> I	semi-annually	4 l	NA	5 x 10 <sup>-5</sup> pCi/l	3-4l	offsite
	Gamma Scan ( <sup>137</sup> Cs) <sup>(e)</sup>	biweekly	10 l	1000 min	10 pCi/l	450 l	offsite
	<sup>3</sup> H	monthly	10 l	150 min	300 pCi/l	5 l	offsite
	<sup>88</sup> Sr	quarterly	10 l	100 min	5.0 pCi/l	1 l	offsite
	<sup>90</sup> Sr	quarterly	10 l	100 min	2.0 pCi/l	1 l	offsite
Fruit	<sup>3</sup> H	annually	2 kg	150 min	300 pCi/l	5 ml (water	offsite
	<sup>90</sup> Sr	annually	2 kg	200 min	0.005 pCi/g	100 gm	offsite
	Gamma Scan ( <sup>137</sup> Cs)	annually	2 kg	1000 min	0.015 pCi/g	250-500 gm	offsite

TABLE D.1. Radiological Monitoring Sampling Summary (Continued)

Medium Sampled	Type of Analysis	Frequency of Analysis	Approximate Sample Size	Count Time	Minimum Detectable Concentration (MDC)	Analysis Aliquot Size	Collected Offsite/Onsite
Crops & Produce	<sup>90</sup> Sr	annually	2 kg	200 min	0.005 pCi/g	100 gm	offsite
	Gamma Scan ( <sup>137</sup> Cs)	annually	2 kg	1000 min	0.015 pCi/g	250-500 gm	offsite
Beef	<sup>90</sup> Sr	annually	1 kg	100 min	0.005 pCi/g	100 gm	offsite
	Gamma Scan ( <sup>137</sup> Cs)	annually	1 kg	1000 min	0.015 pCi/g	250-500 gm	offsite
Poultry	<sup>90</sup> Sr	semiannually	1 chicken (breast)	100 min	0.005 pCi/g	100 gm	offsite
	Gamma Scan ( <sup>137</sup> Cs)	semiannually	1 chicken (breast)	1000 min	0.015 pCi/g	250-500 gm	offsite
Eggs	<sup>90</sup> Sr	semiannually	1 doz.	100 min	0.005 pCi/g	100 gm	offsite
	Gamma Scan ( <sup>137</sup> Cs)	semiannually	1 doz.	1000 min	0.015 pCi/g	250-500 gm	offsite
Fish fillet	<sup>90</sup> Sr	15 per year	1 fish fillet	100 min	0.005 pCi/g	100 gm	offsite/onsite
	Gamma Scan ( <sup>137</sup> Cs)	15 per year	1 fish fillet	1000 min	0.015 pCi/g	250-500 gm	offsite/onsite
Fish Carcass	<sup>90</sup> Sr	15 per year	1 fish carcass	100 min	0.005 pCi/g	100 gm	offsite/onsite
	Gamma Scan ( <sup>137</sup> Cs)	15 per year	1 fish carcass	1000 min	0.015 pCi/g	250-500 gm	offsite/onsite
Ducks	Gamma Scan ( <sup>137</sup> Cs)	36 per year	1 duck (breast)	1000 min	0.015 pCi/g	250-500 gm	onsite
Game Birds	Gamma Scan ( <sup>137</sup> Cs)	22 per year	1 bird (muscle)	1000 min	0.015 pCi/g	250-500 gm	onsite
Deer	Gamma Scan ( <sup>137</sup> Cs)	8 per year	1 kg (muscle)	1000 min	0.015 pCi/g	250-500 gm	onsite
	Pu	8 per year	1 kg (liver)	1000 min	6 x 10 <sup>-4</sup> pCi/g	100 gm	onsite
	<sup>90</sup> Sr	2 per year	500 gm (bone)	100 min	0.005 pCi/g	100 gm	onsite
Rabbits	Gamma Scan ( <sup>137</sup> Cs)	16 per year	500 gm (muscle)	1000 min	0.015 pCi/g	250-500 gm	onsite
	Pu	16 per year	1 liver	1000 min	6 x 10 <sup>-4</sup> pCi/g	100 gm	onsite
	<sup>90</sup> Sr	16 per year	250 gm (bone)	100 min	0.005 pCi/g	100 gm	onsite
Soil	<sup>90</sup> Sr	annually	1.5 kg	100 min	0.005 pCi/g	100 gm	offsite/onsite
	U	annually	1.5 kg	NA	0.01 pCi/g	10 gm	offsite/onsite
	Pu	annually	1.5 kg	1000 min	6 x 10 <sup>-4</sup> pCi/g	100 gm	offsite/onsite
	<sup>241</sup> Am	annually	1.5 kg	1000 min	0.05 pCi/g	10 gm	offsite/onsite
	Gamma Scan ( <sup>137</sup> Cs)	annually	1.5 kg	100 min	0.03 pCi/g	500 gm	offsite/onsite
Native Vegetation	<sup>90</sup> Sr	annually	1 kg	200 min	0.005 pCi/g	100 gm	offsite/onsite
	U	annually	1 kg	NA	0.01 pCi/g	10 gm	offsite/onsite
	Pu	annually	1 kg	1000 min	6 x 10 <sup>-4</sup> pCi/g	100 gm	offsite/onsite
	Gamma Scan ( <sup>137</sup> Cs)	annually	1 kg	1000 min	0.03 pCi/g	125 gm	offsite/onsite
Direct Radiation Exposure	Thermoluminescent Dosimeter	monthly	5 TLDs per dosimeter	NA	1.0 mR <sup>(f)</sup>	NA	offsite/onsite

- (a) Tritiated water vapor
- (b) Ten locations
- (c) Eight locations
- (d) Four locations

- (e) Four dairies are sampled monthly
  - (f) Absolute sensitivity in the manner it is used is well below one millirem.
- NA = Not applicable

**APPENDIX E**  
**DATA ANALYSIS**



## APPENDIX E

### DATA ANALYSIS

The measurement of any physical quantity, be it temperature, distance, time, or radioactivity has some degree of inherent uncertainty associated with the final result. The uncertainty results from the combination of all possible inaccuracies in the measurement process including, for example, the reading of the result, the calibration of the measurement device, numerical rounding errors, etc. In this report, individual radioactivity measurements are accompanied by a plus or minus ( $\pm$ ) analytical uncertainty term. This term represents the statistical counting error (two-standard deviations) associated with the measurement of the radioactivity in the sample. Reported means also include an uncertainty term. The term used to express the uncertainty associated with the mean is the two-standard error of the mean (95% confidence interval) and includes consideration of the uncertainty of the individual results as well as their variability with respect to each other. Maximum and minimum values are also included in most data tables.

Radionuclide concentrations in many environmental type samples are very low, near zero, such that the uncertainty associated with the measurement is large relative to the result of the measurement. Concentrations may, in fact, be so low that the associated analytical uncertainty is equal to or greater than the reported result. In such cases, the radionuclide concentration was too low to be measured given the analytical technique used, and individual results are noted with the less-than symbol (<). Although results which are less than their associated analytical uncertainty may not represent a true quantity in themselves, it is nevertheless appropriate to use the values when calculating the mean (i.e., average) of a set of similarly analyzed samples. Mean concentrations reported in this document therefore are calculated using all reported analytical results including those less than their associated analytical uncertainty.

Footnotes to the tables further explain the data presented.



**APPENDIX F**  
**DOSE CALCULATIONS AND EFFLUENT DATA**



## APPENDIX F

### DOSE CALCULATIONS AND EFFLUENT DATA

The impact on the public from operations involving radioactive materials at Hanford is assessed in terms of the radiation "dose equivalent." The radiation dose equivalent is expressed in units of millirem and provides a means for expressing radiation impact regardless of the type or source of radiation and the means by which exposure is incurred. The reported millirem dose equivalent can be compared to the dose standards in Appendix C, which have been established by the DOE.

For certain types of exposure pathways, the dose equivalent results from the inhalation or ingestion of radionuclides in the air, water, foods, etc., such that the radionuclides may be metabolically absorbed by the body and retained for some time. In addition, long-lived radionuclides may be deposited on the ground and become a source of long-term exposure. To fully account for the dose equivalent received in these cases, the dose impact is expressed as the "cumulative dose equivalent" (or, cumulative dose), also reported in units of millirem.

The cumulative dose includes the total dose received for a period of 50 years following release of the radionuclide to the environment including the dose incurred as a result of residual radionuclides remaining in the environment beyond the year of their release. The calculation of cumulative dose thus considers the long-term residency of the individual or population for which it is presented.

Where possible, cumulative radiation doses provided in this report are based on measured radionuclide concentrations in environmental media, and conversion factors are applied to relate the environmental concentrations in terms of dose. The preferred method of assessing environmental doses is to perform the radionuclide measurements as close to the point of exposure as possible (i.e., in drinking water, air, foods, etc.). However, the quantities of radionuclides actually released from Hanford are usually too low to be measured in the offsite environment, and, in most cases, doses are calculated based on measurements at the release point, to which are applied environmental dispersion or reconcen-

tration factors as appropriate for the various possible exposure pathways. Exposure pathways considered in dose calculations are illustrated in Figure 2.

Regardless of the location or type of measurements upon which the environmental radiation doses are based, a set of standardized computer programs are used to perform the calculations (Houston, Strenge, and Watson 1974; Napier, Kennedy, and Soldat 1980; Strenge and Watson 1973). These programs contain internally consistent models that use site specific dispersion and uptake parameters when available. Because the calculated results are highly dependent on the specific inputs and assumptions used, a general description of the calculations and input data is provided here.

#### TYPES OF DOSE CALCULATIONS PERFORMED

The impact of Hanford operations is estimated in order to provide assurance that the health and safety of the public is not being jeopardized and that applicable regulations are being complied with. To those ends, various specific dose impacts are evaluated. These are:

1. **Fence-Post Whole Body Dose Rate.** This is an evaluation of the maximum external radiation dose rate at any time during the year in areas accessible by the public. This rate is normally based on measurements taken at locations of potential public access in close proximity to operating facilities.
2. **Maximum Exposed Individual Organ Dose.** The maximum exposed individual (MI) is a member of the offsite population who, by virtue of his location and living habits, would receive the highest radiation dose. The MI is hypothetical in that an actual offsite individual is not identified. However, the MI is realistic to the extent that all exposure pathways are credible. The assessment of MI organ doses provides an estimate of the maximum radiation doses that a member of the public could receive from long-term exposure to Hanford operations. Exposure pathways that are considered are:

- inhalation of radioactive airborne effluents
- submersion in radioactive airborne effluents
- ingestion of foodstuffs contaminated by effluents deposited on the ground by airborne deposition and by irrigation with Columbia River water
- drinking sanitary water obtained from the Columbia River
- exposure to ground contaminated by airborne deposition and by irrigation with Columbia River water
- ingestion of fish taken from the Columbia River
- recreation along the Columbia River—boating, swimming and shoreline activities.

3. **80-km Population Doses.** While there are no regulatory limits for collective population doses, such an evaluation provides an indication of the overall impact of Hanford operations. The 80-km population dose represents the summed products of average dose and number of individuals involved for all possible pathways. The units are man-rem.

The MI exposure pathways depicted in Figure 2 are also assumed to be available to the offsite population. However, in the case of releases to the Columbia River, only that portion of the full 80-km population using river water are potentially exposed. The river related exposure pathways are drinking water, irrigated food stuff, fish consumption, and river recreation. Descriptions of river related pathways are as follows:

- **Drinking Water**—The cities of Richland and Pasco obtain their municipal water from the Columbia River downstream from Hanford. The city of Kennewick began drawing a portion of its municipal water from the river in late 1980. During 1984, approximately 40% of Kennewick drinking water was drawn from the Columbia River. The total affected population was approximately 70,000.
- **Irrigated Foodstuff**—Columbia River water is withdrawn for irrigation of home vegetable gardens in the Riverview District of Franklin County of Pasco. Approximately 2,000 people are estimated to be affected.

- **River Recreation**—These activities include swimming, boating, and shoreline recreation. The population residing adjacent to the river within 80 km of Hanford is assumed to be effected by these pathways and is estimated to number 125,000.
- **Fish Consumption**—Population doses due to consumption of fish obtained locally from the Columbia River are calculated based on an estimated total annual catch of 15,000 kg/yr without reference to a specific population group.

## DATA

Input data necessary to perform dose calculations are extensive. Calculations based on measured effluent release require data describing initial transport through the atmosphere or river, transfer or accumulation in terrestrial and aquatic pathways, public exposure, and dosimetry. By comparison, calculations based on measurement of radioactive material concentrations in foodstuffs only require the data describing exposure and dosimetry. These data are discussed in more detail in the sections that follow.

## POPULATION DISTRIBUTION

Geographic distributions of population residing within an 80-km radius of the four operating areas are listed in Tables F.1 through F.4. These distributions are based on 1980 Bureau of Census data (Sommer, Rau, and Robinson 1981). Population exposure to airborne effluents is determined through the use of population weighted X/Q values of dispersion factors for each compass sector and annular ring.

## ATMOSPHERIC DISPERSION

Radioactive material released to the atmosphere becomes diluted as it is carried away from the release point by the wind. The degree of dilution and magnitude of resultant air concentrations are predicted by atmospheric dispersion models that employ site specific measurements of the occurrence frequency for wind speed, wind direction, and atmospheric stability. The products of the dispersion model are annual average dispersion factors (X/Q, units Ci/m<sup>3</sup>/Ci/sec = sec/m<sup>3</sup>) that, when combined with annual average release rates, will predict average radionuclide air con-

**TABLE F.1.** Distribution of Population in 80-km Radius of the 100-N Reactor by Population Grid Sector<sup>(a)</sup>

Compass Direction	Number of People					Totals
	0-16 km	16-32 km	32-48 km	48-64 km	64-80 km	
NORTH	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
EAST	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
SOUTH	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
WEST	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
<b>TOTALS</b>	<b>251</b>	<b>6,270</b>	<b>62,325</b>	<b>153,267</b>	<b>118,035</b>	<b>340,148</b>

(a) Based on 1980 census data.

**TABLE F.2.** Distribution of Population in 80-km Radius of 200 Area Hanford Meteorological Tower by Population Grid Sector<sup>(a)</sup>

Compass Direction	Number of People					Totals
	0-16 km	16-32 km	32-48 km	48-64 km	64-80 km	
NORTH	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
EAST	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
SOUTH	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
WEST	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
<b>TOTALS</b>	<b>110</b>	<b>17,500</b>	<b>107,234</b>	<b>93,954</b>	<b>122,145</b>	<b>340,943</b>

(a) Based on 1980 census data.

**TABLE F.3.** Distribution of Population in 80-km Radius of the FFTF by Population Grid Sector<sup>(a)</sup>

Compass Direction	Number of People					Totals
	0-16 km	16-32 km	32-48 km	48-64 km	64-80 km	
NORTH	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
EAST	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
SOUTH	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
WEST	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
<b>TOTALS</b>	<b>25,361</b>	<b>85,950</b>	<b>49,980</b>	<b>39,368</b>	<b>63,087</b>	<b>263,746</b>

(a) Based on 1980 census data.

**TABLE F.4.** Distribution of Population in 80-km Radius of 300 Area by Population Grid Sector<sup>(a)</sup>

Compass Direction	Number of People					Totals
	0-16 km	16-32 km	32-48 km	48-64 km	64-80 km	
NORTH	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
EAST	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
SOUTH	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
WEST	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
<b>TOTALS</b>	<b>52,734</b>	<b>76,466</b>	<b>19,230</b>	<b>59,220</b>	<b>56,891</b>	<b>264,541</b>

(a) Based on 1980 census data.

centrations for the year. Annual average dispersion factors for the 100, 200, 300, and 400 Areas during 1984 are listed in Tables F.5 through F.8.

### TERRESTRIAL AND AQUATIC PATHWAYS

Following release and initial transport through the environment, radioactive materials may enter terrestrial or aquatic pathways that lead to public exposure. These potential pathways include fish consumption, drinking water, and consumption of foodstuffs and are generally comprised of compartments between which the radionuclides move. For example, radioactive material released to the river is diluted (compartment 1), after which it may be withdrawn at a certain rate for irrigation (compartment 2), deposited on the plants and soil (compartments 3 and 4), and taken into the plant via the roots and leaves (compartment 5). The compartment transfer factors used for dose calculation in this report are described by Houston, Strenge and Watson (1974) and Napier, Kennedy, and Soldat (1980).

Other parameters affecting the movement of radionuclides within potential exposure path-

ways include irrigation rates, growing period, hold up, etc. These parameters are listed in Table F.9. Note that certain parameters are specific to maximum and average individuals.

### PUBLIC EXPOSURE

Offsite radiation dose impact is related to the extent of public exposure to or consumption of radionuclides associated with Hanford operations. Parameters describing assumed diet, residency and river recreation for maximum and average individuals are provided in Tables F.10 through F.12, respectively.

### DOSE CALCULATION DOCUMENTATION

Assurance of quality in dose calculations is provided in several ways. First, comparisons are made against doses calculated for previous annual reports and differences are validated. Second, all computed doses are reviewed through the Hanford Dose Overview Program. Third, computer codes and inputs to the codes are documented. Summaries of this information are provided in Tables F.13 through F.17.

TABLE F.5. Annual Average Atmospheric Dispersion (X/Q) Around The 100-N Area During 1984 for an 89-m Release Height<sup>(a)</sup>

Direction	sec/m <sup>3</sup>									
	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	7.11E-08	6.11E-08	5.19E-08	4.18E-08	3.42E-08	2.13E-08	1.20E-08	5.76E-09	3.92E-09	2.92E-09
NNE	6.23E-08	5.93E-08	5.11E-08	4.15E-08	3.41E-08	2.15E-08	1.06E-08	6.10E-09	4.21E-09	3.18E-09
NE	1.21E-07	9.66E-08	8.29E-08	6.72E-08	5.53E-08	3.48E-08	1.72E-08	1.00E-08	6.99E-09	5.33E-09
ENE	1.09E-07	8.68E-08	8.00E-08	6.79E-08	5.77E-08	3.85E-08	2.02E-08	1.21E-08	8.48E-09	6.49E-09
E	2.26E-07	1.08E-07	9.10E-08	7.49E-08	6.25E-08	4.04E-08	2.05E-08	1.20E-08	8.31E-09	6.30E-09
ESE	1.78E-07	7.13E-08	5.65E-08	4.53E-08	3.72E-08	2.35E-08	1.16E-08	6.71E-09	4.63E-09	3.50E-09
SE	1.55E-07	6.47E-08	4.88E-08	3.79E-08	3.05E-08	1.88E-08	9.19E-09	5.36E-09	3.74E-09	2.85E-09
SSE	8.54E-08	4.12E-08	3.35E-08	2.71E-08	2.24E-08	1.43E-08	7.15E-09	4.18E-09	2.91E-09	2.21E-09
S	8.28E-08	5.29E-08	4.37E-08	3.50E-08	2.87E-08	1.79E-08	8.68E-09	4.94E-09	3.39E-09	2.55E-09
SSW	5.02E-08	3.46E-08	2.85E-08	2.27E-08	1.85E-08	1.14E-08	5.57E-09	3.22E-09	2.23E-09	1.69E-09
SW	3.43E-08	3.29E-08	2.74E-08	2.22E-08	1.84E-08	1.17E-08	5.95E-09	3.55E-09	2.51E-09	1.93E-09
WSW	5.57E-08	3.88E-08	3.24E-08	2.62E-08	2.15E-08	6.73E-09	3.94E-09	2.76E-09	2.76E-09	2.10E-09
W	1.13E-07	8.93E-08	7.61E-08	6.14E-08	5.03E-08	3.12E-08	1.50E-08	8.49E-09	5.79E-09	4.34E-09
WNW	8.76E-08	6.18E-08	4.98E-08	3.93E-08	3.18E-08	1.93E-08	9.10E-09	5.06E-09	3.41E-09	2.53E-09
NW	6.40E-08	5.44E-08	4.34E-08	3.38E-08	2.70E-08	1.62E-08	7.47E-09	4.12E-09	2.77E-09	2.05E-09
NNW	5.50E-08	3.89E-08	3.11E-08	2.44E-08	1.07E-08	1.19E-08	5.53E-09	3.06E-09	2.06E-09	1.53E-09

(a) Calculated from meteorological data collected at the 100-N Area and the Hanford Meteorological Station.

**TABLE F.6. Annual Average Atmospheric Dispersion (X/Q) Around The 200 Areas During 1984 for an 89-m Release Height<sup>(a)</sup>**

Direction	sec/m <sup>3</sup>									
	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	4.89E-08	3.69E-08	3.25E-08	2.66E-08	2.19E-08	1.38E-08	6.73E-09	3.87E-09	2.67E-09	2.02E-09
NNE	3.79E-08	2.83E-08	2.56E-08	2.13E-08	1.77E-08	1.13E-08	5.56E-09	3.19E-09	2.19E-09	1.65E-09
NE	4.58E-08	2.93E-08	2.65E-08	2.20E-08	1.84E-08	1.18E-08	5.88E-09	3.42E-09	2.38E-09	1.81E-09
ENE	5.85E-08	4.17E-08	3.67E-08	3.06E-08	2.56E-08	1.68E-08	8.62E-09	5.11E-09	3.58E-09	3.73E-09
E	5.87E-08	5.71E-08	5.29E-08	4.47E-08	3.78E-08	2.48E-08	1.27E-08	7.51E-09	5.24E-09	3.99E-09
ESE	6.15E-08	6.94E-08	6.29E-08	5.21E-08	4.33E-08	2.76E-08	1.36E-08	7.80E-09	5.36E-09	4.03E-09
SE	9.89E-08	7.75E-08	6.67E-08	5.42E-08	4.45E-08	2.79E-08	1.36E-08	7.74E-09	5.29E-09	3.97E-09
SSE	8.66E-08	6.06E-08	4.95E-08	3.29E-08	3.17E-08	1.93E-08	9.09E-09	5.07E-09	3.43E-09	2.56E-09
S	1.12E-07	6.27E-08	4.61E-08	3.46E-08	2.71E-08	1.56E-08	6.91E-09	3.72E-09	2.46E-09	1.81E-09
SSW	7.76E-08	4.10E-08	2.91E-08	2.15E-08	1.66E-08	9.36E-09	4.10E-09	2.22E-09	1.48E-09	1.09E-09
SW	6.97E-08	3.80E-08	2.68E-08	1.97E-08	1.52E-08	8.54E-09	3.69E-09	1.97E-09	1.20E-09	9.49E-10
WSW	7.48E-08	3.56E-08	2.59E-08	1.94E-08	1.52E-08	8.77E-09	3.93E-09	2.14E-09	1.44E-09	1.06E-09
W	8.44E-08	5.23E-08	3.95E-08	2.99E-08	2.35E-08	1.35E-08	6.07E-09	3.34E-09	2.25E-09	1.68E-09
WNW	7.28E-08	4.49E-08	3.62E-08	2.85E-08	2.30E-08	1.38E-08	6.43E-09	3.56E-09	2.39E-09	1.77E-09
NW	6.06E-08	5.02E-08	4.13E-08	3.27E-08	2.65E-08	1.61E-08	7.59E-09	4.23E-09	2.86E-09	2.13E-09
NNW	4.67E-08	2.89E-08	2.45E-08	1.99E-08	1.65E-08	1.05E-08	5.20E-09	3.00E-09	2.06E-09	1.56E-09

(a) Calculated from meteorological data collected at the Hanford Meteorological Station.

**TABLE F.7. Annual Average Atmospheric Dispersion (X/Q) Around The 300 Area During 1984 for a Ground-Level Release Height<sup>(a)</sup>**

Direction	sec/m <sup>3</sup>									
	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	7.93E-06	1.29E-06	5.89E-07	3.57E-07	2.47E-07	1.19E-07	4.53E-08	2.26E-08	1.43E-08	1.02E-08
NNE	7.19E-06	1.15E-06	5.22E-07	3.15E-07	2.17E-07	1.04E-07	3.89E-08	1.92E-08	1.21E-08	8.61E-09
NE	1.45E-05	2.34E-06	1.06E-06	6.38E-07	4.40E-07	2.10E-07	7.84E-08	3.86E-08	2.43E-08	1.73E-08
ENE	8.78E-06	1.42E-06	6.47E-07	3.92E-07	2.71E-07	1.30E-07	4.93E-08	2.45E-08	1.55E-08	1.11E-08
E	1.03E-05	1.69E-06	7.70E-07	4.68E-07	3.25E-07	1.58E-07	6.04E-08	3.03E-08	1.93E-08	1.38E-08
ESE	7.17E-06	1.15E-06	5.21E-07	3.16E-07	2.18E-07	1.05E-07	3.97E-08	1.97E-08	1.25E-08	8.90E-09
SE	7.04E-06	1.12E-06	5.08E-07	3.07E-07	2.13E-07	1.02E-07	3.86E-08	1.91E-08	1.21E-08	8.62E-09
SSE	6.08E-06	9.68E-07	4.37E-07	2.64E-07	1.82E-07	8.68E-08	3.27E-08	1.62E-08	1.02E-08	7.29E-09
S	2.79E-06	4.32E-07	1.92E-07	1.15E-07	7.82E-08	3.65E-08	1.33E-08	6.38E-09	3.97E-09	2.79E-09
SSW	4.02E-07	6.00E-08	2.61E-08	1.53E-08	1.03E-08	4.62E-09	1.59E-09	7.35E-10	4.44E-10	3.05E-10
SW	4.11E-07	6.35E-08	2.86E-08	1.72E-08	1.18E-08	5.60E-09	2.09E-09	1.03E-09	6.50E-10	4.63E-10
WSW	2.27E-07	3.52E-08	1.59E-08	9.61E-09	6.63E-09	3.16E-09	1.18E-09	5.78E-10	3.63E-10	2.57E-10
W	6.87E-07	1.14E-07	5.21E-08	3.17E-08	2.20E-08	1.07E-08	4.10E-09	2.06E-09	1.31E-09	9.40E-10
WNW	9.84E-07	1.55E-07	6.99E-08	4.21E-08	2.90E-08	1.38E-08	5.14E-09	2.52E-09	1.58E-09	1.12E-09
NW	3.50E-06	5.68E-07	2.59E-07	1.57E-07	1.09E-07	5.25E-08	2.01E-08	1.00E-08	6.40E-09	4.58E-09
NNW	6.60E-06	1.07E-06	4.85E-07	2.94E-07	2.04E-07	9.81E-08	3.73E-08	1.86E-08	1.18E-08	8.47E-09

(a) Calculated from meteorological data collected at the 300 Area and the Hanford Meteorological Station.

**TABLE F.8. Annual Average Atmospheric Dispersion (X/Q) Around the 400 Areas During 1984 for an 89-m Release Height<sup>(a)</sup>**

Direction	sec/m <sup>3</sup>									
	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	7.41E-06	1.19E-06	5.42E-07	3.29E-07	2.29E-07	1.11E-07	4.23E-08	2.12E-08	1.35E-08	9.66E-09
NNE	5.06E-06	8.04E-07	3.65E-07	2.21E-07	1.53E-07	7.34E-08	2.78E-08	1.38E-08	8.78E-09	6.27E-09
NE	3.14E-06	4.99E-07	2.27E-07	1.38E-07	9.54E-08	4.59E-08	1.74E-08	8.68E-09	5.51E-09	3.94E-09
ENE	2.19E-06	3.47E-08	1.58E-07	9.26E-08	6.67E-08	3.22E-08	1.23E-08	6.14E-09	3.90E-09	2.79E-09
E	3.37E-06	5.32E-07	2.42E-07	1.46E-07	1.01E-07	4.85E-08	1.83E-08	9.06E-09	5.74E-09	4.09E-09
ESE	3.93E-06	6.25E-07	2.84E-07	1.71E-07	1.18E-07	5.66E-08	2.13E-08	1.05E-08	6.64E-09	4.72E-09
SE	4.72E-06	7.54E-07	3.42E-07	2.06E-07	1.42E-07	6.81E-08	2.56E-08	1.26E-08	7.99E-09	5.69E-09
SSE	3.88E-06	6.20E-07	2.82E-07	1.70E-07	1.18E-07	5.64E-08	2.13E-08	1.06E-08	6.70E-09	4.78E-09
S	5.42E-06	8.63E-07	3.92E-07	2.37E-07	1.64E-07	7.87E-08	2.98E-08	1.48E-08	9.42E-09	6.73E-09
SSW	.91E-06	4.62E-07	2.11E-07	1.28E-07	8.86E-08	4.27E-08	1.63E-08	8.15E-09	5.19E-09	3.71E-09
SW	2.25E-06	3.57E-07	1.62E-07	9.76E-08	6.75E-08	3.23E-08	1.22E-08	6.04E-09	3.83E-09	2.73E-09
WSW	1.59E-06	2.51E-07	1.14E-07	6.91E-08	4.78E-08	2.03E-08	8.76E-09	4.37E-09	2.78E-09	1.98E-09
W	2.06E-06	3.25E-07	1.47E-07	8.90E-08	6.16E-08	2.96E-08	1.12E-08	5.59E-09	3.55E-09	2.54E-09
WNW	2.09E-06	3.30E-07	1.49E-07	9.02E-08	6.24E-08	2.99E-08	1.13E-08	5.64E-09	3.58E-09	2.56E-09
NW	2.35E-06	3.72E-07	1.69E-07	1.02E-07	7.05E-08	3.39E-08	1.28E-08	6.38E-09	4.05E-09	2.89E-09
NNW	4.39E-06	7.05E-07	3.20E-07	1.94E-07	1.34E-07	6.43E-08	2.44E-08	1.21E-08	7.68E-09	5.48E-09

(a) Calculated from meteorological data collected at the 400 Area and the Hanford Meteorological Station.

**TABLE F.9. Pathway Parameters**

	Holdup (days, except as noted) <sup>(a)</sup>		Growing Period, days	Yield, kg/m <sup>2</sup>	Irrigation Rate, l/m <sup>2</sup> /month
	Maximum Individual	Average Individual			
Leafy vegetables	1	14	90	1.5	150
Other above-ground vegetables	1	14	60	0.7	160
Potatoes	10	14	90	4	180
Other root vegetables	1	14	90	5	150
Berries	1	14	60	2.7	150
Melons	1	14	90	0.8	150
Orchard fruit	10	14	90	1.7	150
Wheat	10	14	90	0.72	0
Other grains	1	14	90	1.4	150
Eggs	1	18	90	0.84	150
Milk	1	4	30	1.3	200
Beef	15	34	90	0.84	140
Pork	15	34	90	0.84	140
Poultry	1	34	90	0.84	140
Fish	24 h	24	—	—	—
Drinking water	24	24	—	—	—

(a) Holdup is the time between harvest and consumption.

**TABLE F.10. Dietary Parameters**

	Consumption, kg/yr	
	Maximum Individual	Average Individual
Leafy veg.	30	15
Other above-ground veg.	30	15
Potatoes	110	100
Other root veg.	72	17
Berries	30	6
Melons	40	8
Orch. fruit	265	50
Wheat	80	72
Other grains	8.3	7.5
Eggs	30	20
Milk	274 <sup>(a)</sup>	230 <sup>(a)</sup>
Beef	40	40
Pork	40	30
Poultry	18	8.5
Fish	40	--- <sup>(c)</sup>
Drinking water	730 <sup>(b)</sup>	438 <sup>(b)</sup>

(a) Units l/yr.

(b) 330 l/yr for infant.

(c) Average individual consumption not identified; radiation doses were calculated based on estimated total annual catch of 15,000 kg.

**TABLE F.11. Residency Parameters**

Parameter	Exposure, h/yr	
	Maximum Individual	Average Individual
Ground Contamination	4383	2920
Air Submersion	8766	8766
Inhalation <sup>(a)</sup>	8766	8766

(a) Inhalation Rates:

Adult - 250 cm<sup>3</sup>/sec routine

Infant - 44 cm<sup>3</sup>/sec

**TABLE F.12. Recreational Activities**

Activity	Exposure, h/yr <sup>(a)</sup>	
	Maximum Individual	Average Individual
Shoreline	500	17
Boating	100	5
Swimming	100	10

(a) Assumes 8-h holdup for maximum individual and 13 h for average.

**TABLE F.13. Documentation of 100 Area Airborne Release Dose Calculation**

Facility name:	100 Area
Releases:	See Table F.18
Meteorological conditions:	1984 annual average, calculated from data collected at 100 N Area and the Hanford Meteorological Station from 1-84 through 12-84. See Table F.5.
X/Q:	Maximum individual 3.2 x 10 <sup>-9</sup> sec/m <sup>3</sup> at 53 km SSE for direct airborne pathways and 4.1 x 10 <sup>-9</sup> sec/m <sup>3</sup> at 41 km SSE for food pathways, 80-km population 1.4 x 10 <sup>-3</sup> person-sec/m <sup>3</sup>
Release height:	82.3 meters effective (60.96 meters actual stack height)
Population distribution:	340,000, see Table F.1
Computer code:	DACRIN, Rev. 1.2, 1980
Calculated dose:	Chronic inhalation, maximum individual and 80-km population, 50-yr dose commitment
Files addressed:	Organ Data Library, Rev. 8-1-84 Radionuclide Library, Rev. 3-19-84
Computer code:	PABLM, Rev. 2.2, 10-1-80
Calculated dose:	Chronic ingestion and ground contamination exposure, maximum individual and 80-km population, 50-year cumulative dose
Files addressed:	Radionuclide Library, Rev. 3-19-85 Food Transfer Library, Rev. 11-11-83 Organ Data Library, Rev. 8-1-84 Ground Dose Factor Library, Rev. 3-15-78
Computer code:	KRONIC, Rev. 3-11-83
Calculated dose:	Chronic air submersion, maximum individual and 80-km population, first year dose
Files addressed:	OLD RDNBET OLD GISLIB

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**TABLE F.14. Documentation of 100 Area Liquid Release Dose Calculation**

Facility name:	100 Area
Releases:	See Table F.22
River flow:	130,000 cfs
Mixing ratio:	1
Reconcentration formula:	3
Shore-width factor:	0.2
Population:	70,000—drinking water pathway 125,000—fish and direct exposure 2,000—irrigated foodstuff
Computer code:	PABLM, Rev. 2.2, 10-1-80
Calculated dose:	Chronic ingestion, direct exposure to water and shoreline, maximum individual and 80-km population, 50-year cumulative dose
Files addressed:	Radionuclide Library, Rev. 3-19-85 Organ Data Library, Rev. 8-1-84 Hanford Specific Bio. Accum. Library Ground Dose Factor Library, Rev. 3-15-78
Computer code:	PABLM, Rev. 2.2, 10-1-80
Calculated dose:	Chronic ingestion and ground contamination, maximum individual and 80-km population, 50-year cumulative dose
Files addressed:	Radionuclide Library, Rev. 3-19-85 Food Transfer Library, Rev. 11-11-83 Organ Data Library, Rev. 8-1-84 Ground Dose Factor Library, Rev. 3-15-78

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**TABLE F.15. Documentation of 200 Areas Airborne Release Dose Calculation**

Facility name:	200 Area
Releases:	See Table F.18
Meteorological conditions:	1984 annual average, calculated from data collected at the Hanford Meteorological Station from 1-84 through 12-84. See Table F.6
X/Q:	Maximum individual $3.2 \times 10^{-9}$ sec/m <sup>3</sup> at 43 km SE for direct airborne pathways and $1.2 \times 10^{-9}$ sec/m <sup>3</sup> at 32 km SE for food pathways, 80-km population $1.3 \times 10^{-3}$ person-sec/m <sup>3</sup>
Release height:	89.2 meters effective (60.96 meters actual stack height)
Population distribution:	341,000, see Table F.2
Computer code:	DACRIN, Rev. 1.2, 1980
Calculated dose:	Chronic inhalation, maximum individual and 80-km population, 50-yr dose commitment
Files addressed:	Organ Data Library, Rev. 8-1-84 Radionuclide Library, Rev. 3-19-85
Computer code:	PABLM, Rev. 2.2, 10-1-80
Calculated dose:	Chronic ingestion and ground contamination exposure, maximum individual and 80-km population, 50-year cumulative dose
Files addressed:	Radionuclide Library, Rev. 3-19-85 Food Transfer Library, Rev. 11-11-83 Organ Data Library, Rev. 8-1-84 Ground Dose Factor Library, Rev. 3-15-78
Computer code:	KRONIC, Rev. 3-11-83
Calculated dose:	Chronic air submersion, maximum individual and 80-km population, first year dose
Files addressed:	OLD RNOBET OLD GISLIB

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**TABLE F.16. Documentation of 300 Area Airborne Release Dose Calculation**

Facility name:	300 Area
Releases:	See Table F.18
Meteorological conditions:	1984 annual average, calculated from data collected at 300 Area and the Hanford Meteorological Station from 1-84 through 12-84. See Table F.7.
X/Q:	Maximum individual $8.3 \times 10^{-8}$ sec/m <sup>3</sup> at 1.3 km SSE for direct airborne pathways and $6.6 \times 10^{-6}$ sec/m <sup>3</sup> at 1.6 km E for food pathways, 80-km population $5.8 \times 10^{-3}$ person-sec/m <sup>3</sup>
Release height:	Ground level
Population distribution:	265,000, see Table F.4
Computer code:	DACRIN, Rev. 1.2, 1980
Calculated dose:	Chronic inhalation, maximum individual and 80-km population, 50-yr dose commitment
Files addressed:	Organ Data Library, Rev. 8-1-84 Radionuclide Library, Rev. 3-19-85
Computer code:	PABLM, Rev. 2.2, 10-1-80
Calculated dose:	Chronic ingestion and ground contamination exposure, maximum individual and 80-km population, 50-year cumulative dose
Files addressed:	Radionuclide Library, Rev. 3-19-85 Food Transfer Library, Rev. 11-11-83 Organ Data Library, Rev. 8-1-84 Ground Dose Factor Library, Rev. 3-15-78
Computer code:	KRONIC, Rev. 3-11-83
Calculated dose:	Chronic air submersion, maximum individual and 80-km population, first year dose
Files addressed:	OLD RND BET OLD GISLIB

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**TABLE F.17. Documentation of 400 Area Airborne Release Dose Calculation**

Facility name:	400 Area
Releases:	See Table F.18
Meteorological conditions:	1984 annual average, calculated from data collected at 400 Area and the Hanford Meteorological Station from 1-84 through 12-84. See Table F.8.
X/Q:	Maximum individual $1.8 \times 10^{-8}$ sec/m <sup>3</sup> at 29 km SSE for direct airborne pathways and $8.4 \times 10^{-7}$ sec/m <sup>3</sup> at 11 km SE for food pathways, 80-km population $5.6 \times 10^{-3}$ person-sec/m <sup>3</sup>
Release height:	Ground level
Population distribution:	264,000, see Table F.3
Computer code:	DACRIN, Rev. 1.2, 1980
Calculated dose:	Chronic inhalation, maximum individual and 80-km population, 50-yr dose commitment
Files addressed:	Organ Data Library, Rev. 8-1-84 Radionuclide Library, Rev. 3-19-85
Computer code:	PABLM, Rev. 2.2, 10-1-80
Calculated dose:	Chronic ingestion and ground contamination exposure, maximum individual and 80-km population, 50-year cumulative dose
Files addressed:	Radionuclide Library, Rev. 3-19-85 Food Transfer Library, Rev. 11-11-83 Organ Data Library, Rev. 8-1-84 Ground Dose Factor Library, Rev. 3-15-78
Computer code:	KRONIC, Rev. 3-11-83
Calculated dose:	Chronic air submersion, maximum individual and 80-km population, first year dose
Files addressed:	OLD RND BET OLD GISLIB

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**TABLE F.18. Radionuclide Discharges to the Atmosphere**

Radionuclide	Half-Life	Release, Ci <sup>(a)</sup>			
		Airborne			
		100 Area	200 Area	300 Area	400 Area
<sup>3</sup> H (HTO)	12.3 yr	1.4 x 10 <sup>0</sup>	2 x 10 <sup>2</sup>	(d)	
<sup>14</sup> C	5730 yr		3 x 10 <sup>0</sup>		
<sup>24</sup> Na	15.0 h	1.7 x 10 <sup>-1</sup>			
<sup>41</sup> Ar	1.8 h	7.7 x 10 <sup>4</sup>			
<sup>54</sup> Mn	303d	5.3 x 10 <sup>-3</sup>			
<sup>56</sup> Mn	2.6 h	6.6 x 10 <sup>-1</sup>			
<sup>59</sup> Fe	46.0 d	7.1 x 10 <sup>-3</sup>			
<sup>58</sup> Co	71.0 d	1.7 x 10 <sup>-3</sup>			
<sup>60</sup> Co	5.3 yr	1.5 x 10 <sup>-2</sup>		6.5 x 10 <sup>-6</sup> (b)	
<sup>76</sup> As	26.4 h	6.5 x 10 <sup>-1</sup>			
<sup>85m</sup> Kr	4.4 h	7.7 x 10 <sup>2</sup>			
<sup>85</sup> Kr	10.7 yr		4 x 10 <sup>5</sup>		1.1 x 10 <sup>3</sup>
<sup>87</sup> Kr	76.0 min	1.1 x 10 <sup>3</sup>			
<sup>88</sup> Kr-Rb	2.8 h	1.9 x 10 <sup>3</sup>			
<sup>89</sup> Sr	52.7 d	1.5 x 10 <sup>-2</sup>			
<sup>90</sup> Sr	27.7 y	1.6 x 10 <sup>-3</sup>	2.3 x 10 <sup>-2</sup>	1.1 x 10 <sup>-4</sup> (c)	1.3 x 10 <sup>-5</sup>
<sup>91</sup> Sr	9.7 h	1.7 x 10 <sup>-1</sup>			
<sup>95</sup> Zr-Nb	35.0 d	6.2 x 10 <sup>-3</sup>	8 x 10 <sup>-3</sup>		
<sup>99m</sup> Mo-Tc	66.7 h	1.6 x 10 <sup>-1</sup>			
<sup>103</sup> Ru-Rh	39.5 d	2.1 x 10 <sup>-3</sup>	5 x 10 <sup>-4</sup>		
<sup>106</sup> Ru-Rh	368 d	5.6 x 10 <sup>-4</sup>	2 x 10 <sup>-1</sup>		
<sup>113</sup> Sb	115 d		6 x 10 <sup>-2</sup>		
<sup>125</sup> Sb	2.7 y		5 x 10 <sup>-4</sup>		
<sup>129</sup> I	1.6 x 10 <sup>7</sup> y		8 x 10 <sup>-2</sup>		
<sup>131</sup> I	8.1 d	3.4 x 10 <sup>-1</sup>	ND <sup>(e)</sup>	3.8 x 10 <sup>-4</sup>	8.7 x 10 <sup>-6</sup>
<sup>132</sup> I	2.3 h	3.1 x 10 <sup>0</sup>			
<sup>133</sup> I	20.3 h	2.6 x 10 <sup>0</sup>			
<sup>135</sup> I	6.7 h	3.9 x 10 <sup>0</sup>			
<sup>133</sup> Xe	5.3 d	3.2 x 10 <sup>2</sup>			
<sup>134</sup> Cs	2.1 y	3.1 x 10 <sup>-5</sup>	1 x 10 <sup>-3</sup>		
<sup>135</sup> Xe	9.1 h	2.3 x 10 <sup>3</sup>			
<sup>137</sup> Cs	30.0 yr	1.6 x 10 <sup>-3</sup>	4 x 10 <sup>-2</sup>		
<sup>138</sup> Cs	32.2 min	3.6 x 10 <sup>3</sup>			
<sup>140</sup> Ba-La	12.8 d	1.5 x 10 <sup>-1</sup>			
<sup>144</sup> Ce-Pr	284 d	1.5 x 10 <sup>-2</sup>	1 x 10 <sup>-1</sup>		
<sup>147</sup> Pm	2.6 y		7 x 10 <sup>-2</sup>		
<sup>155</sup> Eu	1.8 yr	2.3 x 10 <sup>-4</sup>			
<sup>212</sup> Pb	10.6 h		2 x 10 <sup>-1</sup>		
U-Nat	4.4 x 10 <sup>9</sup> yr		1.7 x 10 <sup>-5</sup>	4.5 x 10 <sup>-6</sup>	
<sup>238</sup> Pu	86.4 yr	3.0 x 10 <sup>-6</sup>			
<sup>239,240</sup> Pu	2.4 x 10 <sup>4</sup>	1.8 x 10 <sup>-5</sup>	7.4 x 10 <sup>-3</sup> (f)	1.7 x 10 <sup>-5</sup>	2.5 x 10 <sup>-6</sup>
<sup>241</sup> Pu	18.1 yr		8 x 10 <sup>-2</sup>		
<sup>241</sup> Am			ND		

(a) Except as noted in this table, all Ci values are as reported by operating contractors via the DOE's Effluent Information System.

(b) Includes 2.1 x 10<sup>-7</sup> Ci reported as mixed activation products, but assumed to be <sup>60</sup>Co for dose calculations.

(c) Includes 9.0 x 10<sup>-6</sup> Ci reported as mixed fission products but assumed to be <sup>90</sup>Sr for dose calculations.

(d) Blank entry indicates no value reported by the operating contractor.

(e) ND; not detected as reported by operating contractor.

(f) Previously reported as 1.4 x 10<sup>-2</sup> Ci from estimate based on gross alpha measurements.

**TABLE F.19. Nonradioactive Discharges to the Atmosphere**

Constituent	Release, Kg			
	100 Area	200 Area	300 Area	1100 Area
Particulates	$4.2 \times 10^4$	$3.8 \times 10^5$	$2.5 \times 10^4$	$1.5 \times 10^3$
Nitrogen Oxides	$1.5 \times 10^5$	$1.0 \times 10^6$	$1.7 \times 10^5$	$8.5 \times 10^3$
Sulfur Oxides	$4.7 \times 10^5$	$1.5 \times 10^6$	$4.4 \times 10^5$	$4.9 \times 10^3$
Carbon Monoxide	$7.7 \times 10^3$		$1.1 \times 10^5$	$2.0 \times 10^1$
Hydrocarbons	$5.7 \times 10^3$		$5.4 \times 10^4$	$5.8 \times 10^2$
Aldehydes	$2.1 \times 10^3$			

**TABLE F.20. Radionuclide Liquid Discharges to Ground Disposal Facilities**

Radionuclide	Half-Life	Release, Ci(a)		
		100 Area	200 Areas	300 Area
$^3\text{H}$ HTO	12.3 yr	$1.4 \times 10^2$	$8.5 \times 10^3$	
$^{32}\text{P}$	14.3 d	$2.6 \times 10^1$		
$^{51}\text{Cr}$	17.8 d	$2.4 \times 10^2$		
$^{54}\text{Mn}$	303 d	$8.5 \times 10^2$		
$^{59}\text{Fe}$	46.0 d	$6.6 \times 10^2$		
$^{58}\text{Co}$	71.0 d	$7.4 \times 10^1$		
$^{60}\text{Co}$	5.3 yr	$1.5 \times 10^3$		
$^{65}\text{Zn}$	245 d	$2.1 \times 10^1$		
$^{89}\text{Sr}$	52.7 d	$4.9 \times 10^2$		
$^{90}\text{Sr}$	27.7 yr	$3.1 \times 10^2$	$1.4 \times 10^1$	
$^{95}\text{ZrNb}$	65.5 d	$7.7 \times 10^2$		
$^{99}\text{Tc}$	$2.1 \times 10^5$ yr			$5.1 \times 10^{-1}$
$^{99}\text{MoTc}$	66.7 h	$6.0 \times 10^2$		
$^{103}\text{Ru}$	39.5 d	$1.5 \times 10^2$		
$^{106}\text{Ru}$	368 d	$1.3 \times 10^2$	$1.0 \times 10^1$	
$^{124}\text{Sb}$	60 d	$1.3 \times 10^1$		
$^{125}\text{Sb}$	2.7 y	$1.4 \times 10^1$		
$^{131}\text{I}$	8.1 d	$4.0 \times 10^2$		
$^{133}\text{Xe}$	5.3 d	$3.9 \times 10^2$		
$^{134}\text{Cs}$	2.1 yr	$1.7 \times 10^1$		
$^{137}\text{Cs}$	30.0 yr	$2.1 \times 10^2$		
$^{140}\text{BaLa}$	12.8 d	$6.1 \times 10^3$		
$^{141}\text{Ce}$	33 d	$2.3 \times 10^2$		
$^{144}\text{CePr}$	284 d	$3.4 \times 10^2$		
$^{147}\text{Pm}$	2.6 yr		$4.5 \times 10^0$	
$^{153}\text{Sm}$	47 h	$2.8 \times 10^2$		
Unidentified beta				$1.9 \times 10^{-1}$
Short-lived radionuclides(b)			$2.2 \times 10^4$	
$^{234}\text{U}$	$2.5 \times 10^5$ yr			$1.9 \times 10^{-1}$
$^{235}\text{U}$	$7.1 \times 10^8$ yr			$1.0 \times 10^{-2}$
$^{238}\text{U}$	$2.4 \times 10^7$ yr			$2.0 \times 10^{-2}$
$^{238}\text{U}$	$4.5 \times 10^9$ yr		$5.0 \times 10^{-2}$	$1.5 \times 10^{-1}$
$^{241}\text{Am}$	458 yr		$7.9 \times 10^{-1}$	
$^{238}\text{Pu}$	86.4 yr	$6.8 \times 10^1$		
$^{239,240}\text{Pu}$	$2.4 \times 10^4$ yr	$4.3 \times 10^0$		
Pu (Total)	—		$2.4 \times 10^0$	
$^{241}\text{Pu}$	—		$1.2 \times 10^1$	
$^{239}\text{Np}$	2.4 d	$9.8 \times 10^2$		

(a) Values are those reported by operating contractors

(b) Short-lived radionuclides  $T_{1/2} < 48$  h.

(c) Blank entry indicates no value reported by the operating contractor.

**TABLE F.21. Nonradioactive Liquid Discharges to Ground Disposal Facilities**

Constituent	Release, Kg (except as noted) <sup>(a)</sup>		
	100 Area <sup>(b)</sup>	200 Area	300 Area
Aluminum sulfate	2.5 x 10 <sup>5</sup>		
Chlorine	1.7 x 10 <sup>4</sup>		
Polyacrylamide	5.9 x 10 <sup>2</sup>		
Sulfuric acid	7.7 x 10 <sup>5</sup>		
Ammonium hydroxide	3.1 x 10 <sup>5</sup> †		
Hydrazine	2.3 x 10 <sup>2</sup>		
Morpholine	1.3 x 10 <sup>3</sup>		
Sodium hydroxide	2.9 x 10 <sup>5</sup>		
<b>Nonradioactive effluents</b>			
Ammonia		4.6 x 10 <sup>4</sup>	
Total Organic Carbon		1.2 x 10 <sup>5</sup>	
NO <sub>3</sub> <sup>-</sup>		5.4 x 10 <sup>4</sup>	8.5 x 10 <sup>4</sup>
Cu			5.0 x 10 <sup>2</sup>
F <sup>-</sup>			2.0 x 10 <sup>3</sup>

(a) Values are those reported by operating contractors.  
 (b) Reported as quantity used.

**TABLE F.22. Radionuclide Liquid Discharges to the Columbia River**

Radionuclide	Half-Life	Release, Ci <sup>(a)</sup>
<sup>3</sup> H (HTO)	12.3 yr	1.4 x 10 <sup>2</sup>
<sup>24</sup> Na	15.0 h	1.4 x 10 <sup>0</sup>
<sup>32</sup> P	14.3 d	8.8 x 10 <sup>-3</sup>
<sup>51</sup> Cr	27.8 d	2.8 x 10 <sup>-1</sup>
<sup>54</sup> Mn	303 d	4.7 x 10 <sup>-1</sup>
<sup>59</sup> Fe	46.0 d	2.4 x 10 <sup>-1</sup>
<sup>58</sup> Co	71.0 d	3.5 x 10 <sup>-2</sup>
<sup>60</sup> Co	5.3 yr	1.3 x 10 <sup>0</sup>
<sup>89</sup> Sr	52.7 d	9.1 x 10 <sup>-1</sup>
<sup>90</sup> Sr	27.7 yr	7.2 x 10 <sup>0</sup>
<sup>95</sup> Zr/Nb	65.5 d	2.9 x 10 <sup>-1</sup>
<sup>99m</sup> Mo/Tc	66.7 h	7.3 x 10 <sup>-1</sup>
<sup>103</sup> Ru	39.5 d	5.5 x 10 <sup>-1</sup>
<sup>106</sup> Ru	368 d	2.9 x 10 <sup>-1</sup>
<sup>124</sup> Sb	60 d	1.6 x 10 <sup>-1</sup>
<sup>125</sup> Sb	2.7 yr	3.0 x 10 <sup>-2</sup>
<sup>131</sup> I	8.1 d	4.4 x 10 <sup>0</sup>
<sup>133</sup> I	20.3 h	6.3 x 10 <sup>0</sup>
<sup>133</sup> Xe	5.3 d	2.7 x 10 <sup>0</sup>
<sup>137</sup> Cs	30.0 yr	2.6 x 10 <sup>-1</sup>
<sup>140</sup> Ba/La	12.8 d	2.4 x 10 <sup>0</sup>
<sup>141</sup> Ce	33 d	3.6 x 10 <sup>-2</sup>
<sup>144</sup> Ce/Pr	284 d	4.4 x 10 <sup>-1</sup>
<sup>238</sup> Pu	86.4 yr	1.0 x 10 <sup>-5</sup>
<sup>239,240</sup> Pu	2.4 x 10 <sup>4</sup> yr	5.4 x 10 <sup>-5</sup>

(a) Values are those reported by contractors.

**TABLE F.23. Composition of Solid Wastes Buried Onsite**

Constituent	Quantities <sup>(a)</sup>
<b>Radioactive</b>	
Uranium	4.8 x 10 <sup>6</sup> g
Plutonium	1.5 x 10 <sup>4</sup> g
Other transuranics and thorium	2.3 x 10 <sup>4</sup> g
Strontium-90	4.4 x 10 <sup>5</sup> Ci
Ruthenium-106	1.3 x 10 <sup>2</sup> Ci
Cesium-137	4.2 x 10 <sup>5</sup> Ci
Other fission and activation products	2.6 x 10 <sup>2</sup>
<b>Nonradioactive</b>	
General wastes	3.1 x 10 <sup>4</sup> m <sup>3</sup>
Asbestos	5.6 x 10 <sup>2</sup> m <sup>3</sup>
Waste chemicals	3.0 x 10 <sup>2</sup> m <sup>3</sup>

(a) Values are those reported by the operating contractors.

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