RECEIVED
SEP 29 1999
OSTI

Hanford Site

1998 Environmental Report

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

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or Battelle Memorial Institute.

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC06-76RLO 1830

Printed in the United States of America

Available to DOE and DOE contractors from the Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831; prices available from (615) 576-8401.

Available to the public from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161

This document was printed on recycled paper.
(9/97)

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, make any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Department of Energy
Richland Operations Office
P.O. Box 550
Richland, Washington 99352

99-EAP-435

AUG 18 1999

Addressees:

THE HANFORD SITE ENVIRONMENTAL REPORT FOR CALENDAR YEAR (CY) 1998 (PNNL-12088), RICHLAND, WASHINGTON, SEPTEMBER 1999

The Hanford Site Environmental Report is prepared and published annually by the U.S. Department of Energy (DOE), Richland Operations Office (RL) for distribution to local, state, and federal government agencies, Congress, the public, the news media, and Hanford employees. The purpose of the report is to provide the reader with the most recent information available on Hanford Site environmental management activities and environmental compliance issues.

This report includes information for CY 1998 and contains sections summarizing the results of environmental monitoring efforts on and around the site, information on Hanford's conformance to environmental permits, and the status of the site's compliance with federal, state, and local regulations. It also discusses important issues and actions for both CY 1998 and early CY 1999.

The report was prepared for RL by the Pacific Northwest National Laboratory (PNNL) and other site contractors and describes programs conducted by PNNL, the Research and Development Contractor; Fluor Daniel Hanford, Inc., the Management and Integration Contractor; Bechtel Hanford, Inc., the Environmental Restoration Contractor; MACTEC-ERS, a prime contractor to DOE's office in Grand Junction, Colorado, which is performing work at Hanford for RL; and numerous subcontractor and enterprise companies at Hanford.

If you have any questions or comments about this report, you may contact me or Dana Ward, of the Environmental Assurance, Permits and Policy Division, on (509) 372-1261.

Sincerely,

Keith A. Klein
Manager

EAP:DCW

Enclosure:
Hanford Site Environmental
Report for 1998

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

September 17, 1999

Recipients of the Hanford Site Environmental Report for Calendar Year 1998

ERROR IN REPORT

In Section 4.2, Surface Water and Sediment Surveillance, the figures on pages 4.39 and 4.40 are reversed. The figures on page 4.39 belong with the figure caption on page 4.40 and the figures on page 4.40 belong with the figure caption on page 4.39. Please hand-correct the figure caption on page 4.39 to read Figure 4.2.15 and the figure caption on page 4.40 to read Figure 4.2.14.

Please call me on (509) 376-8264 if you have any questions or concerns about this change.

Sincerely,

R. W. (Bill) Hanf
Hanford Site Environmental Report Production Coordinator
Surface Environmental Surveillance Project

902 Battelle Boulevard • P.O. Box 999 • Richland, WA 99352

Telephone (509) 376-8264 ■ Email bill.hanf@pnl.gov ■ Fax (509) 376-2210

PNNL-12088
UC-602

Hanford Site Environmental Report
for Calendar Year 1998

Editors
R. L. Dirkes
R. W. Hanf
T. M. Poston

September 1999

Prepared for the U.S. Department of Energy by
Pacific Northwest National Laboratory
under contract DE-AC06-76RLO 1830, with
contributions from Fluor Daniel Hanford, Inc.
and its enterprise companies, Bechtel Hanford, Inc.
and its subcontractors, and MACTEC-ERS

Pacific Northwest National Laboratory
Richland, Washington 99352

Preface

U.S. Department of Energy (DOE) Order 5400.1, "General Environmental Protection Program," establishes the requirement for environmental protection programs at DOE sites and facilities. These programs ensure that DOE operations comply with applicable federal, state, and local environmental laws and regulations, executive orders, and Department policies.

This Hanford Site environmental report is prepared annually pursuant to DOE Orders 5400.1 and 231.1, "Environment, Safety, and Health Reporting," and DOE M 231.1-1, *Environment, Safety and Health Reporting Manual*, to summarize environmental data that characterize Hanford Site environmental management performance and demonstrate compliance status. This report also highlights significant environmental programs and efforts. More detailed environmental compliance, monitoring, surveillance, and study reports may be of value; therefore, to the extent practical, these additional reports have been referenced in the text.

Although this report was written to meet DOE reporting requirements and guidelines, it is also intended to be useful to members of the public, public officials, regulators, and Hanford Site contractors. The "Helpful Information" section lists acronyms, abbreviations, conversion information, and nomenclature that may be useful for understanding this report.

This report is produced for the Environmental Assurance, Permits and Policy Division of the DOE Richland Operations Office by the Pacific Northwest National Laboratory's Public Safety and Resource Protection Program. Pacific Northwest National Laboratory is operated by Battelle (the site research and development contractor) for DOE. Battelle is a not-for-profit, independent, contract research institute. Major portions of this report were written by staff from the Pacific Northwest National Laboratory and selected subcontractors and alliance subcontractors of Fluor Daniel Hanford, Inc. (the site management and integration contractor). Bechtel Hanford, Inc. (the site environmental restoration contractor) and MACTEC-ERS also prepared or provided input to selected sections.

Copies of this report have been provided to many libraries in communities around the Hanford Site and to several university libraries in Washington and Oregon. Copies can also be found at DOE's Hanford Reading Room located in the Consolidated Information Center on the campus of Washington State University at Tri-Cities. Copies of the report can be obtained from Mr. R. W. (Bill) Hanf, Pacific Northwest National Laboratory, P.O. Box 999, Richland, Washington 99352 (bill.hanf@pnl.gov) while supplies last or can be purchased from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161.

This report has been issued in two hard-copy formats and an electronic format. The hard copy includes this large technical report and a smaller (approximately 50 pages), less-detailed, summary report. The electronic versions of both hard-copy documents are available on the Internet at http://hanford.pnl.gov/envreport/ or http://hanford.pnl.gov/envreport/1998.

Inquiries regarding this report may be directed to Mr. D. C. (Dana) Ward, DOE Richland Operations Office, Environmental Assurance, Permits and Policy Division, P.O. Box 550, Richland, Washington 99352 (Dana_C_Ward@apimc01.rl.gov) or to Mr. T. M. (Ted) Poston, Pacific Northwest National Laboratory, P.O. Box 999, Richland, Washington 99352 (ted.poston@pnl.gov).

Contents

Preface iii

Summary xxvii

Acknowledgments xlix

Report Contributors li

Helpful Information liii
- Scientific Notation liii
- Units of Measurement liii
- Radioactivity Units liv
- Radiological Dose Units lv
- Chemical and Elemental Nomenclature lvi
- Understanding the Data Tables lvi
  - Total Propagated Analytical Uncertainty lvi
  - Standard Error of the Mean lvii
  - Median, Maximum, and Minimum Values lviii
  - Negative Numbers lviii
- Understanding Graphic Information lviii
- Greater Than or Less Than Symbols lix
- References lx

1.0 Introduction 1.1
- 1.0.1 Overview of the Hanford Site 1.1
  - 1.0.1.1 Site Description 1.3
- 1.0.2 Historical Site Operations 1.5
  - 1.0.2.1 The 300 Area 1.6
  - 1.0.2.2 The 100 Areas 1.6
  - 1.0.2.3 The 200 Areas 1.7
  - 1.0.2.4 The 400 Area 1.10
- 1.0.3 Current Site Mission 1.10
- 1.0.4 Site Management 1.11
- 1.0.5 Major Site Activities 1.13
  - 1.0.5.1 Waste Management 1.13
  - 1.0.5.2 Spent Nuclear Fuel Projects 1.14
  - 1.0.5.3 Facility Stabilization 1.14
  - 1.0.5.4 Environmental Restoration 1.14
  - 1.0.5.5 Research and Technology Development 1.14
- 1.0.6 Site Environmental Programs 1.15
  - 1.0.6.1 Effluent Monitoring, Waste Management, and Chemical Inventory Programs 1.15

1.0.6.2 Near-Facility Environmental Monitoring Program 1.15
1.0.6.3 Sitewide Environmental Surveillance 1.15
1.0.6.4 Groundwater Monitoring and Vadose Zone Baseline Characterization 1.15
1.0.6.5 Other Environmental Programs 1.16
1.0.7 References 1.16

2.0 Environmental and Regulatory Compliance Summary 2.1

2.1 Stakeholder and Tribal Involvement 2.3
2.1.1 Regulatory Oversight 2.3
2.1.2 Hanford Federal Facility Agreement and Consent Order 2.4
2.1.3 The Role of Indian Tribes 2.4
2.1.4 Hanford Natural Resource Trustee Council 2.5
2.1.5 Public Participation 2.6
2.1.6 Hanford Advisory Board 2.7
2.1.7 Hanford Site Technology Coordination Group 2.8

2.2 Compliance Status 2.11
2.2.1 Hanford Federal Facility Agreement and Consent Order, 1998 Performance 2.11
2.2.2 Environmental Management Systems Development 2.11
2.2.2.1 Chemical Management System 2.13
2.2.3 Comprehensive Environmental Response, Compensation, and Liability Act 2.14
2.2.4 Emergency Planning and Community Right-To-Know Act 2.14
2.2.5 Resource Conservation and Recovery Act 2.16
2.2.5.1 Hanford Facility RCRA Permit 2.16
2.2.5.2 RCRA/Dangerous Waste Permit Applications and Closure Plans 2.16
2.2.5.3 RCRA Groundwater Monitoring Project Management 2.16
2.2.5.4 RCRA Inspections 2.21
2.2.6 Clean Air Act 2.22
2.2.6.1 Clean Air Act Enforcement Inspections 2.23
2.2.7 Clean Water Act 2.24
2.2.7.1 Liquid Effluent Consent Order 2.25
2.2.8 Safe Drinking Water Act 2.26
2.2.9 Toxic Substances Control Act 2.27
2.2.10 Federal Insecticide, Fungicide, and Rodenticide Act 2.27
2.2.11 Endangered Species Act 2.28
2.2.12 National Historic Preservation Act, Archaeological Resources Protection Act, Native American Graves Protection and Repatriation Act, and American Indian Religious Freedom Act 2.29
2.2.13 National Environmental Policy Act 2.29
2.2.13.1 Recent Environmental Impact Statements 2.30
2.2.13.2 Programmatic Environmental Impact Statements 2.31
2.2.13.3 Site-Specific Environmental Impact Statements in Progress 2.31
2.2.14 Hanford Site Permitting Summary 2.31

2.3 Activities, Accomplishments, and Issues 2.33
2.3.1 Hanford Federal Facility Agreement and Consent Order 2.33
2.3.1.1 Waste Management 2.33
2.3.1.2 Environmental Restoration 2.34
2.3.1.3 Tank Waste Remediation System 2.35
2.3.1.4 Facilities Transition 2.35
2.3.2 Pollution Prevention Program 2.35
2.3.3 Environmental Molecular Sciences Laboratory 2.36
2.3.4 Spent Nuclear Fuel Project 2.37
2.3.5 Facility Stabilization Project 2.38
2.3.5.1 B Plant 2.38
2.3.5.2 Facility Stabilization and Environmental Restoration Team 2.39
2.3.5.3 300 Area Stabilization Project 2.39
2.3.5.4 Waste Encapsulation and Storage Facility 2.40
2.3.5.5 Plutonium Finishing Plant 2.40
2.3.5.6 Plutonium-Uranium Extraction Plant 2.41
2.3.6 Fast Flux Test Facility 2.41
2.3.6.1 History 2.41
2.3.6.2 Possible Future Misisons 2.42
2.3.7 Advanced Reactors Transition Project 2.43
2.3.8 Tank Waste Remediation System Activities 2.43
2.3.8.1 Waste Tank Status 2.43
2.3.8.2 Waste Tank Safety Issues 2.44
2.3.8.3 Watch List Tanks 2.44
2.3.8.4 Vadose Zone Characterization Near Single-Shell Underground Waste Storage Tanks 2.47
2.3.8.5 Waste Immobilization 2.49
2.3.9 Solid Waste Management Activities 2.50
2.3.9.1 Central Waste Complex 2.50
2.3.9.2 Waste Receiving and Processing Facility 2.50
2.3.9.3 Radioactive Mixed Waste Disposal Facilities 2.51
2.3.9.4 T Plant Complex 2.51
2.3.9.5 Radioactive Mixed Waste Treatment and Disposal 2.52
2.3.9.6 Radioactive Mixed Waste Treatment Contracts 2.52
2.3.9.7 Navy Reactor Compartments 2.52
2.3.9.8 325 Building Hazardous Waste Treatment Units 2.53
2.3.9.9 Underground Fuel Storage Tanks 2.53
2.3.10 Liquid Effluent Activities 2.53
2.3.10.1 242-A Evaporator 2.53
2.3.10.2 Liquid Effluent Retention Facility 2.53
2.3.10.3 200 Areas Effluent Treatment Facility 2.54
2.3.10.4 200 Areas Treated Effluent Disposal Facility 2.54
2.3.10.5 300 Area Treated Effluent Disposal Facility 2.55

2.3.10.6 340 Waste Handling Facility 2.55
2.3.10.7 Miscellaneous Streams 2.56
2.3.10.8 Vadose Zone Characterization Summary 2.56
2.3.11 Revegetation and Mitigation Planning 2.57
2.3.12 Environmental Restoration Project 2.58
2.3.12.1 Environmental Restoration Disposal Facility 2.58
2.3.12.2 Waste Site Remediation Activities 2.58
2.3.12.3 100-N Area Project 2.59
2.3.12.4 Decommissioning Project 2.59
2.3.12.5 Surveillance/Maintenance and Transition Project 2.60
2.3.13 Groundwater/Vadose Zone Integration Project 2.60
2.3.13.1 Integration 2.60
2.3.13.2 Groundwater Restoration Activities 2.61
2.3.13.3 Vadose Zone Activities 2.62
2.3.14 Noxious Weed Control Program 2.63
2.3.15 Research and Technology Development Activities 2.63

2.4 Environmental Occurrences 2.67
2.4.1 Emergency Occurrences 2.67
2.4.2 Unusual Occurrences 2.68
2.4.3 Off-Normal Occurrences 2.69

2.5 Waste Management and Chemical Inventories 2.71
2.5.1 Waste Management 2.71
2.5.2 Chemical Inventories 2.73

2.6 References 2.75

3.0 Facility-Related Monitoring 3.1

3.1 Facility Effluent Monitoring 3.3
3.1.1 Airborne Emissions 3.4
3.1.1.1 Radioactive Airborne Emissions 3.4
3.1.1.2 Nonradioactive Airborne Emissions 3.6
3.1.2 Liquid Effluents 3.7
3.1.2.1 Radioactive Liquid Effluents 3.7
3.1.2.2 Nonradioactive Hazardous Materials in Liquid Effluents 3.8
3.1.3 CERCLA and Washington Administrative Code Chemical Releases 3.9

3.2 Near-Facility Environmental Monitoring 3.11
3.2.1 Air Monitoring 3.11
3.2.2 Surface-Water Disposal Units and 100-N Area Riverbank Springs Monitoring 3.17
3.2.3 Radiological Surveys 3.19

3.2.4 Soil and Vegetation Sampling from Operational Areas 3.22
3.2.4.1 Radiological Results for Soil Samples 3.23
3.2.4.2 Radiological Results for Vegetation Samples 3.28
3.2.5 External Radiation 3.31
3.2.6 Investigative Sampling 3.36

3.3 References 3.39

4.0 Environmental Surveillance Information 4.1
4.0.1 Surface Environmental Surveillance 4.1
4.0.1.1 Surveillance Objectives 4.2
4.0.1.2 Surveillance Design 4.3

4.1 Air Surveillance 4.7
4.1.1 Collection of Air Samples and Analytes Tested for at Each Sample Location 4.7
4.1.2 Radiological Results for Air Samples 4.13

4.2 Surface Water and Sediment Surveillance 4.17
4.2.1 Columbia River Water 4.17
4.2.1.1 Collection of River-Water Samples and Analytes of Interest 4.21
4.2.1.2 Radiological Results for River-Water Samples 4.22
4.2.1.3 Nonradiological Results for River-Water Samples 4.27
4.2.2 Columbia River Sediments 4.29
4.2.2.1 Collection of Sediment Samples and Analytes of Interest 4.30
4.2.2.2 Radiological Results for River Sediment Samples 4.31
4.2.2.3 Radiological Results for Riverbank Spring Sediment Samples 4.31
4.2.2.4 Nonradiological Results for Columbia and Snake River Sediment Samples 4.31
4.2.3 Riverbank Springs Water 4.34
4.2.3.1 Riverbank Springs Water Samples and Analytes of Interest 4.35
4.2.3.2 Results for Riverbank Springs Water 4.36
4.2.3.3 Radiological Results for Riverbank Springs Water Samples 4.36
4.2.3.4 Nonradiological Results for Riverbank Springs Water Samples 4.38
4.2.4 Onsite Pond Water 4.39
4.2.4.1 Collection of Pond Water Samples and Analytes of Interest 4.40
4.2.4.2 Radiological Results for Pond Water Samples 4.42
4.2.5 Offsite Water 4.42
4.2.5.1 Collection, Analysis, and Results for Irrigation Canal Water 4.45

4.3 Hanford Site Drinking Water Surveillance 4.47
4.3.1 Radiological Monitoring of Hanford Site Drinking Water Systems 4.47
4.3.2 Collection of Drinking Water Samples and Analytes of Interest 4.49
4.3.3 Radiological Results for Hanford Site Drinking Water 4.51

4.4 Food and Farm Product Surveillance 4.55
4.4.1 Milk Samples and Analytes of Interest 4.57
4.4.2 Vegetable Samples and Analytes of Interest 4.59
4.4.3 Fruit Samples and Analytes of Interest 4.60
4.4.4 Wine Samples and Analytes of Interest 4.60

4.5 Fish and Wildlife Surveillance 4.61
4.5.1 Fish Samples and Analytes of Interest 4.63
4.5.2 Wildlife Sampling 4.65
4.5.2.1 Deer and Elk Samples and Analytes of Interest 4.65
4.5.2.2 Pheasant Samples and Analytes of Interest 4.67

4.6 Soil and Vegetation Surveillance 4.69
4.6.1 Soil Sampling 4.69
4.6.2 Vegetation Sampling 4.74
4.6.3 Tree Sampling 4.75

4.7 External Radiation Surveillance 4.79
4.7.1 External Radiation Measurements 4.80
4.7.1.1 External Radiation Results 4.84
4.7.2 Radiological Survey Results 4.86

4.8 References 4.91

5.0 Potential Radiological Doses from 1998 Hanford Operations 5.1
5.0.1 Maximally Exposed Individual Dose 5.2
5.0.2 Special Case Exposure Scenarios 5.5
5.0.2.1 Maximum "Boundary" Dose Rate 5.6
5.0.2.2 Sportsman Dose 5.6
5.0.2.3 Fast Flux Test Facility Drinking Water 5.7
5.0.3 Comparison with Clean Air Act Standards 5.7
5.0.4 Collective Dose to the Population Within 80 km 5.8
5.0.5 Doses from Other than DOE Sources 5.11
5.0.6 Hanford Public Radiological Dose in Perspective 5.11
5.0.7 Dose Rates to Animals 5.13
5.0.8 References 5.14

6.0 Groundwater and Vadose Zone Monitoring 6.1
6.0.1 Groundwater Monitoring 6.1
6.0.1.1 Monitoring Objectives 6.1
6.0.1.2 Monitoring Design 6.1
6.0.2 Vadose Zone Monitoring 6.3

6.1 Hanford Groundwater Monitoring Project 6.5
6.1.1 Geologic Setting 6.7
6.1.2 Groundwater Hydrology 6.7
6.1.3 Contaminant Transport 6.17
6.1.4 Groundwater Modeling 6.18
6.1.5 Groundwater Monitoring 6.19
6.1.5.1 Groundwater Sampling and Analytes of Interest 6.20
6.1.5.2 Data Interpretation 6.24
6.1.6 Groundwater Monitoring Results 6.26
6.1.6.1 Radiological Monitoring Results for the Unconfined Aquifer 6.27
6.1.6.2 Chemical Monitoring Results for the Unconfined Aquifer 6.49
6.1.6.3 Radiological and Chemical Monitoring Results for the Basalt-Confined Aquifer 6.65
6.1.7 RCRA Summary 6.67
6.1.7.1 100 Areas Facilities 6.67
6.1.7.2 200 Areas Single-Shell Tank Farms 6.69
6.1.7.3 200 Areas Liquid Effluent Disposal Facilities 6.71
6.1.7.4 200 Areas Low-Level Burial Grounds 6.73
6.1.7.5 Liquid Effluent Retention Facility 6.74
6.1.7.6 300 Area Process Trenches 6.74
6.1.7.7 Nonradioactive Dangerous Waste Landfill 6.75

6.2 Vadose Zone Characterization and Monitoring 6.77
6.2.1 Tank Farms Vadose Zone Baseline Characterization Project 6.77
6.2.1.1 Data Collection and Analysis 6.78
6.2.1.2 Activities for 1998 ..... 6.80
6.2.2 Vadose Zone Monitoring at Waste Disposal Facilities 6.87
6.2.2.1 Subsurface Characterization and Vadose Zone Monitoring 6.87
6.2.2.2 Immobilized Low-Activity Waste Site 6.91
6.2.2.3 Borehole 41-09-39 Extension to Groundwater 6.95
6.2.2.4 200 Areas Assessment 6.98
6.2.2.5 Soil-Vapor Monitoring 6.101
6.2.3 Historical Gross Gamma-Ray Log-Time Series 6.109

6.3 References 6.113

7.0 Other Hanford Site Environmental Programs 7.1

7.1 Climate and Meteorology 7.3
7.1.1 Historical Information 7.5
7.1.2 Results of 1998 Monitoring 7.5

7.2 Ecosystem Monitoring (Plants and Wildlife) 7.7
7.2.1 Chinook Salmon 7.7

7.2.2 Bald Eagle 7.8
7.2.3 Hawks 7.9
7.2.4 Rocky Mountain Elk 7.10
7.2.5 Mule Deer 7.11
7.2.6 Plant Biodiversity Inventories 7.11
7.2.7 Sagebrush Die-Off 7.12

7.3 Cultural Resources 7.17
7.3.1 Native American Involvement 7.17
7.3.2 Public Involvement 7.17
7.3.3 Section 106 Activities 7.18
7.3.4 Section 110 Activities 7.18
7.3.4.1 Historic District 7.20
7.3.4.2 Hanford Curation Strategy 7.21
7.3.4.3 Locke Island Monitoring 7.22
7.3.5 Education and Research 7.22

7.4 Community-Operated Environmental Surveillance Program 7.23

7.5 Noxious Weed Control Program 7.25
7.5.1 Background 7.25
7.5.2 1998 Noxious Weed Control Activities 7.25

7.6 References 7.29

8.0 Quality Assurance 8.1
8.0.1 Environmental Surveillance and Groundwater Monitoring 8.1
8.0.1.1 Project Management Quality Assurance 8.1
8.0.1.2 Sample Collection Quality Assurance/Quality Control 8.1
8.0.1.3 Analytical Results Quality Assurance/Quality Control 8.2
8.0.1.4 DOE and EPA Comparison Studies 8.3
8.0.1.5 Pacific Northwest National Laboratory Evaluations 8.5
8.0.1.6 Laboratory Internal Quality Assurance Programs 8.7
8.0.1.7 Media Audits and Comparisons 8.9
8.0.2 Effluent Monitoring and Near-Facility Environmental Monitoring 8.9
8.0.2.1 Sample Collection Quality Assurance 8.11
8.0.2.2 Analytical Results Quality Assurance 8.11
8.0.3 References 8.15

Appendix A - Additional Monitoring Results for 1998 ..... A.1
Appendix B - Glossary B.1
Appendix C - Standards and Permits C.1
Appendix D - Dose Calculations D.1

Appendix E - Radionuclides Detected by Gamma Spectroscopy E.1
Appendix F - Threatened and Endangered Species F.1

Figures

H.1 Data Plotted Using a Linear Scale lviii

H.2 Data Plotted Using a Logarithmic Scale lix

H.3 Data With Error Bars Plotted Using a Linear Scale lix

1.0.1 The Hanford Site and Surrounding Area 1.2

1.0.2 Waste Processing, Storage, and Disposal Facilities in the 200 Areas 1.8

3.1.1 Liquid Releases of Selected Radionuclides from Hanford Site Facilities, 1991 Through 1998 ..... 3.4

3.1.2 Airborne Releases of Selected Radionuclides from Hanford Site Facilities, 1991 Through 1998 ..... 3.5

3.2.1 Average Activities of Selected Radionuclides in Near-Facility Air Samples Compared to Those in Distant Communities, 1993 Through 1998 ..... 3.14

3.2.2 Average Activities of Selected Radionuclides in Near-Facility Soil Samples Compared to Those in Distant Communities, 1993 Through 1998 ..... 3.24

3.2.3 Average Activities of Selected Radionuclides in Near-Facility Vegetation Samples Compared to Those in Distant Communities, 1993 Through 1998 ..... 3.29

3.2.4 Average Annual Dose Rate at N Springs 3.34

3.2.5 Annual Average Thermoluminescent Dosimeter Results in the 100-N Area 3.35

3.2.6 Annual Average Thermoluminescent Dosimeter Results in the 200/600 Areas 3.35

3.2.7 Annual Average Thermoluminescent Dosimeter Results in the 300/400 Areas and at the 300 Area Treated Effluent Disposal Facility 3.36

4.0.1 Primary Exposure Pathways 4.4

4.1.1 Air Sampling Locations, 1998 ..... 4.8

4.1.2 Gross Alpha in Airborne Particulate Samples, 1993 Through 1998 ..... 4.14

4.1.3 Gross Beta in Airborne Particulate Samples, 1993 Through 1998 ..... 4.14

4.1.4 Annual Average Strontium-90 Activities in Air, 1993 Through 1998 ..... 4.15

4.1.5 Iodine-129 Activities in Air, 1993 Through 1998 ..... 4.15

4.1.6 Annual Average Plutonium-239,240 Activities in Air, 1993 Through 1998 ..... 4.16

4.1.7 Annual Average Uranium-238 Activities in Air, 1993 Through 1998 ..... 4.16

4.2.1 Water and Sediment Sampling Locations, 1998 ..... 4.20

4.2.2 Mean Monthly Columbia River Flow Rates, 1998 ..... 4.21

4.2.3 Annual Average Gross Alpha Activities in Columbia River Water, 1993 Through 1998 ..... 4.23

4.2.4 Annual Average Gross Beta Activities in Columbia River Water, 1993 Through 1998 ..... 4.23

4.2.5 Annual Average Tritium Activities in Columbia River Water, 1993 Through 1998 ..... 4.24

4.2.6 Annual Average Strontium-90 Activities in Columbia River Water, 1993 Through 1998 ..... 4.24

4.2.7 Annual Average Total Uranium Activities in Columbia River Water, 1993 Through 1998 ..... 4.25

4.2.8 Annual Average Iodine-129 Activities in Columbia River Water, 1993 Through 1998 ..... 4.25

4.2.9 Tritium Activities in Water Samples from Columbia River Transects, September 1998 ..... 4.27

4.2.10 U.S. Geological Survey Columbia River Water Quality Measurements, 1993 Through 1998 ..... 4.28

4.2.11 Median, Maximum, and Minimum Activities of Selected Radionuclides Measured in Columbia and Snake River Sediments, 1993 Through 1998 ..... 4.32

4.2.12 Median, Maximum, and Minimum Activities of Selected Metals Measured in Columbia and Snake River Sediments, 1993 Through 1998 ..... 4.33

4.2.13 Average Acid Volatile Sulfide, Simultaneously Extracted Zinc, Sum of Simultaneously Extracted in Columbia River Sediments for 1997 and 1998 ..... 4.34

4.2.14 Concentrations of Constituents of Interest in Riverbank Springs Water Near the Old Hanford Townsite, 1993 Through 1998 ..... 4.39

4.2.15 Concentrations of Constituents of Interest in 300 Area Riverbank Springs Water, 1993 Through 1998 ..... 4.40

4.2.16 Median, Maximum, and Minimum Gross Beta and Tritium Activities in Fast Flux Test Facility Pond Water Samples, 1993 Through 1998 ..... 4.43

4.2.17 Median, Maximum, and Minimum Activities of Selected Radionuclides in West Lake Water Samples, 1993 Through 1998 ..... 4.44

4.3.1 Hanford Site Primary Drinking Water Supply Facilities, 1998 ..... 4.50

4.3.2 Tritium Activities in Drinking Water from Three Wells in the 400 Area, 1984 Through 1998 ..... 4.53

4.4.1 Food and Farm Product Sampling Locations, 1998 ..... 4.56

4.4.2 Median, Maximum, and Minimum Strontium-90 Activities in Milk, 1993 Through 1998 ..... 4.58

4.4.3 Median, Maximum, and Minimum Iodine-129 Activities in Milk, 1993 Through 1998 ..... 4.58

4.4.4 Median, Maximum, and Minimum Tritium Activities in Wine Samples Collected in 1993 Through 1998 ..... 4.60

4.5.1 Fish and Wildlife Sampling Locations, 1998 ..... 4.62

4.6.1 Soil and Vegetation Sampling Locations, 1998 ..... 4.70

4.6.2 Median, Maximum, and Minimum Radionuclide Activities of Strontium-90, Cesium-137, Plutonium-238, and Plutonium-239,240 in Soil, 1992 Through 1998 ..... 4.73

4.6.3 Median, Maximum, and Minimum Radionuclide Activities of Strontium-90 in Natural Vegetation, 1992 Through 1998 ..... 4.74

4.7.1 Thermoluminescent Dosimeter Locations and Station Numbers on the Hanford Site, 1998 ..... 4.81

4.7.2 Thermoluminescent Dosimeter Locations and Station Numbers for Community, Distant, and Perimeter Sites, 1998 ..... 4.82

4.7.3 Thermoluminescent Dosimeter Locations and Station Numbers on the Columbia River, 1998 ..... 4.83

4.7.4 Annual Average Dose Rates, 1993 Through 1998 ..... 4.86

5.0.1 Locations Important to Dose Calculations 5.3

5.0.2 Calculated Dose to the Hypothetical, Maximally Exposed Individual, 1994 Through 1998 ..... 5.6

5.0.3 Calculated Dose to the Population Within 80 km of the Hanford Site, 1994 Through 1998 ..... 5.9

5.0.4 National Annual Average Radiological Doses from Various Sources 5.10

6.1.1 Active Liquid Wastewater Discharge Sites at Hanford 6.6

6.1.2 Water Supply Wells in the Unconfined Aquifer 6.8

6.1.3 Geologic Cross Section of the Hanford Site 6.9

6.1.4 Saturated Thickness of the Unconfined Aquifer 6.11

6.1.5 Water-Table Elevations for the Unconfined Aquifer at the Hanford Site and in Adjacent Areas East and North of the Columbia River, June 1998 ..... 6.12

6.1.6 Transmissivity Distribution in the Unconfined Aquifer 6.13

6.1.7 Change in Water-Table Elevations Between 1944 and 1979 ..... 6.14

6.1.8 Change in Water-Table Elevations Between 1979 and 1995 ..... 6.15

6.1.9 Change in Water-Table Elevations Between 1997 and 1998 ..... 6.16

6.1.10 Unconfined Aquifer Monitoring Well Locations, 1998 ..... 6.21

6.1.11 Confined Aquifer Monitoring Well Locations, 1998 ..... 6.22

6.1.12 Locations of RCRA Groundwater Monitoring Projects 6.23

6.1.13 Average Tritium Activities in the Unconfined Aquifer, 1998 ..... 6.28

6.1.14 Tritium Activities in Well 199-K-30, 1982 Through 1998 ..... 6.29

6.1.15 Tritium Activities in Well 699-24-33, 1962 Through 1998 ..... 6.31

6.1.16 Tritium Activities in Well 699-40-1, 1963 Through 1998 ..... 6.31

6.1.17 Historical Tritium Activities on the Hanford Site 6.32

6.1.18 Average Tritium Activities and Groundwater Flow Near the 300 Area, 1998 ..... 6.34

6.1.19 Tritium Activities in Well 699-S19-E13, 1983 Through 1998 ..... 6.35

6.1.20 Average Iodine-129 Activities in the Unconfined Aquifer, 1998 ..... 6.37

6.1.21 Average Technetium-99 and Strontium-90 Activities in the Unconfined Aquifer Near the 200-East Area, 1998 ..... 6.39

6.1.22 Average Technetium-99 Activities and Uranium Concentrations in the Unconfined Aquifer in the 200-West Area, 1998 ..... 6.40

6.1.23 Average Uranium Concentrations in the Unconfined Aquifer in the 300 Area, 1998, and Concentration Trends for Select Wells 6.43

6.1.24 Average Strontium-90 Activities in the Unconfined Aquifer in the 100-B,C Area, 1998 ..... 6.44

6.1.25 Average Strontium-90 Activities in the Unconfined Aquifer in the 100-N Area, 1998 ..... 6.46

6.1.26 Average Carbon-14 Activities in the 100-K Area, 1998 ..... 6.48

6.1.27 Average Nitrate Concentrations in the Unconfined Aquifer, 1998 ..... 6.50

6.1.28 Average Filtered Chromium Concentrations in the 100-D and 100-H Areas, 1998, and Concentration Trends for Selected Wells 6.54

6.1.29 Average Filtered Chromium Concentrations in the 100-K Area, 1998 ..... 6.56

6.1.30 Average Carbon Tetrachloride Concentrations in the Unconfined Aquifer in the 200-West Area, 1998 ..... 6.58

6.1.31 Average Chloroform Concentrations in the Unconfined Aquifer in the 200-West Area, 1998 ..... 6.60

6.1.32 Average Trichloroethylene Concentrations in the Unconfined Aquifer in the 200-WestArea, 1998 ..... 6.61

6.1.33 Average Trichloroethylene Concentrations in the Vicinity of the Former Horn Rapids Landfill and Richland North Area, 1998 ..... 6.63

6.1.34 Average Tetrachloroethylene Concentrations in the 300 Area, 1998 ..... 6.64

6.1.35 Tritium and Other Contaminants Detected in Confined Aquifer Wells, 1998 ..... 6.66

6.2.1 Plan View of BX Tank Farm with Monitoring Boreholes 6.78

6.2.2 Example of a Radionuclide Concentration Log 6.79

6.2.3 Comparison of Cesium-137 Concentrations from Log Runs 6 Through 12 in Borehole 41-09-39, 200-West Area 6.82

6.2.4 Vadose Zone Contamination at the BX Tank Farm, 200-East Area 6.84

6.2.5 Vadose Zone Contamination at the C Tank Farm, 200-East Area 6.85

6.2.6 Vadose Zone Contamination at the S Tank Farm, 200-West Area 6.86

6.2.7 Location of Boreholes Logged at the 216-Z-1A Tile Field, 216-Z-9 Trench, and 216-Z-12 Crib, 200-West Area 6.88

6.2.8 Locations of the Immobilized Low-Activity Waste Site and Characterization Boreholes 299-E17-21, B8501, and B8502, 200-East Area 6.92

6.2.9 Distribution of Technetium-99 and Cesium-137 in the Vadose Zone Sediments from Depth and the Water Extractable Nitrate Concentrations from Borehole 41-09-39, SX Tank Farm, 200-West Area 6.97

6.2.10 Location of the 216-B-2 Ditch System, 200-East Area 6.99

6.2.11 Location of Wells and Deep Soil-Vapor Monitoring Probes at the Carbon Tetrachloride Vapor-Extraction Site, 200-West Area 6.102

6.2.12 Locations of Shallow Soil-Vapor Monitoring Probes at the Carbon Tetrachloride Vapor-Extraction Site, 200-West Area 6.103

6.2.13 Time-Series Concentration of Carbon Tetrachloride in Soil Vapor Extracted from the 216-Z-1A/-12/-18 Well Fields, 200-West Area 6.105

6.2.14 Conceptual Model of Carbon Tetrachloride and Wastewater Migration Beneath 216-Z-9 Trench, 200-West Area 6.108

6.2.15 Example Analysis of Historical Gross Gamma-Ray Logs from Borehole 41-00-08 in the SX Tank Farm 6.110

7.1.1 Hanford Meteorological Monitoring Network Wind Roses, 1998 ..... 7.4

7.2.1 Chinook Salmon Spawning Redds in the Hanford Reach, 1948 Through 1998 ..... 7.8

7.2.2 Bald Eagles Observed Along the Hanford Reach, 1961 Through 1998 ..... 7.9

7.2.3 Elk on the Hanford Site: Post-Calving and Post-Hunting Periods, 1975 Through 1998 ..... 7.10

7.2.4 Median Number of Fawns Observed per 100 Adult Does During Roadside Surveys, 1993 Through 1998 ..... 7.12

7.2.5 Rare Plant Locations on the Hanford Site Based on 1994, 1995, 1997, and 1998 Surveys Conducted by The Nature Conservancy of Washington 7.13

7.3.1 Cultural Resource Reviews Requested Each Calendar Year 7.19

7.3.2 Historic Sites are Commonly Found During Surveys Conducted at the Hanford Site 7.19

7.3.3 1948 Aerial Photograph of the Former 1100 Area Showing Irrigated Farms and Hanford Development 7.19

7.3.4 Hanford Buildings and Structures Documented with a Washington State Historic Property Inventory Form 7.20

7.3.5 105-C Reactor, One of Several Structures Included in the Hanford Site Manhattan Project and Cold War Era Historic District 7.21

7.4.1 Community Members See Environmental Surveillance in Action at a Community-Operated Environmental Surveillance Station in Richland 7.23

Tables

H.1 Names and Symbols for Units of Measure liii

H.2 Conversion Table liv

H.3 Names and Symbols for Units of Radioactivity liv

H.4 Names and Symbols for Units of Radiation Dose or Exposure lv

H.5 Radionuclides and Their Half-Lives lvi

H.6 Elemental and Chemical Constituent Nomenclature lvii

2.2.1 Emergency Planning and Community Right-To-Know Act Compliance Reporting, 1998 ..... 2.16

2.2.2 RCRA Interim- and Final-Status Groundwater Monitoring Projects, as of September 1998 ..... 2.17

2.2.3 RCRA Well Installation Summary, 1998 ..... 2.20

2.5.1 Quantities of Solid Wastes Generated on the Hanford Site 2.72

2.5.2 Quantities of Solid Wastes Received from Offsite 2.72

2.5.3 Quantities of Hazardous Wastes Shipped Offsite 2.72

2.5.4 Radioactive Solid Wastes Stored or Disposed of on the Hanford Site, 1998 ..... 2.73

2.5.5 Quantities of Bulk Liquid Wastes Generated and Stored on the Hanford Site in 1998 and in Each of the Previous 5 Years 2.74

2.5.6 Average Balance of 10 Hazardous Chemicals Stored in Greatest Quantity on the Hanford Site, 1998 ..... 2.74

3.1.1 Radionuclides Discharged to the Atmosphere, 1998 ..... 3.7

3.1.2 Nonradioactive Constituents Discharged to the Atmosphere, 1998 ..... 3.8

3.1.3 Radionuclides in 200 Areas' Liquid Effluents Discharged to the State-Approaved Land Disposal Site in 1998 ..... 3.9

3.1.4 Radionuclides in 100 Areas' Liquid Effluents Discharged to the Columbia River, 1998 ..... 3.9

3.1.5 Reportable Spills, 1998 ..... 3.10

3.2.1 Near-Facility Routine Environmental Monitoring Samples and Locations, 1998 ..... 3.12

3.2.2 Near-Facility Air Sampling Locations and Analyses, 1998 ..... 3.13

3.2.3 Annual Average and Maximum Activities of Radionuclides in Near-Facility Air Samples, 1998 ..... 3.15

3.2.4 Radiological Results for Liquid Samples from a Surface-Water Disposal Unit, 200 Areas, 1998 ..... 3.18

3.2.5 Radiological Results for Aquatic Vegetation Samples from Surface-Water Disposal Units, 200 Areas, 1998 ..... 3.19

3.2.6 Radiological Results for Sediment Samples from Surface-Water Disposal Units, 200 Areas, 1998 ..... 3.19

3.2.7 Radionuclides Activities in 100-N Area Riverbank Springs, 1998 ..... 3.20

3.2.8 Nonradiological Results for Water Samples from a Surface-Water Disposal Unit, 200 Areas, 1998 ..... 3.20

3.2.9 Outdoor Contamination Status, 1998 ..... 3.21

3.2.10 Zone Status Change of Posted Contamination Areas, 1998 ..... 3.22

3.2.11 Average Radionuclide Activities Detected in Surface Soil Samples Near the 1301-N Liquid Waste Disposal Facility, 1993 Through 1998 ..... 3.25

3.2.12 Average Radionuclide Activities Detected in 100-N Area Surface Soil Samples, 1993 Through 1998 ..... 3.26

3.2.13 Activities of Selected Radionuclides in 100-N Area Soils, 1998 ..... 3.26

3.2.14 Activities of Selected Radionuclides in 200/600 Areas Soils, 1998 ..... 3.27

3.2.15 Activities of Selected Radionuclides in 300/400 Areas Soils, 1998 ..... 3.27

3.2.16 Average Radionuclide Activities Detected in Vegetation Samples Collected Near the 1301-N Liquid Waste Disposal Facility, 1993 Through 1998 ..... 3.30

3.2.17 Average Radionuclide Activities Detected in 100-N Area Vegetation Samples, 1993 to 1998 ..... 3.30

3.2.18 Average Radionuclide Activities Detected in N Springs Vegetation Samples, 1993 to 1998 ..... 3.31

3.2.19 Activities of Selected Radionuclides in 100-N Area Vegetation, 1998 ..... 3.31

3.2.20 Activities of Selected Radionuclides in 200/600 Areas Vegetation, 1998 ..... 3.32

3.2.21 Activities of Selected Radionuclides in 300/400 Areas Vegetation, 1998 ..... 3.32

3.2.22 Thermoluminescent Dosimeter Results for Waste Handling Facilities, 1997 and 1998 ..... 3.33

4.0.1 Routine Environmental Surveillance Sample Types and Measurement Locations, 1998 ..... 4.6

4.1.1 Air Sampling Locations, Sample Composite Groups, and Analyses, 1998 ..... 4.9

4.1.2 Airborne Radionuclide Activities in the Hanford Environs, 1998 Compared to Previous Years 4.11

4.2.1 Surface-Water Surveillance, 1998 ..... 4.18

4.2.2 Sediment Surveillance, 1998 ..... 4.19

4.2.3 Selected Radionuclide Activities in 100-N Area Riverbank Springs Water, 1993 Through 1998 ..... 4.37

4.2.4 Activity Ranges of Selected Nonradiological Chemicals in Riverbank Springs, 1993 Through 1998 ..... 4.41

4.3.1 DOE-Owned Drinking Water Systems on the Hanford Site, 1998 ..... 4.48

4.3.2 Selected Radiological Constituents in Hanford Site Drinking Water, 1998 Annual Average Activities 4.51

4.3.3 Tritium Activities in 400 Area Drinking Water Wells, 1998 ..... 4.52

4.4.1 Locations, Sampling Frequencies, and Analyses Performed for Routinely Sampled Food and Farm Products, 1998 ..... 4.57

4.5.1 Locations, Species, and Contaminants Sampled for Fish and Wildlife, 1998 ..... 4.63

4.5.2 Cesium-137 and Strontium-90 Activities in Columbia River Carp and Suckers, 1998 Compared to Previous 8 Years 4.64

4.5.3 Activities of Selected Radionuclides in Deer and Elk, 1998 Compared to Previous 8 Years 4.66

4.5.4 Activities of Selected Radionuclides in Upland Game, 1998 Compared to Previous 8 Years 4.67

4.6.1 Routine Soil and Vegetation Samples Collected and Analyzed, 1998 ..... 4.71

4.6.2 Comparison of Strontium-90, Cesium-137, and Plutonium-239,240 Activities in Soils at Remote Locations with Site Background Observed On and Offsite Concentrations 4.72

4.6.3 Radionuclide Activities in Shoreline Vegetation, 1998 Compared to 1990-1992 ..... 4.75

4.6.4 Classification of Trace Metal Concentrations in Onsite Fruit Tree Samples Collected in 1997 and 1998 Compared to Nominal Background and Nominal Toxic Reference Concentrations 4.76

4.6.5 Tritium in Fruit Tree Samples Collected from the Hanford Site, 1997 and 1998 ..... 4.77

4.6.6 Strontium-90 Activities in Fruit Tree Samples Collected from the Hanford Site, 1997 and 1998 ..... 4.78

4.7.1 Dose Rates Measured by Thermoluminescent Dosimeters at Perimeter and Offsite Locations, 1998 Compared to Previous 5 Years 4.84

4.7.2 Dose Rates Measured by Thermoluminescent Dosimeters Along the Hanford Reach of the Columbia River, 1998 Compared to Previous 5 Years 4.85

4.7.3 Dose Rates Measured by Thermoluminescent Dosimeters on the Hanford Site, 1998 Compared to Previous 5 Years 4.85

4.7.4 Average Exposure Rates Measured by Pressurized Ionization Chambers at Four Offsite Locations, 1998 ..... 4.88

4.7.5 Quarterly Average Exposure Rates Measured by Thermoluminescent Dosimeters at Four Offsite Locations, 1998 ..... 4.89

5.0.1 Dose to the Hypothetical, Maximally Exposed Individual Residing at Sagemoor from 1998 Hanford Operations 5.5

5.0.2 Dose to the Population from 1998 Hanford Operations 5.9

5.0.3 Summary of Doses to the Public in the Vicinity of the Hanford Site from Various Sources, 1998 ..... 5.10

5.0.4 Estimated Risk from Various Activities and Exposures 5.12

5.0.5 Activities Comparable in Risk to the 0.02-mrem Dose Calculated for the 1998 Maximally Exposed Individual 5.13

6.1.1 Chemical and Radiological Groundwater Contaminants and Their Link to Site Operations 6.18

6.1.2 Hanford Site Well Naming System 6.24

6.1.3 Radionuclides and Chemicals Analyzed for in Groundwater, 1998 ..... 6.25

6.2.1 Conservative and Best Estimates of Distribution Coefficient Values of Units 1, 2, and 3 at Borehole 299-E17-21, 200-East Area 6.94

6.2.2 Conservative and Best Estimates of Distribution Coefficient Values for the Hanford Formation at Borehole 299-E17-21, 200-East Area 6.95

6.2.3 Carbon Tetrachloride Inventory in Primary Disposal Sites, 200-West Area 6.106

7.1.1 Monthly Climatological Data from the Hanford Meteorology Station, 1998 ..... 7.6

7.2.1 Numbers of *Rorippa Columbiae* Stems Counted Along the Hanford Reach of the Columbia River, 1994 and 1998 ..... 7.14

7.2.2 Decline of Shrub Conditions Measured Along Six Transects Within and Along the Boundaries of the Sagebrush Die-Off Area on the Hanford Site 7.15

8.0.1 Summary of Surface Environmental Surveillance Project Field Duplicate Results, 1998 ..... 8.2

8.0.2 Summary of Performance on EPA Water Pollution and Water Supply Studies, 1998 ..... 8.3

8.0.3 Summary of Performance on DOE Quality Assessment Program Samples, 1998 ..... 8.4

8.0.4 Summary of Performance on EPA Laboratory Intercomparison Studies Samples, 1998 ..... 8.5

8.0.5 Summary of Hanford Groundwater Monitoring Project Double-Blind Spike Determinations, 1998 ..... 8.6

8.0.6 Summary of Surface Environmental Surveillance Project Blind Spiked Determinations, 1998 ..... 8.7

8.0.7 Comparison of the Quality Assurance Task Force Intercomparison Well Water Sample, 1998 ..... 8.8

8.0.8 Comparison of U.S. Food and Drug Administration Cosampling, 1998 ..... 8.10

8.0.9 Comparison of Thermoluminescent Dosimeter Results with Known Exposure, 1998 ..... 8.10

8.0.10 Hanford Site Laboratories Used by Contractor and Sample Type, 1998 ..... 8.11

8.0.11 Waste Sampling and Characterization Facility Performance on DOE Quality Assessment Program Samples, 1998 ..... 8.12

8.0.12 222-S Analytical Laboratory Performance on DOE Quality Assessment Program Samples, 1998 ..... 8.13

8.0.13 Waste Sampling and Characterization Facility Performance on EPA Laboratory Intercomparison Studies Samples, 1998 ..... 8.13

8.0.14 222-S Analytical Laboratory Performance on EPA Laboratory Intercomparison Studies Samples, 1998 ..... 8.14

A.1 Radionuclide Activities in Columbia River Water at Priest Rapids Dam, 1998 Compared to Previous 5 Years A.2

A.2 Radionuclide Activities in Columbia River Water at the Richland Pumphouse, 1998 Compared to Previous 5 Years A.3

A.3 Radionuclide Activities Measured in Columbia River Water Along Transects of the Hanford Reach, 1998 ..... A.4

A.4 Selected U.S. Geological Survey Columbia River Water Quality Data, 1998 ..... A.5

A.5 Radionuclide Activities in Sediments from the Columbia and Snake Rivers and from Columbia River Shoreline Springs, 1998 Compared to Previous 5 Years A.6

A.6 Median Metal Concentrations in Columbia and Snake River Sediments, 1998 ..... A.9

A.7 Radionuclide Activities Measured in Riverbank Springs Water, 1998 Compared to Previous 5 Years A.10

A.8 Activities of Selected Radionuclides in Soil, 1998 Compared to Previous 6 Years A.12

A.9 Radionuclide Activities in Soil Collected from the Fitzner-Eberhardt Arid Lands Ecology Reserve A.13

A.10 Activities of Selected Radionuclides in Vegetation, 1998 Compared to Previous 6 Years A.14

A.11 Metal Concentrations in Hanford Site Fruit Tree Samples, 1997 and 1998 ..... A.15

C.1 Washington State Water Quality Standards for the Hanford Reach of the Columbia River C.2

C.2 Selected Drinking Water Standards C.3

C.3 Selected Surface Freshwater Quality Criteria for Toxic Pollutants C.4

C.4 Radiation Standards for Protection of the Public from All Routine DOE Activities C.5

C.5 Selected Derived Concentration Guides C.6

C.6 Environmental Permits C.7

D.1 Food Pathway Parameters Used in Dose Calculations, 1998 ..... D.4

D.2 Dietary Parameters Used in Dose Calculations, 1998 ..... D.5

D.3 Residency Parameters Used in Dose Calculations, 1998 ..... D.5

D.4 Recreational Parameters Used in Dose Calculations, 1998 ..... D.6

D.5 Technical Details of 100 Areas Airborne Release Dose Calculations, 1998 ..... D.6

D.6 Technical Details of 100-N Area Liquid Release Dose Calculations, 1998 ..... D.7

D.7 Technical Details of 200 Areas Airborne Release Dose Calculations, 1998 ..... D.8

D.8 Technical Details of 300 Area Airborne Release Dose Calculations, 1998 ..... D.9

D.9 Technical Details of 400 Area Airborne Release Dose Calculations, 1998 ..... D.10

D.10 Annual Dose to Workers in the 400 Area from Ingestion of Drinking Water Obtained from Groundwater Wells D.11

D.11 Annual Dose to Workers in the 300 Area from Ingestion of Drinking Water Obtained from the Columbia River D.12

E.1 Radionuclides Analyzed by Gamma Spectroscopy E.1

F.1 Federal- or Washington State-Listed Threatened and Endangered Species Occurring or Potentially Occurring on the Hanford Site F.2

F.2 Washington State Candidate Animal Species Potentially Found on the Hanford Site F.3

F.3 Washington State Plant Species of Concern Occurring on the Hanford Site F.4

Summary

This Hanford Site environmental report is prepared annually to summarize environmental data and information, to describe environmental management performance, to demonstrate the status of compliance with environmental regulations, and to highlight major environmental programs and efforts.

The report is written to meet requirements and guidelines of the U.S. Department of Energy (DOE) and to meet the needs of the public. This summary has been written with a minimum of technical terminology.

Individual sections of the report are designed to

- describe the Hanford Site and its mission
- summarize the status of compliance with environmental regulations
- describe the environmental programs at the Hanford Site
- discuss the estimated radionuclide exposure to the public from 1998 Hanford Site activities
- present the effluent monitoring, environmental surveillance, and groundwater protection and monitoring information
- discuss the activities to ensure quality.

More detailed information can be found in the body of the report, the cited references, and the appendixes.

The Hanford Site and its Mission

The Hanford Site in southcentral Washington State is approximately 1,450 km^2 (560 mi^2) of semi-arid shrub and grasslands located just north of the confluence of the Snake and Yakima Rivers with the Columbia River. This land, with restricted public access, provides a buffer for the smaller areas historically used for the production of nuclear materials, waste storage, and waste disposal. Approximately 6% of the land area has been disturbed, is actively used, and is divided into operational areas:

- the 100-B,C, 100-D, 100-F, 100-H, 100-K, and 100-N Areas, which lie along the south shore of the Columbia River in the northern portion of the Hanford Site (containing reactors used primarily for plutonium production; now all shut down)
- the 200-East and 200-West Areas, which lie in the center of the Hanford Site near the basalt outcrops of Gable Mountain and Gable Butte (formerly used for plutonium processing; now focused on waste management)
- the 300 Area, near the southern border of the Hanford Site (containing laboratories, support facilities, and former reactor fuel manufacturing facilities)
- the 400 Area, between the 300 and 200 Areas (home of the Fast Flux Test Facility)
- the Richland North Area, in the northern part of the city of Richland (includes leased office buildings for DOE and its contractors).

The 600 Area is the designation for land between the operational areas. Areas off the Hanford Site used for research and technology development and administrative functions can be found in Richland, Kennewick, and Pasco, the nearest cities.

The Hanford Site was acquired by the federal government in 1943 and, until 1989, was dedicated primarily to the production of plutonium for national defense and the management of the resulting wastes. With the shutdown of the production facilities in the 1970s and 1980s, missions were diversified to include

research and development in the areas of energy, waste management, and environmental restoration.

DOE has ended the production of nuclear materials for weapons at the Hanford Site. The current mission being implemented by DOE Richland Operations Office is now:

- waste management, environmental restoration, and facilities stabilization
- research and technology development.

Current waste management activities at the Hanford Site include primarily managing wastes with high and low levels of radioactivity (from the nuclear materials production activities) in the 200-East and 200-West Areas. Key waste management facilities include the underground waste storage tanks, Environmental Restoration Disposal Facility, Central Waste Complex, low-level burial grounds, 200 Areas Effluent Treatment Facility, Waste Receiving and Processing Facility, 242-A Evaporator, State-Approved Land Disposal Site, Liquid Effluent Retention Facility, and 200 Areas Treated Effluent Disposal Facility. In addition, irradiated nuclear fuel is stored in the 100-K Area in fuel storage basins.

Environmental restoration includes activities to decontaminate and decommission facilities and to clean up or restore inactive waste sites. The Hanford surplus facilities program conducts surveillance and maintenance of such facilities; the cleanup and disposal of more than 100 facilities have begun.

Research and technology development activities are intended to improve the techniques and reduce the costs of waste management, environmental protection, and site restoration.

Operations and activities on the site are managed by DOE Richland Operations Office through four prime contractors and numerous subcontractors. Each contractor is responsible for the safe, environmentally sound maintenance and management of its facilities and operations, management of its wastes, and monitoring of its operations and effluents for environmental compliance.

The principal contractors include the following:

- Fluor Daniel Hanford, Inc.
- Battelle Memorial Institute
- Bechtel Hanford, Inc.
- Hanford Environmental Health Foundation
- MACTEC-ERS.

Non-DOE operations and activities include commercial power production by Energy Northwest (formerly known as the Washington Public Power Supply System) at its WNP-2 Reactor and operation of a commercial low-level radioactive waste burial site by US Ecology, Inc. Kaiser Aluminum and Chemical Corporation leases the 313 Building to operate a formerly DOE-owned extrusion press. The National Science Foundation has built the Laser Interferometer Gravitational-Wave Observatory facility near Rattlesnake Mountain. R. H. Smith Distributing operates vehicle fueling stations in the former 1100 Area and the 200 Areas. Washington State University at Tri-Cities operates three laboratories in the 300 Area. Livingston Rebuild Center, Inc. leases the former 1171 Building in the former 1100 Area to rebuild train locomotives. Johnson Controls, Inc. operates 42 diesel and natural gas fueled package boilers for producing steam in the 200 and 300 Areas and also has compressors supplying compressed air to the site. Immediately adjacent to the southern boundary of the Hanford Site, Siemens Power Corporation operates a commercial nuclear fuel fabrication facility and Allied Technology Group Corporation operates a low-level radioactive waste decontamination, supercompaction, and packaging disposal facility.

Compliance with Environmental Regulations

DOE Order 5400.1, "General Environmental Protection Program," describes the environmental standards and regulations applicable at DOE facilities. These standards and regulations fall into three categories: 1) DOE directives; 2) federal legislation and executive orders; and 3) state and local statutes, regulations, and requirements. The following summarizes the status of Hanford's compliance with applicable regulations and lists the environmental occurrences for 1997.

A key element in Hanford's compliance program is the Hanford federal facility agreement and consent order (also known as the Tri-Party Agreement; Ecology et al. 1989). The Tri-Party Agreement is an agreement among the U.S. Environmental Protection Agency (EPA), Washington State Department of Ecology, and DOE for achieving compliance with the remedial action provisions of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA 1980) and with treatment, storage, and disposal unit regulation and corrective action provisions of the Resource Conservation and Recovery Act (RCRA 1976). From 1989 through 1998, a total of 597 enforceable Tri-Party Agreement milestones and 246 unenforceable target dates were completed on or ahead of schedule. Fifty-eight milestones scheduled for 1998 were completed.

Comprehensive Environmental Response, Compensation, and Liability Act

This act established a program to ensure that sites contaminated by hazardous substances are cleaned up by responsible parties or the government. The act primarily covers waste cleanup of inactive sites.

Preliminary assessments conducted for the Hanford Site revealed approximately 2,200 known individual waste sites where hazardous substances may have been disposed of in a manner that requires further evaluation to determine impact to the environment.

The DOE is actively pursuing the remedial investigation/feasibility study process at some operable units on the Hanford Site. The operable units currently being studied were selected as a result of Tri-Party Agreement negotiations.

In 1998, the Hanford Site was in compliance with requirements of the act. Cleanup is under way at various areas on the site. Full-scale remediation of waste sites continued in the 100 and 300 Areas in 1998.

Emergency Planning and Community Right-To-Know Act

This act requires that the public be provided with information about hazardous chemicals in the community and establishes emergency planning and notification procedures to protect the public from a release. The act calls for creation of state emergency response commissions to guide planning for chemical emergencies. State commissions have also created local emergency planning committees to ensure community participation and planning.

To provide the public with the basis for emergency planning, the act contains requirements for periodic reporting on hazardous chemicals stored and/or used near the community. The 1998 Hanford Site's emergency and hazardous chemical inventory was issued to the State Emergency Response Commission, local county emergency management committees, and local fire departments in February 1999. The inventory report contained information on hazardous materials in storage across the site. If required, a toxic chemical release inventory report is issued each year, which provides details regarding releases,

offsite transfers, and source reduction activities involving any toxic chemicals used in excess of regulatory thresholds during the previous year. Reporting thresholds for phosphoric acid were exceeded in 1997, so a report was issued in June 1998. During 1998, the Hanford Site was in compliance with the reporting and notification requirements contained in this act.

Resource Conservation and Recovery Act

This act establishes regulatory standards for the generation, transportation, storage, treatment, and disposal of hazardous wastes. The Washington State Department of Ecology has been authorized by EPA to implement its dangerous waste program except for some provisions of the Hazardous and Solid Waste Amendments of 1984. The Washington State Department of Ecology implements the state's regulations, which are often more stringent. The act primarily covers ongoing waste management at active facilities.

At the Hanford Site, over 60 treatment, storage, and disposal units have been identified that must be permitted or closed in accordance with the act and Washington State regulations. These units are required to operate under the Washington State Department of Ecology's interim-status compliance requirements. Approximately one-half of the units will be closed.

Subtitle I of the act deals with regulation of underground storage tank systems. These regulations were added to the act by the Hazardous and Solid Waste Amendments of 1984. EPA developed regulations implementing technical standards for tank performance and management, including standards governing the cleanup and closure of leaking tanks. These regulations do not apply to the single- and double-shell tanks, which are regulated as treatment, storage, and disposal facilities.

Clean Air Act

The purpose of this act is to protect public health and welfare by safeguarding air quality, bringing polluted air into compliance, and protecting clean air from degradation. In Washington State, the provisions of the act are implemented by EPA, Washington State Department of Ecology, Washington State Department of Health, and local air authorities.

Washington State regulations require applicable controls and annual reporting of all radioactive air emissions. The Hanford Site operates under a license for such emissions. The conditions specified in the license will be incorporated into the Hanford Site air operating permit, scheduled to be issued in 1999.

Revisions to the act for radioactive air emissions were issued in December 1989. Emissions from the Hanford Site are within the state and EPA offsite emissions standard of 10 mrem/yr. Nearly all Hanford Site sources currently meet the procedural requirements for flow measurement, emissions measurement, quality assurance, and sampling documentation.

The local air authority (the Benton Clean Air Authority) regulations pertain to detrimental effects, open burning, odor, opacity, and asbestos handling. The authority has also been delegated responsibility to enforce the EPA asbestos regulations under the revised act. The site remains in compliance with the regulations.

Clean Water Act

This act applies to point discharges to waters of the United States. At the Hanford Site, the regulations are applied through National Pollutant Discharge Elimination System permits that govern effluent discharges to the Columbia River. The permits specify discharge points (called outfalls),

effluent limitations, and monitoring requirements. Several permit violations occurred at the 300 Area Treated Effluent Disposal Facility in 1998 despite the use of best available technology. An application to modify the facility's discharge permit has been submitted.

Safe Drinking Water Act

The National Primary Drinking Water Regulations of the Safe Drinking Water Act apply to the drinking water supplies at the Hanford Site and are enforced by the Washington State Department of Health. In 1998, all Hanford Site water systems were in compliance with requirements and agreements.

Toxic Substances Control Act

The application of this act's requirements to the Hanford Site involves regulation of the chemicals called polychlorinated biphenyls. The site is currently in compliance with an agreement to store these wastes beyond the regulatory limit. All radioactive polychlorinated biphenyl wastes are being stored pending development of treatment and disposal technologies and capabilities.

Federal Insecticide, Fungicide, and Rodenticide Act

EPA is responsible for ensuring that a chemical, when used according to label instructions, will not present unreasonable risks to human health or the environment. This act and specific chapters of the Revised Code of Washington apply to storage and use of pesticides. In 1998, the Hanford Site was in compliance with these requirements.

Endangered Species Act

Many rare species of native plants and animals are known to occur on the Hanford Site. Three of these (bald eagle, peregrine falcon, and Aleutian Canada goose) are listed by the U.S. Fish and Wildlife Service as endangered or threatened. Steelhead trout and spring chinook salmon are listed by the National Marine Fisheries Service. Other species are listed by the Washington State Department of Fish and Wildlife as endangered, threatened, or sensitive. Hanford Site activities complied with this act in 1998.

National Historic Preservation Act, Archaeological Resources Protection Act, Native American Graves Protection and Repatriation Act, and American Indian Religious Freedom Act

Cultural resources on the Hanford Site are subject to the provisions of these acts. In 1998, the Hanford Site was in compliance with these acts.

National Environmental Policy Act

This act establishes environmental policy to prevent or eliminate damage to the environment and to enrich our understanding of ecological systems and natural resources. This act requires that major federal projects with significant impacts be carefully reviewed and reported to the public in environmental impact statements. Other documents such as environmental assessments are also prepared in accordance with requirements of the act.

Several environmental impact statements related to programs or activities on the Hanford Site are in process or in the planning stage.

Environmental Occurrences

Onsite and offsite environmental occurrences (spills, leaks) of radioactive and nonradioactive effluent materials during 1998 were reported to DOE and other federal and state agencies as required by law. All emergency, unusual, and off-normal occurrence reports, including event descriptions and corrective actions, are available for review in the DOE Hanford

Reading Room located on the campus of Washington State University at Tri-Cities, Richland, Washington. There was one emergency occurrence report and one environmentally significant unusual occurrence report filed in 1998. There were several off-normal environmental release-related occurrence reports filed during 1998.

Environmental Management Services

At the Hanford Site, contractors are in the process of implementing Integrated Environment, Health, and Safety Management Systems. These systems, contractually mandated by DOE, are intended to integrate environment, health, and safety into the way work is planned and performed, protecting the worker, public, and environment. The Integrated Environment, Health, and Safety Management System includes important aspects of an environmental management system. The international standard ISO 14001 for environmental management systems has been used to develop the system. Implementation of the Integrated Environment, Health, and Safety Management System constitutes implementation of the environmental management system. Current DOE direction calls for implementation of the Integrated Environment, Health, and Safety Management System by September 2000.

Waste Management and Chemical Inventories

Radioactive, hazardous, and mixed waste is generated at approximately 200 facilities on the Hanford Site. These wastes are handled and prepared for safe storage on the site or shipped off the site for treatment and disposal. In addition to newly generated waste, significant quantities of waste remain from over 50 yr of nuclear material production. This waste from past operations at the Hanford Site resides in waste sites or is stored in several places awaiting cleanup and ultimate safe storage or disposal. Examples are high-level radioactive waste stored in single- and double-shell tanks and transuranic waste stored in vaults and on storage pads. Most of the environmental monitoring performed at the Hanford Site is focused on protecting the public from exposure to this waste and waste handling activities. See Section 2.5, "Waste Management and Chemical Inventories," for details.

Environmental Monitoring Information

Environmental monitoring of the Hanford Site consists of effluent monitoring, environmental surveillance, and groundwater and vadose zone monitoring. Effluent monitoring is performed as appropriate by the operators at the facility or at the point of release to the environment. Additional monitoring is conducted in the environment near facilities that discharge, or have discharged, effluents. Environmental surveillance consists of sampling and analyzing environmental media on and off the site to detect and quantify potential contaminants and to assess their environmental and human health significance.

The overall objectives of the monitoring and surveillance programs are to demonstrate compliance with applicable federal, state, and local regulations; confirm adherence to DOE environmental protection policies; and support environmental management decisions.

Effluent Monitoring

Effluent monitoring includes facility effluent monitoring (monitoring effluents at the point of release to the environment) and near-facility environmental monitoring (monitoring the environment near operating facilities).

Facility Effluent Monitoring. Liquid and gaseous effluents that may contain radioactive and/or hazardous constituents are continually monitored at the Hanford Site. The monitoring is done mainly by collecting effluent samples near points where the effluent is released into the environment. These samples are analyzed for selected constituents and the results evaluated against federal, state, and local regulatory standards and permit requirements.

Effluent stream flows are determined mostly through the use of measuring instruments, with a lesser number calculated using process information. Effluents with the potential of containing radioactivity that may reach prescribed threshold levels are monitored for gross alpha and gross beta activity and, as warranted, specific gamma-emitting radionuclides. When warranted, nonradioactive hazardous constituents are also monitored.

The radioactivity in effluents released from most Hanford facilities is at or near levels practically indistinguishable from naturally occurring radioactivity present everywhere in the world. Cumulatively, these low levels contribute very little to the radiation dose received by people living in areas surrounding the site.

Near-Facility Environmental Monitoring. The near-facility environmental monitoring program is designed to protect the environment adjacent to Hanford facilities and to ensure compliance with federal, state, and local regulations. Specifically, this program monitored new and existing sites, processes, and facilities for potential impacts and releases; fugitive emissions and diffuse sources from contaminated areas; and surplus facilities before decontamination or decommissioning. Air, surface water, springs, surface contamination, soil, vegetation, external radiation, and investigative sampling (which can include wildlife) were sampled. Some of the parameters typically monitored are pH, radionuclide activities, radiation exposure levels, and concentrations of selected hazardous chemicals. Samples are collected from known or expected effluent pathways. These pathways are generally downwind of potential or actual airborne releases and downgradient of liquid discharges.

Near-Facility Air Monitoring. Radioactivity in air was sampled by a network of continuously operating samplers at 71 locations near nuclear facilities. Air samplers were primarily located within approximately 500 m (1,500 ft) of sites and/or facilities having the potential for, or history of, environmental releases, with an emphasis on the prevailing downwind directions. Of the radionuclide analyses performed, strontium-90, cesium-137, plutonium-239,240, and uranium were consistently detected in the 100-K, 100-N, and 200 Areas. Cobalt-60 was consistently detected in the 100-N Area. Air levels for these radionuclides were elevated near facilities compared to the levels measured off the site.

Surface-Water Disposal Units and 100-N Springs Monitoring. Samples collected from surface-water disposal units (ponds, ditches) included water, sediment, and aquatic vegetation. Only water samples were taken at 100-N Area shoreline springs. Radiological analyses of water samples from surface-water disposal units included strontium-90, plutonium-238, plutonium-239,240, uranium, tritium, and gamma-emitting radionuclides. Radiological analyses of sediment and aquatic vegetation samples were performed for strontium-90, plutonium-239,240, uranium, and gamma-emitting radionuclides. Nonradiological analyses were performed for pH, temperature, and nitrates.

When liquid samples from surface-water disposal units in the 200 Areas were analyzed for radionuclides, the results were less than the DOE derived concentration guides and, in most cases, were equal to or less than the analytical detection limits. Although some elevated levels were seen in both aquatic vegetation and sediment, in all cases, the analytical results were much less than the standards used for radiological control. The results for pH were well within the 2.0

to 12.5 pH standard for liquid effluent discharges based on the discharge limits listed in the Resource Conservation and Recovery Act. The analytical results for nitrates were all less than the 45-mg/L EPA drinking water standard for public water supplies.

Groundwater springs along the 100-N Area shoreline are sampled annually to verify the reported radionuclide releases to the Columbia River from past N Reactor operations. By characterizing the radionuclide activities in the springs along the shoreline, the results can be compared to the activities measured at the facility effluent monitoring well. In 1998, the radionuclide activities detected in samples from shoreline springs were highest in springs nearest the effluent monitoring well.

Near-Facility Radiological Surveys. In 1998, there were approximately 3,641 ha (8,997 acres) of posted outdoor contamination areas and 587 ha (1,450 acres) of posted underground radioactive materials areas, not including active facilities, at the Hanford Site. These areas were typically associated with burial grounds, covered ditches, cribs, and tank farms. The posted contamination areas vary between years because of an ongoing effort to clean, stabilize, and remediate areas of known contamination. During this time, new areas of contamination were being identified. It was estimated that the external dose rate at 80% of the identified outdoor contamination areas was less than 1 mrem/h measured at 1 m (3.28 ft), though direct dose rate readings from isolated radioactive specks (a diameter of less than 0.6 cm [0.25 in.]) could have been considerably higher. Contamination levels of this magnitude did not significantly add to dose rates for the public or Hanford Site workers in 1998.

Soil and Vegetation Sampling from Operational Areas. Soil and vegetation samples were collected on or adjacent to waste disposal units and from locations downwind and near or within the boundaries of the operating facilities. Samples were collected to detect potential migration and deposition of facility effluents. Special samples were also taken where physical or biological transport problems were identified. Migration can occur as the result of resuspension from radioactively contaminated surface areas, absorption of radionuclides by the roots of vegetation growing on or near underground and surface-water disposal units, or by waste site intrusion by animals. Some radionuclide activities in soil and vegetation samples from near facilities were elevated when compared to activities measured off the site. The levels show a large degree of variance; in general, samples collected on or adjacent to waste disposal facilities had significantly higher radionuclide activities than those collected farther away.

Near-Facility External Radiation. External radiation fields were measured near facilities and waste handling, storage, and disposal sites to measure, assess, and control the impacts of operations.

Four new thermoluminescent dosimeter monitoring sites were established in the 100-B,C Area during late 1998 to evaluate environmental restoration activities at the 116-B-11 Water Retention Basin and the 116-C-1 Liquid Waste Disposal Trench. The 1998 average was comparable to offsite background levels.

Five thermoluminescent dosimeter locations were established in the 100-D,DR Area during late 1996 to evaluate environmental restoration activities at the 116-D-7 and 116-DR-9 Water Retention Basins. The 1998 readings were comparable to offsite background levels.

This is the sixth year that thermoluminescent dosimeters have been placed in the 100-K Area, surrounding the 105-K East and 105-K West Fuel Storage Basins (K Basins) and adjacent reactor buildings. Dose rates decreased noticeably in 1998 as the result of the removal of stored radioactive waste.

At the 100-N Area, the 1998 thermoluminescent dosimeter results indicate that direct radiation levels were again highest near facilities that had contained or received liquid effluent from N Reactor.

These facilities primarily include the 1301-N and 1325-N Liquid Waste Disposal Facilities. Although the results for these two facilities were noticeably higher than those for other 100-N Area thermoluminescent dosimeter locations, they were approximately 17% lower than exposure levels measured at these locations in 1997. Eight dosimeters that were located in low background areas were removed from the network in 1998, which caused an artificial 22% overall annual average increase.

The highest dose rates in the 200/600 Areas were measured near waste handling facilities such as tank farms. The highest dose rate was measured at the A Tank Farm complex (200-East Area). The average annual dose rate in the 200 Areas measured in 1998 was 104 mrem/yr, approximately 5% lower than the dose rate measured in 1997.

Two thermoluminescent dosimeter locations were established at the Environmental Restoration Disposal Facility during late 1996 to evaluate the disposal activities in progress. Readings in 1998 were comparable to offsite background levels.

The highest dose rates in the 300 Area were measured near installations such as the 340 Waste Handling Facility. The average annual dose rate measured in the 300 Area in 1998 was 110 mrem/yr, equal to the average measured in 1997. The average annual dose rate at the 300 Area Treated Effluent Disposal Facility in 1998 was 82 mrem/yr, a slight increase (1%) relative to the average dose rate measured in 1997.

The average annual dose rate measured in the 400 Area in 1998 was 84 mrem/yr, a decrease of 2% compared to the average dose rate measured in 1997.

Investigative Sampling. To confirm the absence or presence of radioactive or hazardous contaminants, or to verify radiological conditions at specific project sites, investigative samples were collected from across the Hanford Site in 1998.

Generally, the predominant radionuclides discovered during these efforts were activation products in the 100 and 200 Areas, and uranium in the 300 Area. Hazardous chemicals generally have not been identified above background levels in preoperational environmental monitoring samples.

Investigative samples in 1998 included soil, vegetation, nests, mammal feces, insects, and wildlife. The samples were collected where known or suspected radioactive contamination was present or to verify radiological conditions at project sites. In 1998, 51 samples were analyzed for radionuclides, and 50 showed some level of contamination. In addition, 133 samples were collected and disposed of without isotopic analyses, though field instrument readings were recorded.

Environmental Surveillance

Environmental surveillance at the Hanford Site includes monitoring environmental media on and off the site for potential chemical and radiological contaminants originating from site operations. The media monitored included air, surface water and sediment, drinking water, food and farm products, fish, wildlife, soil, vegetation, and external radiation.

Air Surveillance. Radioactivity in air were monitored at 39 continuously operating onsite locations, at the Hanford Site perimeter, and in nearby and distant communities. Nine of these locations were community-operated environmental surveillance stations that were managed and operated by local school teachers. At all locations, particulates were filtered from the air and analyzed for radionuclides. Air was sampled and analyzed for selected gaseous radionuclides at key locations. Several radionuclides released at the Hanford Site are also found worldwide from two other sources: naturally occurring radionuclides and radioactive fallout from historical nuclear activities not associated with Hanford operations. The potential influence of emissions from Hanford Site activities on

local radionuclide activities was evaluated by comparing differences between levels measured at distant locations within the region and levels measured at the site perimeter.

In 1998, the site perimeter annual average gross alpha air concentration was slightly higher than the distant community location concentrations. There were no differences observed between the annual average gross beta air concentrations measured at the Hanford Site perimeter and those measured at distant community locations. Quarterly composite samples were analyzed for numerous specific gamma-emitting radionuclides; however, no radionuclides of Hanford origin were detected.

Annual average tritium activities for 1998 at the Hanford Site perimeter were not significantly different than annual average activities at the distant community locations. As a result of tritium studies in selected 300 Area facilities, 300 Area annual average activities in air were elevated when compared to other onsite locations. However, this effect did not increase annual average levels at site perimeter locations.

Iodine-129 activities were statistically elevated at the Hanford Site perimeter compared to the distant locations, indicating a measurable Hanford source; however, the average activity at the site perimeter was only 0.000001% of the DOE derived concentration guide of 70 pCi/m^3. The DOE derived concentration guide is the air concentration that would result in a radiation dose equal to the DOE public dose limit (100 mrem/yr).

The annual average strontium-90 activities at the Hanford Site perimeter were not significantly higher than the annual average levels at the distant community locations. The maximum level was 0.004% of the DOE derived concentration guide of 9 pCi/m^3.

Plutonium-239,240 annual average activities at the Hanford Site perimeter were slightly lower than the annual average activities at the distant community locations. The maximum onsite plutonium-239,240 level was 0.025% of the DOE derived concentration guide of 0.02 pCi/m^3.

Uranium isotopic activities (uranium-234, -235, and -238) were similar at onsite, perimeter, and distant locations in 1998. The annual average uranium activity at the site perimeter was 0.03% of the 0.1 pCi/m^3 DOE derived concentration guide.

No air samples were collected in 1998 to test for chemical contaminants.

Surface-Water and Sediment Surveillance. The Columbia River was one of the primary environmental exposure pathways to the public during 1998 as a result of past operations at the Hanford Site. Radiological and chemical contaminants entered the river along the Hanford Reach primarily through seepage of contaminated groundwater. Water samples were collected from the river at various locations throughout the year to determine compliance with applicable standards.

Although radionuclides associated with Hanford operations continued to be identified routinely in Columbia River water during the year, activities remained extremely low at all locations and were well below standards. The activities of tritium, iodine-129, and uranium were significantly higher (5% significance level) at the Richland Pumphouse (downstream from the site) than at Priest Rapids Dam (upstream from the site), indicating contribution along the Hanford Reach. Transect sampling (multiple samples collected across the river) in 1998 revealed elevated tritium activities along the Benton County shoreline near the 100-N Area, Old Hanford Townsite, 300 Area, and Richland Pumphouse. Total uranium activities were elevated along the Franklin County shoreline near the 300 Area and the Richland Pumphouse and likely resulted from groundwater seepage and water from irrigation return canals on the east of the river that contained naturally occurring uranium.

Several metals and anions were detected in transect samples collected upstream and downstream of the site. Nitrate concentrations were slightly elevated along the Benton County shoreline at the Old Hanford Townsite. Nitrate, sulfate, and chloride were slightly elevated along the Franklin County shoreline of the 300 Area and Richland Pumphouse transects and likely resulted from groundwater seepage associated with extensive irrigation north and east of the Columbia River. With the exception of nitrate, sulfate, and chloride, no consistent differences were found between average quarterly metal and anion contaminant concentrations in the Vernita Bridge and Richland Pumphouse transect samples. All metal and anion concentrations in Columbia River water collected in 1998 were less than the Washington State ambient surface-water quality criteria levels for both acute and chronic toxicity. Arsenic concentrations exceeded EPA standards; however, similar concentrations were found at Vernita Bridge (background location) and Richland Pumphouse.

In 1998, samples of Columbia River surface sediments were collected from permanently flooded monitoring sites above McNary Dam (downstream of the site) and Priest Rapids Dam (upstream of the site) and from two periodically inundated riverbank springs along the Hanford Reach. In addition, sediment samples were collected behind Ice Harbor Dam on the Snake River. Strontium-90 was the only radionuclide to exhibit consistently higher median activities at McNary Dam compared to the other locations. No other radionuclides measured in sediments in 1998 exhibited appreciable differences in activities between locations. The activities of radionuclides in sediment collected from riverbank springs were similar at both locations and were comparable to activities observed in 1998 river sediments. Detectable amounts of most metals were found in all river sediment samples. The highest maximum and median concentrations of chromium were found in riverbank springs sediment. River sediment was also analyzed for simultaneously extracted metals and acid volatile sulfide (SEM/AVS). The SEM/AVS ratios are typically a better indicator of sediment toxicity than traditional total metals concentrations. When the amount of sulfide exceeds the amount of the metals (SEM/AVS ratio is below 1), the metal concentration in the sediment porewater will be low because of the limited solubility of the metal sulfides. For 1998, the SEM/AVS molar ratios were close to one for Priest Rapids Dam and Hanford Reach sediments, with zinc as the dominant metal. The molar ratios for sediment from McNary Dam were above one, indicating a potential for some metals to be present in the sediment porewater, with zinc as the primary metal present. Ice Harbor Dam had similar concentrations of acid volatile sulfide as McNary Dam, but zinc concentrations were lower.

Water samples were collected from eight Columbia River shoreline spring areas in 1998. All radiological contaminant activities measured in riverbank springs water in 1998 were less than DOE derived concentration guides. However, the spring at the 100-N Area that has historically exceeded the DOE derived concentration guide for strontium-90 was not flowing during the 1998 sample collection visit. An alternate spring was sampled at the 100-N Area in 1998, but the strontium-90 sample was lost during processing at the analytical laboratory. Tritium activities at the Old Hanford Townsite and 100-N riverbank springs exceeded the applicable Washington State ambient surface-water quality criteria and were close to the state criteria for springs at the 100-B and 100-K Areas. There are currently no ambient surface-water quality criteria levels directly applicable to uranium; however, total uranium exceeded the site-specific proposed EPA drinking water standard in the 300 Area riverbank spring. All other radionuclides were below the Washington State ambient surface-water quality criteria levels.

Nonradiological contaminants measured in riverbank springs located on the Hanford shoreline in 1998 were below Washington State ambient

surface-water acute toxicity levels, except for chromium at the 100-B, 100-D, 100-K, and 100-H Area riverbank springs. It should be noted that riverbank spring sampling protocols do not lend themselves to a direct comparison of most metal concentrations measured in riverbank springs to ambient surface-water acute and chronic toxicity levels. The standards are used instead as points of reference. Arsenic concentrations in riverbank springs water were well below the applicable ambient surface water chronic toxicity levels, but concentrations in all samples exceeded the Federal limit. Nitrate concentrations at all locations were below the EPA drinking water standard.

Water was collected from two onsite ponds located near operational areas in 1998. Although the ponds were not accessible to the public and did not constitute a direct offsite environmental impact during the year, they were accessible to migratory waterfowl and other animals. As a result, a potential biological pathway existed for the removal and dispersal of onsite pond contaminants. With the exception of uranium-234 and uranium-238 in water samples from West Lake, radionuclide activities in the onsite pond water were below DOE derived concentration guides. The median gross alpha, gross beta, and total uranium activities in West Lake exceeded the applicable ambient surface-water quality criteria levels. Activities of most radionuclides in water collected from both ponds during 1998 were similar to those observed during past years.

Irrigation water from the Riverview canal near Pasco was sampled three times in 1998 to determine radionuclide activities. Radionuclide activities in offsite irrigation water were below the DOE derived concentration guides and ambient surface-water quality criteria levels and were similar to those observed in Columbia River water.

Drinking Water Surveillance. Surveillance of Hanford Site drinking water was conducted to verify the quality of water supplied by site drinking water systems and to comply with regulatory requirements. Radiological monitoring was performed by the Pacific Northwest National Laboratory and DE&S Hanford, Inc.; nonradiological monitoring was conducted by DynCorp Tri-Cities Services, Inc. Radiological results are discussed in this report; nonradiological results are reported directly to the Washington State Department of Health.

During 1998, radionuclide activities in Hanford Site drinking water were similar to those observed in recent years and were in compliance with Washington State Department of Health and EPA drinking water standards.

Food and Farm Product Surveillance. The Hanford Site is situated in a large agricultural area that produces a wide variety of food products and alfalfa. In 1998, milk, vegetables, fruit, and wine were collected from areas around the site and were analyzed for cobalt-60, strontium-90, iodine-129, cesium-137, and tritium.

Most farm products sampled did not contain measurable levels of cobalt-60 or cesium-137. Iodine-129 was measured in milk at levels that appeared to be slightly elevated in downwind locations. Activities of iodine-129 in milk collected at downwind locations have decreased in the past 5 years, approaching the levels observed in milk collected at the upwind location. Strontium-90 was present in milk in equivalent levels at upwind and downwind locations. Tritium was also measured in milk samples and observed activities were believed to be influenced by the source of water used by the dairies. Tritium activities in wine were low and the Yakima Valley wines were lower than the Columbia Basin wines. Measurable levels of man-made radioactivity were not detected in vegetable and fruit samples collected in 1998.

Fish and Wildlife Surveillance. Carp and large-scale suckers were collected from the Columbia River in 1998. Radionuclide levels in carp collected

from the Hanford Reach in 1998 were similar to the levels observed in carp and suckers from the reference background site located nearly 80 km (50 mi) upstream from the Hanford Site.

Wildlife sampled and analyzed in 1998 for radioactive constituents included elk, deer, and pheasants. Radionuclide levels in Hanford-resident wildlife were similar to levels in wildlife collected at reference background locations. The highest strontium-90 levels in deer bone samples from Hanford were collected near the closed reactors. Until recently, elk have not inhabited areas on the Hanford Site where the potential for uptake of radionuclides exists. Radionuclide levels found in four road-killed elk in 1998 did not suggest exposure to the Hanford-derived sources.

Soil and Vegetation Surveillance. Soil and vegetation samples were collected on and off the Hanford Site for the first time since 1994 as routine samples. Activities of strontium-90, cesium-137, and plutonium-239,240 in soil were similar to levels last observed from 1992 through 1994. Activities of cesium-137, uranium-238, plutonium-238, and plutonium-239,240 were below detection limits in vegetation samples collected in 1998. Strontium-90 was found in plant samples at levels comparable to values detected in 1992 to 1994 and does not indicate a positive or negative trend. Special leaf and fruit samples were also collected from trees grown near 100-F Area and the Old Hanford Townsite. These samples were analyzed for radiological materials and trace metals. Concentrations of 13 trace metals were within expected background concentrations based on published data. Strontium-90 and cesium-137 activities were similar to those observed in previous sampling, however, tritium activities were lower than levels observed in tree sampling conducted in 1997.

External Radiation Surveillance. During 1998, thermoluminescent dosimeters were used to measure radiological dose rates at both onsite and offsite locations. Radionuclides contributing to the measured dose rates were of either natural or anthropogenic (man-made) origin. The dose rates did not change significantly from the dose rates measured in the previous 5 yr. The 1998 annual average background dose rate, measured in communities considered distant from the Hanford Site, was 70 ± 2 mrem per year. In 1997, the average background dose rate was 67 ± 1 mrem per year and in 1996, the average background dose rate was 71 ±1 mrem per year. The 1998 annual average perimeter dose rate was 88 ± 7 mrem per year. In 1997, the perimeter annual average was 89 ± 10 mrem per year and in 1996, the annual average perimeter dose rate was 88 ± 10. All onsite thermoluminescent dosimeters averaged 85 ± 9 mrem per year in 1998. This compares favorably to the 85 ± 5 mrem per year reported for 1997 and the 86 ± 5 mrem per year measured in 1996. Columbia River shoreline dosimeters in 1998 averaged 91 ± 17 mrem per year, and in 1996 and 1997, the shoreline annual averages were 89 ± 7 and 90 ± 6 mrem per year, respectively. The 1998 annual average dose rate along the 100-N Area shoreline was 127 ± 21 mrem per year, while in 1997, the annual average was 121 ± 22 mrem per year. The 100-N Area shoreline dose rate (127 ± 20 mrem per year) is approximately 50% greater that the typical shoreline dose rate (86 ± 9 mrem per year).

Groundwater and Vadose Zone Monitoring

Monitoring of radiological and chemical constituents in groundwater at the Hanford Site was performed to characterize physical and chemical trends in the flow system, to establish groundwater quality baselines, to assess groundwater remediation, and to identify new or existing groundwater problems. Groundwater monitoring was also performed to verify compliance with applicable environmental laws and regulations and to fulfill commitments made in official DOE documents. Samples were collected from over 600 wells to determine the distribution of radiological and chemical constituents in Hanford Site groundwater. In addition,

hydrogeologic characterization and modeling of the groundwater flow system were used to assess the monitoring network and to evaluate potential impacts of groundwater contaminants.

Vadose zone monitoring was conducted to characterize radioactive and hazardous waste in the soil column from past intentional liquid waste disposals, accidental spills, and leachate from solid waste burial grounds. Subsurface source characterization and vadose zone monitoring, using spectral gamma logging and soil-gas monitoring, were conducted during 1997 in the vicinity of single-shell underground waste storage tanks and selected liquid waste disposal sites.

Groundwater Protection and Monitoring. The Hanford Groundwater Monitoring Project was responsible for groundwater surveillance and monitoring activities at the Hanford Site. This project incorporates sitewide groundwater monitoring mandated by DOE orders with near-field groundwater monitoring conducted to ensure that operations in and around specific waste disposal facilities comply with applicable regulations. Groundwater monitoring was required by the Resource Conservation and Recovery Act at 25 waste treatment, storage, and disposal units. Monitoring status and results for each of these units are summarized in this report.

To assess the quality of groundwater, measured sample concentrations were compared with the EPA drinking water standards and the DOE derived concentration guides. Groundwater is used for drinking at three locations on the Hanford Site. In addition, water supply wells for the city of Richland are located near the southern boundary of the Hanford Site. Radiological constituents detected at levels greater than their respective EPA drinking water standards in one or more onsite wells included tritium, iodine-129, technetium-99, uranium, strontium-90, cesium-137, carbon-14, gross alpha, and gross beta. Tritium, uranium, and strontium-90 were detected at levels greater than their respective DOE derived concentration guides.

Extensive tritium plumes extend from the 200-East and 200-West Areas into the 600 Area. The plume from the 200-East Area extends east and southeast, discharging to the Columbia River. This plume has impacted tritium activities in the 300 Area at levels of more than one-half the EPA drinking water standard. The spread of this plume farther south than the 300 Area is restricted by the groundwater flow away from the Yakima River, recharge from agricultural irrigation, and the recharge basins associated with the north Richland well field. Groundwater with tritium at levels above the EPA drinking water standard also discharges to the Columbia River at the 100-N Area. A small but high level tritium plume near the 100-K East Reactor also may discharge to the river. Tritium levels greater than the EPA drinking water standard were also found in the 100-B,C, 100-D, 100-F, and 400 Areas. Tritium occurred at levels above the DOE derived concentration guide in the 100-K and 200 Areas.

Iodine-129 was detected at levels greater than the EPA drinking water standard in the 200-East Area and in an extensive part of the 600 Area (to the east and southeast of the 200-East Area). The iodine-129 contamination extends as far east as the Columbia River but at levels less than the EPA drinking water standard. The iodine-129 and tritium plumes share common sources. Iodine-129 at levels greater than the EPA drinking water standard also extends into the 600 Area to the northwest of the 200-East Area, into the 600 Area in the southern part of the 200-West Area, and to the northeast in the north-central part of the 200-West Area.

Technetium-99 activities greater than the EPA drinking water standard were found in the northwestern part of the 200-East Area and adjacent 600 Area. Technetium-99 was also detected at levels greater than the EPA drinking water standard in the 200-West Area and adjacent 600 Area. In the upper basalt-confined aquifer, technetium-99 activities were found above the EPA drinking water standard in one well in the northern part of the 200-East Area.

Greater than 338 million L (89 million gal) of groundwater have been treated and greater than 53.9 g (1.9 oz) of technetium-99 have been removed from groundwater since a pump-and-treat system began operating in the 200-West Area in 1994.

Uranium was detected at levels greater than the EPA drinking water standard in groundwater in the 100-F, 100-H, 200, 300, and 600 Areas. Wells near U Plant in the 200-West Area showed activities greater the DOE derived concentration guide. A pump-and-treat system has removed 80.4 kg (177 lb) of uranium from groundwater in the 200-West Area since 1994. Groundwater with uranium levels greater than the EPA drinking water standard is discharging to the Columbia River from the 300 Area.

The strontium-90 plume in the 100-N Area, which contains activities greater than the EPA drinking water standard and the DOE derived concentration guide, discharges to the Columbia River. Localized areas in the 100-K and 200-East Areas and near the former Gable Mountain Pond in the 600 Area also contain strontium-90 at levels greater than the DOE derived concentration guide. Strontium-90 was detected at levels greater than the EPA drinking water standard in the 100, 200, and 600 Areas. Strontium-90 continues to be remediated in the 100-N Area by a pump-and-treat system to reduce the amount of strontium-90 entering the Columbia River.

Cesium-137 was detected above the EPA drinking water standard in a localized area associated with a former injection well in the 200-East Area. Plutonium was also detected in this localized area, but at levels less than the 100-mrem/yr dose equivalent guideline.

Cobalt-60 was detected in the 200-East Area and adjacent 600 Area but at levels less than the EPA drinking water standard.

Carbon-14 activity exceeded the EPA drinking water standard near each of the reactors in the 100-K Area.

Several nonradioactive chemicals regulated by EPA and Washington State were also present in Hanford Site groundwater. These were nitrate, chromium, carbon tetrachloride, chloroform, trichloroethylene, tetrachloroethylene, cis-1,2-dichloroethylene, cyanide, and fluoride. Of these chemicals, nitrate, chromium, and carbon tetrachloride are the most widely distributed constituents in Hanford Site groundwater.

Nitrate concentrations exceeded the EPA drinking water standard in all areas, except the 100-B,C and 400 Areas. The nitrate plumes in the 100 Areas discharge to the Columbia River. A nitrate plume emanating from the 200-East Area extends east and southeast in the same area as the tritium plume. Nitrate from sources in the northwestern part of the 200-East Area is present in the adjacent 600 Area at levels greater than the EPA drinking water standard. Nitrate levels greater than the EPA drinking water standard occur in two areas of the 200-West Area and adjoining 600 Area. A pump-and-treat system in the 200-West Area has removed 7,910 kg (17,442 lb) of nitrate from groundwater.

Chromium was detected above the EPA drinking water standard in the 100-D, 100-H, and 100-K Areas and in localized sites in the 100 B/C, 100-K, 200-East, 200-West, and 600 Areas. Since pump-and-treat systems began operating in the 100-D, 100-H, and 100-K Areas in 1997, 98 kg (209 lb) of chromium has been removed from groundwater.

An extensive plume of carbon tetrachloride at levels greater than the EPA drinking water standard occurs in groundwater in the 200-West Area and adjoining 600 Area. As of September 1998, greater than 953 million L (251 million gal) of groundwater have been treated at two pump-and-treat systems operating in the 200-West Area, resulting in the removal of approximately 2,113 kg (4,667 lb) of carbon tetrachloride.

Levels of trichloroethylene and chloroform were above the EPA drinking water standard in the 200-West Area. Trichloroethylene was found at

levels greater than the EPA drinking water standard in the 100-F Area and the nearby 600 Area. Trichloroethylene was also detected at levels above the EPA drinking water standard in the 100-K and 300 Areas and near the former Horn Rapids Landfill in the southern part of the Hanford Site.

A new plume of tetrachloroethylene with levels above the EPA drinking water standard was detected in the 300 Area. However, levels fell below the standard by the end of 1998.

Cis-1,2-dichloroethylene concentrations were above the EPA drinking water standard in one well in the 300 Area. Cyanide was detected in groundwater in the 200-East Area but at levels below the EPA drinking water standard. Fluoride was detected at a level above the EPA drinking water standard in one well in the 200-West Area.

Tank Farms Vadose Zone Baseline Characterization Project. The multiyear vadose zone baseline characterization project at the single-shell tank farms continued in 1998. This project involves spectral gamma-ray geophysical logging of approximately 800 existing boreholes surrounding the tank farms, creating a database of information and providing interpretations and three-dimensional visualizations (computer-generated illustrations) of the subsurface contamination. The geophysical logging method is used to determine the activity of gamma-emitting radionuclides in the subsurface. These data are then used to outline the regions of major subsurface contamination and to identify where to focus the effort of a more comprehensive vadose zone characterization program.

During 1998, the baseline logging was completed. Spectral gamma data were acquired in 79 boreholes in T Farm and B Farm. Reports were completed for 27 tanks and 3 tank farms. Report preparation, repeat logging, shape factor analysis, and high-rate logging will continue through 1999.

Vadose Zone Monitoring at Waste Disposal Facilities. Radioactive and hazardous waste in the soil column from past intentional liquid waste disposals, accidental spills, and leachate from solid waste burial grounds at the Hanford site are potential sources of current and future groundwater contamination. Subsurface source characterization and vadose zone monitoring, using spectral gamma logging and soil-gas monitoring were conducted during 1998. Also in 1998, physical, chemical and hydraulic properties were measured from samples obtained from characterization boreholes at the Immobilized Low-Activity Waste site, which is the site for privatization activities associated with retrieval and processing tank waste located in the 200-East Area, to support performance assessment modeling; at the 216-B-2-2 ditch, in the 200-East Area, to support 200 Areas soils remediation; and at the extension of borehole 41-09-39 in the 200-West Area SX single-shell tank farm to support tank remediation/closure.

The objectives of vadose zone monitoring are to document contaminant location and to determine moisture and radionuclide movement in the soil column. Spectral gamma logging is an in situ measurement of subsurface gamma-emitting radionuclides obtained through cased monitoring wells that are completed in the vadose zone or extended into the saturated zone. By periodically recording gamma-ray activity at various depths, changes over time can be documented.

During 1998, in situ spectral gamma logging was performed in 21 boreholes at the 216-Z-1A, -9, and -12 liquid waste-disposal facilities associated with the Plutonium Finishing Plant located in the 200-West Area. Cesium-137, protactinium-233, plutonium-239, and americium-241 were identified in the logs. Comparisons of log data collected in 1998 with data from past logging events suggest that some changes have occurred in radionuclide activity around two boreholes in the 216-Z-1A tile field and around one borehole in the 216-Z-12 crib.

In one borehole at the 216-Z-1A tile field, there was an apparent decrease in protactinium-233 activity to ~1/3 of 1991 values between 13.4 and 15 m (43.9 to 49.2 ft), with no apparent change above or below that zone. This suggests a lateral, not a vertical, change in protactinium-233 activity. Also, between 13 and 16 m (42.6 and 52.5 ft), cesium-137 activity decreased by a factor of ~3, compared to the 1991 log. In another borehole at the 216-Z-1A tile field, a 51% increase in protactinium-233 activity was found between 6 and 16 m (19.7 and 52.5 ft) and a 22% increase between 28 and 29 m (91.9 and 95.1 ft) when compared to previous logs. Only one borehole at the 216-Z-12 crib suggested that there were changes in subsurface distribution of radionuclides since the last logging in 1993. Protactinium-233 showed an apparent 16% increase, and plutonium-239 showed an apparent 123% increase over the 4.6 to 5.5 m (15 to 18 ft) depth interval. The general conclusion is that transuranics were relatively mobile at the time of discharge to the 216-Z-1A tile field but have been fairly stable since.

The Tank Waste Remediation Systems program is focusing on resolving tank safety issues, planning for waste retrieval, developing waste-pretreatment and -treatment facilities, and evaluating waste-storage and -disposal needs for single-shell tank wastes. Vitrification and onsite disposal of low-activity waste from single-shell tanks are included in the strategy described in the Hanford Site Federal Facility Agreement and Consent Order (commonly known as the Tri-Party Agreement; Washington State Department of Ecology et al. 1989). The current plan is to dispose of immobilized low-activity tank waste in new facilities in the south-central part of the 200-East Area and in four existing vaults (unused, reinforced concrete structures remaining at the former Grout Treatment Facility) along the eastern side of the 200-East Area. In 1998, three boreholes were drilled at the southwestern corner of the Immobilized Low-Activity Waste disposal site in support of the performance assessment activities for the disposal options.

Geologic logging of the deepest boreholes at the Hanford Site showed for the first time the existence of three paleosols (layers) in a single borehole. The paleosols, which represent significant time intervals when soil development took place in the geologic past, have the potential to retard downward movement of moisture through the vadose zone at their location. The detailed stratigraphy from the borehole sets a good background for the subsequent chemical transport, physical properties, and estimation of recharge tests.

Twenty samples from the borehole were analyzed for physical and hydraulic properties. The variability among the hydrologic and physical data was within the range previously reported for 200 Areas sediments. This increases confidence that existing data sets are representative of the range of physical and hydrologic properties present in the uncontaminated portions of the 200 Areas and may be representative of many of the contaminated portions of the 200 Areas. The data represent the most complete set of physical properties and hydrologic properties measured on undisturbed core samples at the Hanford Site. The data will be input to performance assessment of the Immobilized Low-Activity Waste disposal site.

Borehole 41-09-39 was initially drilled in 1996 at the SX single-shell tank farm, in the 200 West Area, in response to the determination that cesium-137 might reside in the soil column at depths greater than previously thought. Geophysical logging confirmed that cesium-137 contamination was present at the total depth of the borehole. Concern was raised that if relatively immobile cesium-137 was present at that depth, then more-mobile, long-lived, tank-waste constituents might be at or near the water table. In response to a recommendation of an expert panel brought together to address these early findings, borehole 41-09-39 was extended to groundwater in 1998 and samples were collected for laboratory analysis of tank-waste components.

Samples from seven selected locations within the borehole were analyzed for radionuclides, chemical constituents, cation-exchange capacity, and particle-size distribution. Detailed geochemical analyses of the seven samples from this borehole showed that tank-waste constituents are predominantly held within or above a prominent geologic layer known as the Plio-Pleistocene unit. Analyses showed that cesium-137 activity in the soils was highest in the Plio-Pleistocene sediments at 40 m (131 ft) depth. Activity dropped off rapidly and was at or below detection levels from 48.8 m (160 ft) to the water table at 64.3 m (210 ft).

Distribution of technetium-99, the most mobile of the long-lived radionuclides found in tank wastes, was sporadic, with most occurrences above the Plio-Pleistocene unit. A single, deep occurrence was noted at the depth postulated to be the highest level reached by groundwater during operation of the 216-U-10 pond (now decommissioned) located west of the SX single-shell tank farm. It is possible that technetium-99 was found in this sediment sample due to horizontal migration from disposal facilities outside the tank farm boundaries.

Groundwater samples were collected from 3, 0.6, and 0.02 m (10, 2, and 0.06 ft) below the water table. Analyses of these samples showed technetium-99 and tritium activities indicative of an upgradient sources. These analyses indicate that groundwater contamination at this specific location is due to non-tank farm sources. More sampling of vadose-zone sediments under the SX tank farm at additional locations is needed to determine whether the contaminants in downgradient monitoring wells may have originated from the single-shell tanks or from non-tank-related liquid discharge facilities nearby.

A characterization borehole was drilled through the 216-B-2-2 ditch, in the 200 East Area, to groundwater during late 1997 and early 1998. This ditch was selected for characterization because it is considered representative of the 200-CW-1 Gable Mountain Pond/B Pond and Ditches Cooling Water Group (formerly the 200-BP-11 Operable Unit).

Chemical and radiochemical analyses were conducted on samples from the borehole. With one exception, the results showed that the distribution of chemical constituents and man-made radionuclides underlying the 216-B-2-2 ditch is consistent with the conceptual model developed for the 200-CW-1 group. The conceptual model for this group is that the highest activity of the primary contaminants of concern will be directly underlying the headend of the ditch. Furthermore, according to the conceptual model, most of the contaminants were expected to be within the uppermost gravel unit, which at this site extends to a depth of 9.1 m (29.8 ft). The only exception was one nontarget volatile organic (total xylenes) detected at 8 µg/kg in the 45.7- to 46.5-m (150- to 152.5-ft) interval.

Soil-vapor extraction is being used to remove the carbon tetrachloride from the vadose zone as part of the 200-West Area expedited response action. To track the effectiveness of the remediation effort, measurements of soil-vapor concentrations of chlorinated hydrocarbons were made at the inlet to the soil-vapor-extraction system, at individual operating extraction wells, and at individual standby wells during 1998.

During a total of 178 d of soil-vapor extraction in 1998, 777 kg (1,700 lb) of carbon tetrachloride were removed from the vadose zone. As of September 1998, ~75,000 kg (165,000 lb) of carbon tetrachloride had been removed from the subsurface since extraction operations started in 1992. Since initiation, the extraction systems are estimated to have removed 7% of the residual mass at the 216-Z-1A/-18 well field and 22% of the mass at the 216-Z-9 well field.

During October 1997 through March 1998, soil-vapor concentrations were monitored near the groundwater and near the ground surface to assess whether a shutdown of the soil-vapor-extraction

system allowed carbon tetrachloride to migrate out of the vadose zone. The results showed that carbon tetrachloride concentrations did not increase significantly at either the shallow probes monitored in 1998 or the deeper probes near the groundwater. This indicates that temporarily suspending operation of the soil-vapor-extraction system for 6 to 9 mo appears to cause minimal detectable vertical transport of carbon tetrachloride through the soil surface to the atmosphere and to have had no negative impact on groundwater quality.

Carbon tetrachloride rebound concentrations indicate that in many areas much of the readily accessible mass has been removed during soil-vapor-extraction operations and that the supply of additional carbon tetrachloride is limited by desorption and/or diffusion from subsurface contaminant sources. Under these conditions, the removal rate of the additional carbon tetrachloride using soil-vapor extraction is controlled by the desorption and diffusion rates of the contaminant.

Potential Radiological Doses from 1998 Hanford Operations

In 1998, potential radiological doses to the public, resulting from exposure to Hanford Site liquid and gaseous effluents, were evaluated to determine compliance with pertinent regulations and limits. These doses were calculated using reported effluent releases and environmental surveillance data using version 1.485 of the GENII computer code and Hanford-specific parameters. The potential dose to the maximally exposed individual in 1998 from site operations was 0.02 mrem (0.2 μSv) compared to 0.01 mrem calculated for 1997. The radiological dose to the population within 80 km (50 miles) of the site, estimated to be 380,000 persons, from 1998 site operations was 0.2 person-rem (0.002 person-Sv), which remained unchanged from the population doses calculated in 1997 and 1996. The average per-capita dose from 1998 site operations was 0.0005 mrem (0.005 μSv).

The national average dose from background sources, according to the National Council on Radiation Protection, is approximately 300 mrem/yr (3 mSv/yr), and the current DOE radiological dose limit for a member of the public is 100 mrem/yr (1 mSv/yr). Therefore, the average individual potentially received 0.0005% of the DOE limit and 0.0002% of the national average background. Special exposure scenarios not included in the dose estimate above included the hunting and consumption of game animals residing on the Hanford Site and exposure to radiation at a publicly accessible location with the maximum exposure rate. Doses from these scenarios would have been small compared to the DOE dose limit. Radiological dose through the air pathway was calculated to be 0.13% of the EPA limit of 10 mrem/yr (0.1 mSv/yr).

Other Hanford Site Environmental Programs

Climate and Meteorology

Meteorological measurements are taken to support Hanford Site emergency preparedness, site operations, and atmospheric dispersion calculations. Hanford Site meteorologists provide weather forecasting, and maintenance and distribution of climatological data.

The Hanford Meteorology Station is located on the 200 Areas plateau, where the prevailing wind direction is from the northwest during all months.

The secondary wind direction is from the southwest. The average speed for 1998 was 12.7 km/h (7.9 mi/h), which was 0.3 km/h (0.2 mi/h) above normal; the peak gust for the year was 90 km/h (56 mi/h).

Precipitation for 1998 totaled 16.4 cm (6.5 in.), 103% of normal, with 18.3 cm (7.2 in.) of snow recorded.

1998 was much warmer than normal, tying 1992 as the warmest year on record. Temperatures for 1998 ranged from 44.4°C (112°F) in July to -18.3°C (-1°F) in December. The highest July temperature ever recorded was 44.4°C (112°F) on July 27, 1998. The first week in May, three daily temperature records were broken or tied. November 1998 was the third warmest on record. For the year 1998, there were 73 d with maximum temperature ≥90°F, the third highest on record. For the 12-mo period, 11 mo were warmer than normal and 1 was cooler than normal. The summer (June, July, and August) and autumn (September, October, and November) of 1998 were the fourth warmest on record.

Cultural Resources

Management of archaeological, historical, and traditional cultural resources at the Hanford Site is provided in compliance with the National Historic Preservation Act, Native American Graves Protection and Repatriation Act, Archaeological Resources Protection Act, and American Indian Religious Freedom Act. During 1998, 150 proposed projects were reviewed to consider their potential effect on significant cultural resources. Other activities included the continuation of a multiyear monitoring study of cutbank erosion and associated impacts to National Register archaeological sites at Locke Island, a large channel island located in the northern extent of the Hanford Reach of the Columbia River. Mitigation of historic buildings and structures continued in 1998 as required by the programmatic agreement for the built environment and the historic district treatment plan.

Public involvement activities are important components of a cultural resources management program. To accomplish this goal, DOE developed mechanisms that allow the public access to cultural resources information and the ability to comment and make recommendations concerning the management of cultural resources on the Hanford Site. In 1998, these mechanisms were woven into a draft involvement plan that includes input provided by the public and Hanford Site staff over the past several years. Native American involvement included the completion of several field surveys, construction monitoring, and monthly cultural issues meetings.

Community-Operated Environmental Surveillance Program

This program was initiated in 1990 to increase the public's involvement in and awareness of Hanford's surveillance program. Nine citizen-operated radiological surveillance stations were operating in 1998.

Noxious Weed Control Program

The noxious weed control program on the Hanford Site was developed in response to federal, state, and local laws requiring eradication or control of noxious weeds. A noxious weed is defined as any plant that, when established, is highly destructive, competitive, or difficult to control by cultural or chemical practices. Typically, noxious weeds are non-native species that invade and displace native species, reduce habitat for fish and wildlife, and contribute to the extinction of sensitive species. Nine plants are on the high-priority list for control at the Hanford Site. These include yellow starthistle, rush skeletonweed, babysbreath, dalmation toadflax, spotted knapweed, diffuse knapweed, Russian knapweed, saltcedar, and purple loosestrife. All these plants were monitored in 1998, but control measures focused on the more invasive species.

Quality Assurance

Comprehensive quality assurance programs, which include various quality control practices and methods to verify data, are maintained to ensure data quality. The programs are implemented through quality assurance plans designed to meet requirements of the American National Standards Institute/ American Society of Mechanical Engineers and DOE Orders. Quality assurance plans are maintained for all activities, and auditors verify conformance. Quality control methods include, but are not limited to, replicate sampling and analysis, analysis of field blanks and blind reference standards, participation in interlaboratory crosscheck studies, and splitting samples with other laboratories. Sample collection and laboratory analyses are conducted using documented and approved procedures. When sample results are received, they are screened for anomalous values by comparing them to recent results and historical data. Analytical laboratory performance on the submitted double blind samples, the EPA Laboratory Intercomparison Studies Program, and the national DOE Quality Assessment Program indicated that laboratory performance was adequate overall, was excellent in some areas, and needed improvement in others.

Acknowledgments

The production of this report was managed by the Pacific Northwest National Laboratory's Public Safety and Resource Protection Program under the direction of R. W. Bryce.

Community-operated environmental surveillance stations were managed by local teachers who were responsible for collecting the samples and maintaining the stations. The managers and alternate managers for each station included the following:

Leslie Groves Park, Richland: C. A. Wagner, Manager, and D. R. Johns, Alternate Manager

Basin City Elementary School, Basin City: C. L. Stevenson, Manager, and K. McEachen, Alternate Manager

Edwin Markham Elementary School, North Franklin County: M. P. Madison, Manager, and K. A. Thomas, Alternate Manager

Kennewick: T. Droppo, Manager, and C. Zwiener-Thomas, Alternate Manager

Kiona-Benton High School, Benton City: A. J. Williamson, Manager, and K. Jones, Alternate Manager.

Mattawa: D. Weberling, Manager, and B. Whitehouse and T. Lyall, Alternate Managers

Othello: J. Oord, Manager, and B. Taylor, Alternate Manager

Columbia Basin College, Pasco: L. DeWitt, Manager, and J. O'Neill, Alternate Manager

Heritage College, Toppenish: D. F. Brown, Manager, and R. A. Landvoy, Alternate Manager.

The authors appreciate the reviews of the draft report by K. R. Price (Pacific Northwest National Laboratory) and D. H. Denham (Bechtel Hanford, Inc.).

The report was prepared by Pacific Northwest National Laboratory staff: B. V. Johnston and L. F. Morasch, editors, and K. R. Neiderhiser, text processor. Graphics were prepared by D. L. Liddell (Lockheed Martin Services, Inc.) and J. P. McDonald, C. A. Newbill, D. C. Lanigan, J. T. Rieger, and R. K. Zufelt (Pacific Northwest National Laboratory). J. Winslow (WinSome Design, Richland, Washington) designed the report cover and layout. This report was produced using Adobe® PageMaker and formatted for the Internet by Pacific Northwest National Laboratory's Electronic Communications Section.

Report Contributors

The production of this Hanford Site environmental report requires the knowledge, skills, experience, and cooperation of many people and several organizations. The contributions and cooperation, often under demanding time constraints, of the following individuals are gratefully acknowledged. The lead authors are listed on each main section of the report and their telephone numbers are included below.

B&W Hanford Company
G. D. Hendricks

Bechtel Hanford, Inc.
K. A. Gano
J. G. Woolard

CH2M Hill Hanford, Inc.
S. J. Ingle
V. J. Rohay ..... (509) 372-9351

DE&S Hanford, Inc.
R. G. Gant ..... (509) 373-3781

DynCorp Tri-Cities Services, Inc.
L. M. Kelly ..... (509) 373-4971

Fluor Daniel Hanford, Inc.
R. C. Brunke
J. J. Kapadia
O. S. Kramer
K. A. Peterson
T. A. Quayle
C. P. Strand

Lockheed Martin Hanford Corp.
D. A. Myers ..... (509) 372-9393
P. A. Powell

MACTEC-ERS
S. E. Kos ..... (509) 376-9916
R. G. McCain ..... (509) 946-3623

Pacific Northwest National Laboratory
E. J. Antonio ..... (509) 375-3809
L. L. Cadwell ..... (509) 376-5659
D. D. Dauble ..... (509) 376-3631
R. L. Dirkes ..... (509) 376-8177
J. L. Downs ..... (509) 376-6641
L. L. Fassbender
B. M. Gillespie ..... (509) 376-5802
R. W. Hanf ..... (509) 376-8264
M. J. Hartman ..... (509) 373-0028
D. W. Harvey ..... (509) 373-2945
D. J. Hoitink ..... (509) 372-6414
D. G. Horton ..... (509) 376-6868
D. R. Newcomer ..... (509) 376-1054
G. W. Patton ..... (509) 376-2027
T. M. Poston ..... (509) 376-5678
K. R. Price ..... (509) 375-5187
K. Rhoads ..... (509) 375-6832
R. J. Serne ..... (509) 376-8429
M. A. Simmons ..... (509) 376-3992
T. L. Stewart
H. T. Tilden II
B. L. Tiller ..... (509) 376-3444
B. A. Williams
M. K. Wright ..... (509) 372-1079

Waste Management Federal Services, Inc., Northwest Operations
L. M. Hay
A. R. Johnson ..... (509) 372-3056
B. M. Markes ..... (509) 372-3483
S. M. McKinney ..... (509) 372-8040
R. M. Mitchell ..... (509) 376-5122
C. J. Perkins ..... (509) 372-8042
R. R. Randall ..... (509) 372-2604
R. C. Roos ..... (509) 376-2115

Waste Management Federal Services of Hanford, Inc.

S. G. Arnold
D. G. Black ..... (509) 376-8458
R. C. Bowman
H. C. Boynton
L. P. Diediker ..... (509) 373-1716
C. R. Haas
J. S. Hill
M. T. Jansky
S. S. Lowe
J. L. Luke
D. E. Nester
D. H. Nichols
J. R. Rosser
D. E. Zaloudek

U.S. Department of Energy, Richland Operations Office

K. V. Clarke
R. G. Holt
D. W. Lloyd
G. M. McClure
D. K. Tano
D. C. Ward
J. H. Zeisloft

Helpful Information

The following information is provided to assist the reader in understanding this report. Definitions of technical terms can be found in Appendix B, "Glossary." A public information summary document is available and may be obtained by following the directions given in the "Preface."

Scientific Notation

Scientific notation is used in this report to express very large or very small numbers. For example, the number 1 billion could be written as 1,000,000,000 or, by using scientific notation, written as 1×10^9. Translating from scientific notation to a more traditional number requires moving the decimal point either left or right from its current location. If the value given is 2.0×10^3, the decimal point should be moved three places to the right so that the number would then read 2,000. If the value given is 2.0×10^{-5}, the decimal point should be moved five places to the left so that the result would be 0.00002.

Units of Measurement

The primary units of measurement used in this report are metric. Table H.1 summarizes and defines the terms and corresponding symbols (metric and nonmetric). A conversion table is also provided in Table H.2.

Table H.1. Names and Symbols for Units of Measure

Symbol	Name
Temperature	
°C	degree Celsius
°F	degree Fahrenheit
Time	
d	day
h	hour
min	minute
s	second
yr	year
Rate	
cfs (or ft^3/s)	cubic foot per second
gpm	gallon per minute
mph	mile per hour
Volume	
cm^3	cubic centimeter
ft^3	cubic foot
gal	gallon
L	liter
m^3	cubic meter
mL	milliliter (1×10^{-3} L)
yd^3	cubic yard

Symbol	Name
Length	
cm	centimeter (1×10^{-2} m)
ft	foot
in.	inch
km	kilometer (1×10^3 m)
m	meter
mi	mile
mm	millimeter (1×10^{-3} m)
µm	micrometer (1×10^{-6} m)
Area	
ha	hectare (1×10^4 m^2)
km^2	square kilometer
mi^2	square mile
ft^2	square foot
Mass	
g	gram
kg	kilogram (1×10^3 g)
mg	milligram (1×10^{-3} g)
µg	microgram (1×10^{-6} g)
ng	nanogram (1×10^{-9} g)
lb	pound
wt%	weight percent
Concentration	
ppb	parts per billion
ppm	parts per million

Table H.2. Conversion Table

Multiply	By	To Obtain	Multiply	By	To Obtain
in.	2.54	cm	cm	0.394	in.
ft	0.305	m	m	3.28	ft
mi	1.61	km	km	0.621	mi
lb	0.454	kg	kg	2.205	lb
gal	3.785	L	L	0.2642	gal
ft^2	0.093	m^2	m^2	10.76	ft^2
acre	0.405	ha	ha	2.47	acres
mi^2	2.59	km^2	km^2	0.386	mi^2
yd^3	0.7646	m^3	m^3	1.308	yd^3
nCi	0.001	pCi	pCi	1,000	nCi
pCi/L	10^{-9}	µCi/mL	µCi/mL	10^{9}	pCi/L
pCi/m^3	10^{-12}	Ci/m^3	Ci/m^3	10^{12}	pCi/m^3
pCi/m^3	10^{-15}	mCi/cm^3	mCi/cm^3	10^{15}	pCi/m^3
mCi/km^2	1.0	nCi/m^2	nCi/m^2	1.0	mCi/km^2
becquerel	2.7×10^{-11}	curie	curie	3.7×10^{10}	becquerel
becquerel	27	pCi	pCi	0.03704	becquerel
gray	100	rad	rad	0.01	gray
sievert	100	rem	rem	0.01	sievert
ppb	0.001	ppm	ppm	1,000	ppb
°F	(°F -32) ÷ 9/5	°C	°C	(°C x 9/5) + 32	°F
g	0.035	oz	oz	28.349	g
metric ton	1.1	ton	ton	0.9078	metric ton

Radioactivity Units

Much of this report deals with levels of radioactivity in various environmental media. Radioactivity in this report is usually discussed in units of curies (Ci) (Table H.3). The curie is the basic unit used to describe the amount of radioactivity present, and activites are generally expressed in terms of fractions of curies in a given mass or volume (e.g., picocuries per liter). One curie is equivalent to 37 billion disintegrations per second or is a quantity of any radionuclide that decays at the rate of 37 billion disintegrations per second. Nuclear disintegrations produce spontaneous emissions of alpha or beta particles, gamma radiation, or combinations of these. In some instances in this report, radioactivity values are expressed with two

Table H.3. Names and Symbols for Units of Radioactivity

Symbol	Name
Ci	curie
cpm	counts per minute
mCi	millicurie (1×10^{-3} Ci)
µCi	microcurie (1×10^{-6} Ci)
nCi	nanocurie (1×10^{-9} Ci)
pCi	picocurie (1×10^{-12} Ci)
aCi	attocurie (1×10^{-18} Ci)
Bq	becquerel

sets of units, one of which is usually included in parentheses or footnotes. These units belong to the International System of Units (SI), and their inclusion in this report is mandated by DOE. SI units are the internationally accepted units and may eventually be the standard for reporting radioactivity and radiation dose in the United States. The basic unit for discussing radioactivity, the curie, can be converted to the equivalent SI unit, the becquerel (Bq), by multiplying the number of curies by 37 billion. The becquerel is defined as one nuclear disintegration per second.

Radiological Dose Units

The amount of ionizing radiation energy absorbed by a living organism is expressed in terms of radiological dose. Radiological dose in this report is usually written in terms of effective dose equivalent and reported numerically in units of millirem (mrem) or in the SI unit millisievert (mSv) (Table H.4). Millirem (millisievert) is a term that relates ionizing radiation and biological effect or risk (to humans). A dose of 1 mrem (0.01 mSv) has a biological effect similar to the dose received from an approximate 1-d exposure to natural background radiation. An acute (short-term) dose of 100,000 to 400,000 mrem (1,000 to 4,000 mSv) can cause radiation sickness in humans. An acute dose of 400,000 to 500,000 mrem (4,000 to 5,000 mSv), if left untreated, results in death approximately 50% of the time. Exposure to lower amounts of radiation (1,000 mrem [10 mSv] or less) produces no immediate observable effects, but long-term (delayed) effects are possible. The average person in the United States receives an annual dose from exposure to naturally produced radiation of approximately 300 mrem (3 mSv). Medical and dental x-rays and air travel add to this total. (See Section 5.0.6, "Hanford Public Radiological Dose in Perspective," for a more in-depth discussion of risk comparisons.) To convert the most commonly used dose term in this report, the millirem, to the SI equivalent, the millisievert, multiply millirem by 0.01. The unit "rad," for radiation absorbed dose, or the SI unit, gray (Gy), are also used in this report. The rad is a measure of the energy absorbed by any material, whereas a rem relates to both the amount of radiation energy absorbed by humans and its consequence. A roentgen (R) is a measure of radiation exposure with no SI equivalent. Generally speaking, 1 R of exposure will result in an effective dose equivalent of 1 rem (10 mSv).

Table H.4. Names and Symbols for Units of Radiation Dose or Exposure

Symbol	Name
mrad	millirad (1 x 10^{-3} rad)
mrem	millirem (1 x 10^{-3} rem)
Sv	sievert
mSv	millisievert (1 x 10^{-3} Sv)
µSv	microsievert (1 x 10^{-6} Sv)
R	roentgen
mR	milliroentgen (1 x 10^{-3} R)
µR	microroentgen (1 x 10^{-6} R)
Gy	gray

Additional information on radiation and dose terminology can be found in Appendix B, "Glossary." A list of the radionuclides discussed in this report, their symbols, and their half-lives are included in Table H.5.

Table H.5. Radionuclides and Their Half-Lives[a]

Symbol	Radionuclide	Half-Life	Symbol	Radionuclide	Half-Life
^{3}H	tritium	12.35 yr	^{152}Eu	europium-152	13.3 yr
^{7}Be	beryllium-7	53.44 d	^{154}Eu	europium-154	8.8 yr
^{14}C	carbon-14	5,730 yr	^{155}Eu	europium-155	5 yr
^{40}K	potassium-40	1.3×10^{8} yr	^{212}Pb	lead-212	10.6 h
^{51}Cr	chromium-51	27.7 d	^{220}Rn	radon-220	56 s
^{60}Co	cobalt-60	5.3 yr	^{222}Rn	radon-222	3.8 d
^{65}Zn	zinc-65	243.9 d	^{232}Th	thorium-232	1.4×10^{10} yr
^{85}Kr	krypton-85	10.7 yr	U or uranium[b]	uranium total	--[c]
^{90}Sr	strontium-90	29.1 yr	^{233}Pa	protactinium-233	27 d
^{95}Zr	zirconium-95	63.98 d	^{234}U	uranium-234	2.4×10^{5} yr
^{99}Tc	technetium-99	2.1×10^{5} yr	^{235}U	uranium-235	7×10^{8} yr
^{103}Ru	ruthenium-103	39.3 d	^{237}Np	neptunium-237	2.14×10^{6} yr
^{106}Ru	ruthenium-106	368.2 d	^{238}U	uranium-238	4.5×10^{9} yr
^{113}Sn	tin-113	115 d	^{238}Pu	plutonium-238	87.7 yr
^{125}Sb	antimony-125	2.8 yr	^{239}Pu	plutonium-239	2.4×10^{4} yr
^{129}I	iodine-129	1.6×10^{7} yr	^{240}Pu	plutonium-240	6.5×10^{3} yr
^{131}I	iodine-131	8 d	^{241}Pu	plutonium-241	14.4 yr
^{134}Cs	cesium-134	2.1 yr	^{241}Am	americium-241	432.2 yr
^{137}Cs	cesium-137	30 yr			

(a) From Shleien (1992).
(b) Total uranium may also be indicated by U-natural (U-nat) or U-mass.
(c) Natural uranium is a mixture dominated by uranium-238, thus the half-life is approximately 4.5×10^{9} yr.

Chemical and Elemental Nomenclature

The chemical contaminants discussed in this report are listed in Table H.6 along with their chemical (or elemental) names and their corresponding symbols.

Understanding the Data Tables

Total Propagated Analytical Uncertainty (2-Sigma Error)

Some degree of uncertainty is associated with all analytical measurements. This uncertainty is the consequence of a series of minor, often unintentional or unavoidable, inaccuracies related to collecting and analyzing the samples. These inaccuracies could include errors associated with reading or recording the result, handling or processing the sample, calibrating the counting instrument, and numerical rounding. With radionuclides, inaccuracies can also result from the randomness of radioactive decay.

Many of the individual measurements in this report are accompanied by a plus/minus (±) value, referred to as the total propagated analytical uncertainty (or 2-sigma error). For samples that are prepared or manipulated in the laboratory prior to counting (counting the rate of radioactive emissions from a sample), the total propagated analytical uncertainty includes both the counting uncertainty and

Table H.6. Elemental and Chemical Constituent Nomenclature

Symbol	Constituent	Symbol	Constituent
Ag	silver	Hg	mercury
Al	aluminum	K	potassium
As	arsenic	LiF	lithium fluoride
B	boron	Mg	magnesium
Ba	barium	Mn	manganese
Be	beryllium	Mo	molybdenum
Br	bromine	NH_3	ammonia
C	carbon	NH_4^+	ammonium
Ca	calcium	N	nitrogen
$CaCo_3$	calcium carbonate	Na	sodium
CaF_2	calcium fluoride	Ni	nickel
CCl_4	carbon tetrachloride	NO_2^-	nitrite
Cd	cadmium	NO_3^-	nitrate
$CHCl_3$	trichloromethane	Pb	lead
Cl^-	chloride	PO_4^{-3}	phosphate
CN^-	cyanide	P	phosphorus
Cr^{+6}	chromium (species)	Sb	antimony
Cr	chromium (total)	Se	selenium
CO_3^{-2}	carbonate	Si	silicon
Co	cobalt	Sr	strontium
Cu	copper	SO_4^{-2}	sulfate
F^-	fluoride	Ti	titanium
Fe	iron	Tl	thallium
HCO_3^-	bicarbonate	V	vanadium

the uncertainty associated with sample preparation and chemical separations. For samples that are not manipulated in the laboratory before counting, the total propagated analytical uncertainty only accounts for the uncertainty associated with counting the sample. The uncertainty associated with samples that are analyzed but not counted includes only the analytical process uncertainty.

The total propagated analytical uncertainty gives information on what the measurement (or result) might be if the same sample were analyzed again under identical conditions. The uncertainty implies that approximately 95% of the time a recount or reanalysis of the same sample would give a value somewhere between the reported value minus the uncertainty and the reported value plus the uncertainty.

If the reported concentration of a given constituent is smaller than its associated uncertainty (e.g., 40 ± 200), the sample may not contain that constituent. Such low-concentration values are considered to be below detection, meaning the concentration of the constituent in the sample is so low that it is undetected by the method and/or instrument. In this situation, the total propagated analytical uncertainty is assumed to be the nominal detection limit.

Standard Error of the Mean

Just as individual values are accompanied by counting uncertainties, mean values (averages) are accompanied by ±2 times the standard error of the calculated mean (±2 standard error of the mean). If the data fluctuate randomly, then two times the standard error of the mean is a measure of the uncertainty in the estimated mean of the data from this randomness. If trends or periodic (e.g., seasonal) fluctuations are present, then two times the standard

error of the mean is primarily a measure of the variability in the trends and fluctuations about the mean of the data. As with total propagated analytical uncertainty, two times the standard error of the mean implies that approximately 95% of the time the next calculated mean will fall somewhere between the reported value minus the standard error and the reported value plus the standard error.

Median, Maximum, and Minimum Values

Median, maximum, and minimum values are reported in some sections of this report. A median value is the middle value when all the values are arranged in order of increasing or decreasing magnitude. For example, the median value in the series of numbers, 1 2 3 3 4 5 5 5 6, is 4. The maximum value would be 6 and the minimum value would be 1. Median, maximum, and minimum values are reported when there are too few analytical results to accurately determine the mean with a ± statistical uncertainty or when the data do not follow a bell-shape (i.e., normal) distribution.

Negative Numbers

There is always a small amount of natural radiation in the environment. The instruments used in the laboratory to measure radioactivity in Hanford Site environmental media are sensitive enough to measure the natural, or background, radiation along with any contaminant radiation in a sample. To obtain a true measure of the contaminant level in a sample, the natural, or background, radiation level must be subtracted from the total amount of radioactivity measured by an instrument. Because of the randomness of radioactive emissions and the very low activities of some contaminants, it is possible to obtain a background measurement that is larger than the actual contaminant measurement. When the larger background measurement is subtracted from the smaller contaminant measurement, a negative result is generated. The negative results are reported because they are essential when conducting statistical evaluations of the data.

Understanding Graphic Information

Graphs are useful when comparing numbers collected at several locations or at one location over time. Graphs make it easy to visualize differences in data where they exist. However, while graphs may make it easy to evaluate data, they also may lead the reader to incorrect conclusions if they are not interpreted correctly. Careful consideration should be given to the scale (linear or logarithmic), concentration units, and type of uncertainty used.

Some of the data graphed in this report are plotted using logarithmic, or compressed, scales. Logarithmic scales are useful when plotting two or more numbers that differ greatly in size. For example, a sample with a concentration of 5 g/L would get lost at the bottom of the graph if plotted on a linear scale with a sample having a concentration of 1,000 g/L (Figure H.1). A logarithmic plot of these same two numbers allows the reader to see both data points clearly (Figure H.2).

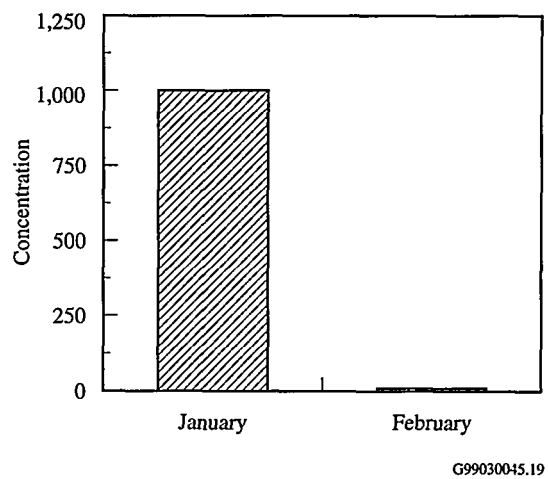


Figure H.1. Data Plotted Using a Linear Scale

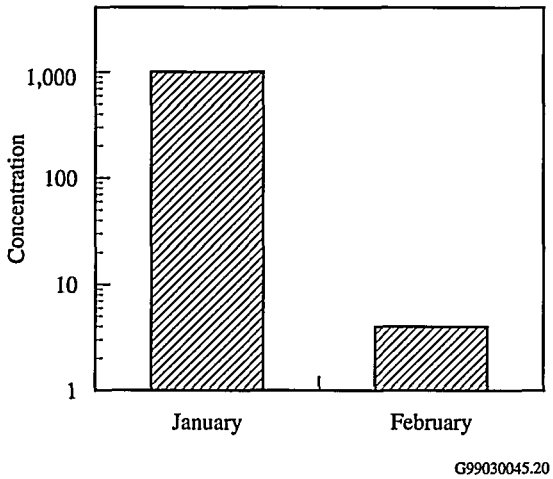


Figure H.2. Data Plotted Using a Logarithmic Scale

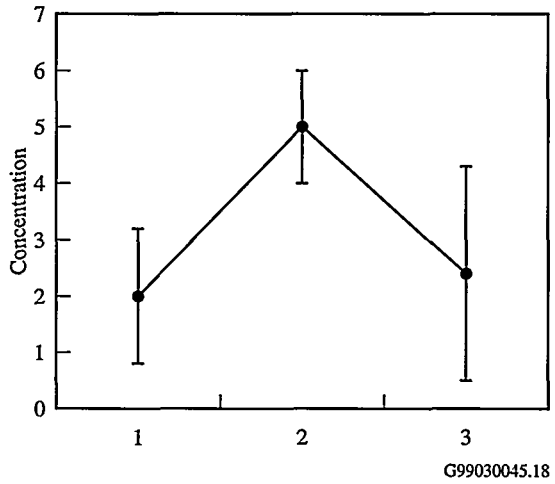


Figure H.3. Data with Error Bars Plotted Using a Linear Scale

The mean (average) and median (defined earlier) values graphed in this report have vertical lines extending above and below the data point. When used with a mean value, these lines (called error bars) indicate the amount of uncertainty (total propagated analytical uncertainty or two standard error of the mean) in the reported result. The error bars in this report represent a 95% chance that the mean is between the upper and lower ends of the error bar and a 5% chance that the true mean is either lower or higher than the error bar.[a] For example, in Figure H.3, the first plotted mean is 2.0 ± 1.1, so there is a 95% chance that the true mean is between 0.9 and 3.1, a 2.5% chance that it is less than 0.9, and a 2.5% chance that it is greater than 3.1. Error bars are computed statistically, employing all of the information used to generate the mean value. These bars provide a quick, visual indication that one mean may be statistically similar to or different from another mean. If the error bars of two or more means overlap, as is the case with means 1 and 3 and means 2 and 3, the means may be statistically similar. If the error bars do not overlap (means 1 and 2), the means may be statistically different. Means that appear to be very different visually (means 2 and 3) may actually be quite similar when compared statistically.

When vertical lines are used with median values, the lower end of each bar represents the minimum concentration measured; the upper end of each bar represents the maximum concentration measured.

Greater Than (>) or Less Than (<) Symbols

Greater than (>) or less than (<) symbols are used to indicate that the actual value may either be larger than the number given or smaller than the number given. For example, >0.09 would indicate that the actual value is greater than 0.09. An inequality symbol pointed in the opposite direction (<0.09) would indicate that the number is less than the value presented. An inequality symbol used with an underscore (≤ or ≥) indicates that the actual value is less than or equal to or greater than or equal to the number given, respectively.

(a) Assuming a normal statistical distribution of the data.

References

American Indian Religious Freedom Act. 1978. Public Law 95-341, as amended, 92 Stat. 469.

Archaeological Resources Protection Act. 1979. Public Law 96-95, as amended, 93 Stat. 721.

Clean Air Act. 1986. Public Law 88-206, as amended, 42 USC 7401 et seq.

Clean Water Act. 1997. Public Law 95-217, as amended, 91 Stat. 1566 and Public Law 96-148 as amended.

Comprehensive Environmental Response, Compensation, and Liability Act. 1980. Public Law 96-150, as amended, 94 Stat. 2767, 42 USC 9601 et seq.

DOE Order 231.1. "Environment, Safety, and Health Reporting."

DOE Order 5400.1. "General Environmental Protection Program."

DOE M 231.1-1. 1995. *Environment, Safety and Health Reporting Manual.* U.S. Department of Energy, Assistant Secretary for Environment, Safety and Health, Office of Nuclear Facility Safety, Washington, D.C.

Emergency Planning and Community Right-To-Know Act. 1986. Public Law 99-499, as amended, 100 Stat. 1728, 42 USC 11001 et seq.

Endangered Species Act. 1973. Public Laws 93-205 through 100-707, as amended, 87 Stat. 884, 16 USC 1531 et seq.

Federal Insecticide, Fungicide, and Rodenticide Act. 1975. Public Laws 94-51 through 94-140, as amended, 7 USC 136 et seq.

ISO 14001. 1996. *Environmental Management Systems—Specifications with Guidance for Use.* American Society for Testing and Materials, West Conshohocken, Pennsylvania.

National Environmental Policy Act. 1969. Public Laws 91-190, as amended, 42 USC 4321 et seq.

National Historic Preservation Act. 1966. Public Law 89-665, as amended, 80 Stat. 915-919.

Native American Graves Protection and Repatriation Act. 1990. Public Law 101-601, as amended, 25 USC 3001 et seq.

Resource Conservation and Recovery Act. 1976. Public Law 94-580, as amended, 90 Stat. 2795, 42 USC 6901 et seq.

Safe Drinking Water Act. 1974. Public Law 93-523, as amended, 88 Stat. 1660, 42 USC 300f et seq.

Shleien, B. 1992. *The Health Physics and Radiological Health Handbook, Revised Edition.* Scinta, Inc., Silver Spring, Maryland.

Toxic Substances Control Act. 1976. Public Law 94-469, as amended, 90 Stat. 2003, 15 USC 2601 et seq.

1.0 Introduction

R. W. Hanf, K. R. Price, and D. G. Black

This Hanford Site environmental report is produced through the joint efforts of the principal site contractors (Pacific Northwest National Laboratory, Fluor Daniel Hanford, Inc. and its subcontractors, Bechtel Hanford, Inc. and its subcontractors, and MACTEC-ERS). This report, published annually since 1958, includes information and summary data that 1) characterize environmental management performance at the Hanford Site; 2) demonstrate the status of the site's compliance with applicable federal, state, and local environmental laws and regulations; and 3) highlight significant environmental monitoring and surveillance programs and projects.

Specifically, this report provides a short introduction to the Hanford Site and its history; discusses the site mission; and briefly highlights the site's various waste management, effluent monitoring, environmental surveillance, and environmental compliance programs and projects. Included are summary data and descriptions for the Hanford Site Groundwater/Vadose Zone Integration Project, the Near-Facility Environmental Monitoring Program, the Integrated Biological Control Program, the Surface Environmental Surveillance Project, the Hanford Groundwater Monitoring Project, the Hanford Cultural Resources Laboratory, wildlife studies, climate and meteorological monitoring, and information about other programs and projects. Also included are sections discussing environmental occurrences, current issues and actions, environmental cleanup activities, compliance issues, and descriptions of major operations and activities. Readers interested in more detail than that provided in this report should consult the technical documents cited in the text and listed in the reference sections. Descriptions of specific analytical and sampling methods used in the monitoring efforts are contained in the Hanford Site environmental monitoring plan (DOE/RL-91-50, Rev. 2).

1.0.1 Overview of the Hanford Site

The Hanford Site lies within the semiarid Pasco Basin of the Columbia Plateau in southeastern Washington State (Figure 1.0.1). The site occupies an area of approximately 1,450 km^2 (approximately 560 mi^2) located north of the city of Richland and the confluence of the Yakima and Columbia Rivers. This large area has restricted public access and provides a buffer for the smaller areas on the site that historically were used for production of nuclear materials, waste storage, and waste disposal. Only approximately 6% of the land area has been disturbed and actively used. The Columbia River flows eastward through the northern part of the Hanford Site and then turns south, forming part of the eastern site boundary. The Yakima River flows near a portion of the southern boundary and joins the Columbia River at the city of Richland.

The cities of Richland, Kennewick, and Pasco (Tri-Cities) constitute the nearest population centers and are located southeast of the site. Land in the surrounding environs is used for urban and industrial development, irrigated and dry-land farming, and grazing. In 1995, wheat represented the largest single crop in terms of area planted in Benton and Franklin Counties. Total area planted in the two counties was 100,770 and 18,810 ha (249,000 and 46,500 acres) for winter and spring wheat, respectively. Alfalfa, apples, asparagus, cherries, corn, grapes, and potatoes are other major crops in Benton and Franklin

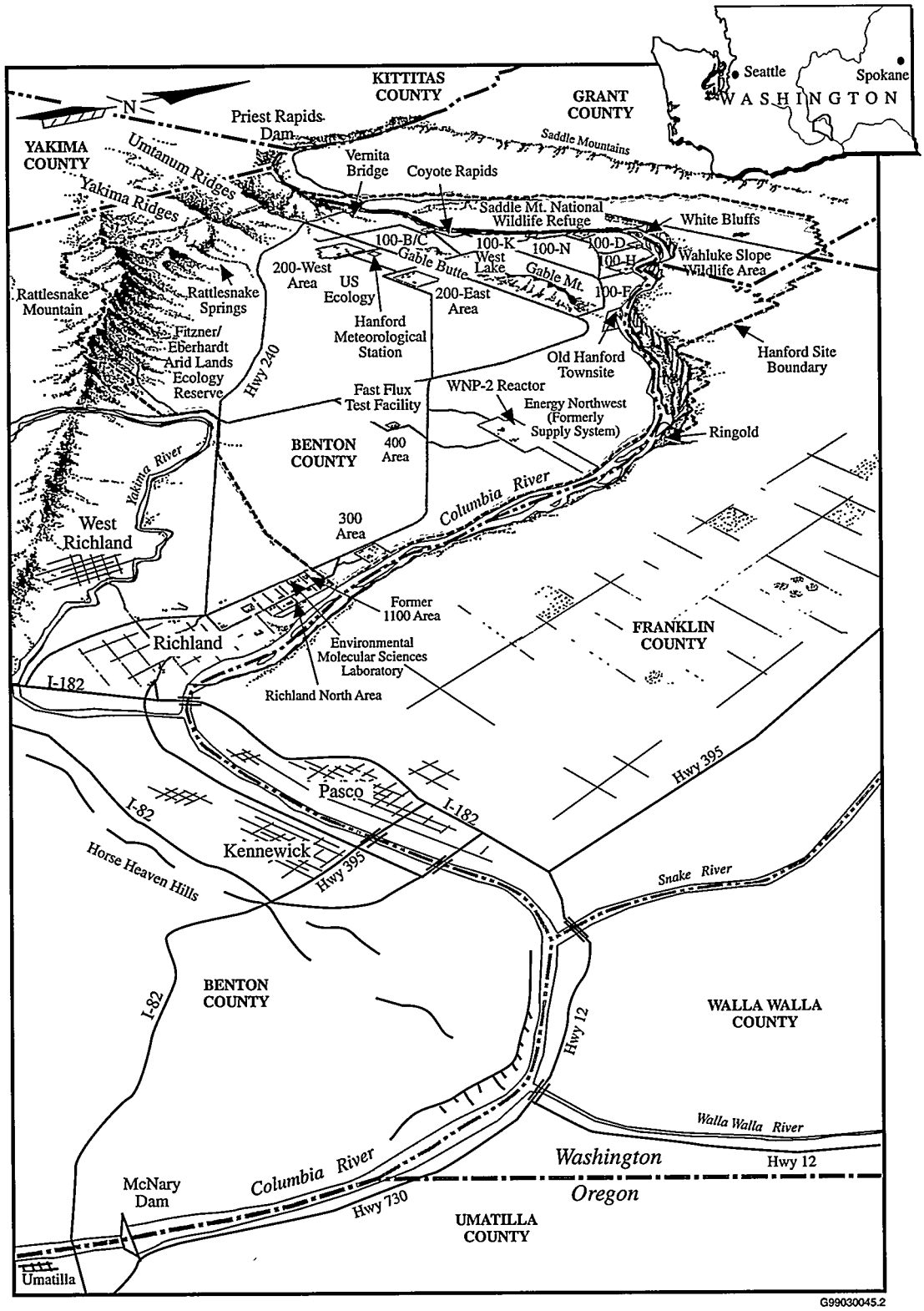


Figure 1.0.1. The Hanford Site and Surrounding Area

Counties. More than 20 food processors in Benton and Franklin Counties produce food products, including potato products, canned fruits and vegetables, wine, and animal feed.

In 1997, approximately 20% of the nonagricultural jobs in Benton and Franklin Counties were located at Hanford. An average of 11,140 employees were working on the site in 1997. Hanford's large portion of the Tri-Cities' employment has had an impact on other areas of employment, directly or indirectly accounting for >40% of all jobs in Benton and Franklin Counties.

Estimates for 1997 placed population totals for Benton and Franklin Counties at 134,100 and 43,900, respectively (Washington State Office of Financial Management 1997a). When compared to the 1990 census data (U.S. Bureau of the Census 1994) in which Benton County had 112,560 individuals and Franklin County had 37,473 individuals, the population totals reflect continued growth. The populations in Benton and Franklin Counties increased by 3,000 and 200, respectively, in 1997.

The 1997 estimates distributed the Tri-Cities' population within each city as follows: Richland 36,500, Pasco 25,300, and Kennewick 49,090. The combined populations of Benton City, Prosser, and West Richland totaled 13,905 in 1997. The unincorporated population of Benton County was 34,555. In Franklin County, incorporated areas (cities and towns) other than Pasco have a total population of 3,385. The unincorporated rural population of Franklin County was 15,215 (Washington State Office of Financial Management 1997a), and the number of people in incorporated areas other than Pasco was 3,385.

The 1997 estimates of racial/ethnic distribution (Washington State Office of Financial Management 1997a) indicate that Asians represent a lower proportion and individuals of Hispanic origin represent a higher proportion of the population in Benton and Franklin Counties than those in Washington State. At the time of the 1990 census (U.S. Bureau of Census 1994), Hispanics accounted for nearly 81% of the minority population around the Hanford Site. The site is also surrounded by a relatively large percentage (approximately 8%) of Native Americans.

Benton and Franklin Counties account for 2.4% of Washington State's population (Washington State Office of Financial Management 1997b). In 1997, the population demographics of Benton and Franklin Counties were quite similar to those found within Washington State. The population in Benton and Franklin Counties under the age of 35 was 54.1%, compared to 50.3% for the state. In general, the population of Benton and Franklin Counties was somewhat younger than that of the state. The 0- to 14-year-old age group accounted for 26.5% of the total bicounty population, compared to 22.6% for the state. In 1997, the 65-year-old and older age group constituted 9.6% of the population of Benton and Franklin Counties, compared to 11.5% for the state.

1.0.1.1 Site Description

The entire Hanford Site was designated a National Environmental Research Park (one of four nationally) by the former U.S. Energy Research and Development Administration, a precursor to the U.S. Department of Energy (DOE).

The major areas on the site include the following:

- The 100 Areas, on the south shore of the Columbia River, are the sites of nine retired plutonium-production reactors, including the dual-purpose N Reactor. The 100 Areas occupy approximately 11 km^2 (4 mi^2).
- The 200-West and 200-East Areas are located on a plateau and are approximately 8 and 11 km (5 and 7 mi), respectively, south of the Columbia River. The 200 Areas cover approximately 16 km^2 (6 mi^2).
- The 300 Area is located just north of the city of Richland. This area covers 1.5 km^2 (0.6 mi^2).
- The 400 Area is approximately 8 km (5 mi) northwest of the 300 Area.

- The 600 Area includes all of the Hanford Site not occupied by the 100, 200, 300, and 400 Areas.
- The former 311-ha (768-acre) 1100 Area is located generally between the 300 Area and the city of Richland and included site support services such as general stores and transportation maintenance. On October 1, 1998, this area was transferred to the Port of Benton as a part of economic diversification efforts and is no longer part of the Hanford Site. However, DOE contractors continue to lease facilities in this area.
- The Richland North Area (off the site) includes the DOE and its contractor facilities, mostly leased office buildings, generally located in the northern part of the city of Richland.

Other facilities (office buildings) are located in the Richland Central Area (located south of Saint Street and Highway 240 and north of the Yakima River), the Richland South Area (located between the Yakima River and Kennewick), and the Kennewick/Pasco area.

Several areas of the site, totaling 665 km^2 (257 mi^2), have special designations. These include the Fitzner/Eberhardt Arid Lands Ecology Reserve (310 km^2 [120 mi^2]), the U.S. Fish and Wildlife Service Saddle Mountain National Wildlife Refuge (approximately 130 km^2 [50 mi^2]), and the Washington State Department of Fish and Wildlife Reserve Area (Wahluke Slope Wildlife Recreation Area) (225 km^2 [87 mi^2]). The Fitzner/Eberhardt Arid Lands Ecology Reserve was established in 1967 by the U.S. Atomic Energy Commission, a precursor to DOE, to preserve shrub-steppe habitat and vegetation. In 1971, the reserve was classified a Research Natural Area as a result of a federal interagency cooperative agreement. In June 1997, DOE transferred management, including access management, of the reserve from Pacific Northwest National Laboratory to the U.S. Fish and Wildlife Service, who will continue to operate the reserve using the in-place management policy (PNL-8506) until a new management plan can be written. This is scheduled to occur within 3 years of the June 1997 transfer date.

Secretary of Energy Bill Richardson announced in April 1999 a proposal to manage the entire Wahluke Slope area as a national wildlife refuge. Because the Washington State Department of Fish and Wildlife expressed an interest in withdrawing from management of the Wahluke Slope Wildlife Recreation Area, the recreation area and the Saddle Mountain National Wildlife Refuge would be combined and managed by the U.S. Fish and Wildlife Service for the DOE. The Wahluke Slope is a prime example of a shrub-steppe habitat that is quickly disappearing in the Pacific Northwest. This land has served as a safety and security buffer zone for Hanford operations since 1943, resulting in an ecosystem that has been relatively untouched.

Non-DOE operations and activities on Hanford Site leased land or in leased facilities include commercial power production by Energy Northwest (formerly known as the Washington Public Power Supply System) (WNP-2 reactor) (4.4 km^2 [1.6 mi^2]) and operation of a commercial low-level radioactive waste burial site by US Ecology, Inc. (0.4 km^2 [0.2 mi^2]). Kaiser Aluminum and Chemical Corporation is leasing the 313 Building in the 300 Area to use an extrusion press that was formerly DOE owned. The National Science Foundation has built the Laser Interferometer Gravitational-Wave Observatory facility near Rattlesnake Mountain for gravitational wave studies. R. H. Smith Distributing operates vehicle-fueling stations in the former 1100 Area and 200 Areas. Washington State University at Tri-Cities operates three laboratories in the 300 Area. Livingston Rebuild Center, Inc. has leased the 1171 Building, in the former 1100 Area, to rebuild train locomotives. Johnson Controls, Inc. operates 42 diesel- and natural gas-fueled package boilers for producing steam in the 200 and 300 Areas (replacing the old coal-fired steam plants) and also has compressors supplying compressed air to the site. Immediately adjacent to the southern boundary of the Hanford Site, Siemens Power Corporation operates a commercial nuclear fuel fabrication facility and

Allied Technology Group Corporation operates a low-level radioactive waste decontamination, super compaction, and packaging facility.

Much of the above information is from PNNL-6415, Rev. 10, where more detailed information can be found.

1.0.2 Historical Site Operations

This section addresses what, until recently, was the historic operational mission of the Hanford Site. However, with the advent of waste treatment and disposal technologies and environmental management, this mission has been replaced by cleanup. Section 1.0.3, "Current Site Mission," Section 1.0.5, "Major Site Activities," and Section 2.3, "Activities, Accomplishments, and Issues," summarize current activities at the Hanford Site.

The Hanford Site was established in 1943 to use technology developed at the University of Chicago and the Clinton Laboratory in Oak Ridge, Tennessee to produce plutonium for some of the nuclear weapons tested and used in World War II. Hanford was the first plutonium production facility in the world. The site was selected by the U.S. Army Corps of Engineers because it was remote from major populated areas and had 1) ample electrical power from Grand Coulee Dam, 2) a functional railroad, 3) clean water from the nearby Columbia River, and 4) sand and gravel that could be used for constructing large concrete structures. For security, safety, and functional reasons, the site was divided into numbered areas (see Figure 1.0.1).

Hanford Site operations have resulted in the production of liquid, solid, and gaseous wastes. Most wastes resulting from site operations have had at least the potential to contain radioactive materials. From an operational standpoint, radioactive wastes were originally categorized (see Table 10.3 in Fitzgerald 1970) as "high level," "intermediate level," or "low level," which referred to the level of radioactivity present. Some high-level solid waste, such as large pieces of machinery and equipment, were placed onto railroad flatcars and stored in underground tunnels. Both intermediate- and low-level solid wastes, consisting of tools, machinery, paper, wood, etc., were placed into covered trenches at storage and disposal sites known as "burial grounds." Beginning in 1970, solid wastes were segregated according to the makeup of the waste material. Solids contaminated with plutonium and other transuranic materials were packaged in special containers and stored in trenches covered with soil for possible later retrieval. High-level liquid wastes were stored in large underground tanks. Intermediate-level liquid waste streams were usually routed to underground structures of various types called "cribs." Occasionally, trenches were filled with the liquid waste and then covered with soil after the waste had soaked into the ground. Low-level liquid waste streams were usually routed to surface impoundments (ditches and ponds). Nonradioactive solid wastes were usually burned in "burning grounds." This practice was discontinued in the late 1960s in response to the Clean Air Act, and the materials were buried at sanitary landfill sites. These storage and disposal sites, with the exception of high-level waste tanks, are now designated as "active" or "inactive" waste sites, depending on whether the site is receiving wastes.

All unrestricted discharges of radioactive liquid wastes to the ground were discontinued in 1997. The 616-A crib (also known as the State-Approved Land Disposal Site) receives radioactive (tritium) liquid waste from the 200 Areas Effluent Treatment Facility. This effluent is the only discharge of radioactive liquid wastes to the ground at Hanford. All other liquids discharged to the ground are licensed by permit from the state of Washington. National Pollutant Discharge Elimination System permits issued by the U.S. Environmental Protection Agency

govern liquid discharges to the Columbia River (Title 40, Code of Federal Regulations, Part 122). Permits from the U.S. Environmental Protection Agency and the Washington State Department of Health govern the discharge of gaseous effluents to the atmosphere. See Section 2.2, "Compliance Status," for details. The status of the high-level waste tanks is discussed in Section 2.3.8, "Tank Waste Remediation System Activities."

1.0.2.1 The 300 Area

From the early 1940s until the advent of the cleanup mission, most research and development activities at the Hanford Site were carried out in the 300 Area, located just north of Richland. The 300 Area was also the location of nuclear fuel fabrication. Nuclear fuel in the form of pipe-like cylinders (fuel elements) was fabricated from metallic uranium shipped in from offsite production facilities. Metallic uranium was extruded into the proper shape and encapsulated in aluminum or zirconium cladding. Copper was an important material used in the extrusion process, and substantial amounts of copper, uranium, and other heavy metals ended up in 300 Area liquid waste streams. Initially, these streams were routed to the 300 Area waste ponds, which were located near the Columbia River shoreline. In more recent times, the low-level liquid wastes were sent to process trenches or shipped to a solar evaporation facility in the 100-H Area (183-H Solar Evaporation Basins). This practice has been discontinued. At this time, all liquid process wastes generated in the 300 Area are sent to the 300 Area Treated Effluent Disposal Facility for treatment and release to the Columbia River according to the requirements of a National Pollutant Discharge Elimination System permit. Sewage wastes are released into the city of Richland sanitary water treatment system.

Former fuel fabrication buildings and facilities are now used for other purposes or are in various stages of cleanup or restoration. For example, the 313 Building that houses a very large and unique aluminum extrusion press is leased by DOE to Kaiser Aluminum and Chemical Corporation.

1.0.2.2 The 100 Areas

The fabricated fuel elements were shipped by rail from the 300 Area to the 100 Areas. The 100 Areas are located on the Columbia River shoreline, where up to nine nuclear reactors were in operation (Section 6.1, "Hanford Groundwater Monitoring Project," discusses these operations). The main component of the nuclear reactors consisted of a large stack (pile) of graphite blocks that had tubes and pipes running through it. The tubes were receptacles for the fuel elements while the pipes carried water to cool the graphite pile. Placing large numbers of slightly radioactive uranium fuel elements into the reactor piles created an intense radiation field and a radioactive chain reaction resulted in the conversion of some uranium atoms into plutonium atoms. Other uranium atoms were split into radioactive "fission products." The intense radiation field also caused some nonradioactive atoms in the structure to become radioactive "activation products."

The first eight reactors, constructed between 1944 and 1955, used water from the Columbia River for direct cooling. Large quantities of water were pumped through the reactor piles and discharged back into the river. The discharged cooling water contained primarily activation products from impurities in the river water made radioactive by neutron activation and radioactive materials that escaped from the fuel elements, tube walls, etc. during the irradiation process. The ninth reactor, N Reactor, was completed in 1963 and was of a modified design. Purified water was recirculated through the reactor core in a closed-loop cooling system. Beginning in 1966, the heat from the closed-loop system was used to produce steam that was sold to Energy Northwest (formerly known as the Washington Public Power Supply System) to generate electricity at the adjacent Hanford Generating Plant.

When fresh fuel elements were pushed into the front face of a reactor's graphite pile, irradiated fuel elements were forced out the rear into a deep pool of water called a "fuel storage basin." After a brief period of storage in the basin, the irradiated fuel was shipped to the 200 Areas for processing. The fuel was shipped in casks by rail in specially constructed railcars. Most of the irradiated fuel produced by the N Reactor from the early 1970s to the early 1980s was the result of electricity production runs. This material was not weapons grade, so was never processed for recovery of plutonium.

Beginning in 1975, N Reactor irradiated fuel was shipped to the K-East and K-West Fuel Storage Basins (K Basins) for temporary storage, where it remains today. This fuel accounts for the majority of the total fuel inventory stored under water in the K Basins. From the early 1980s until its shutdown in 1987, N Reactor operated to produce weapons-grade material. Electricity production continued during this operating period but was actually a byproduct of the weapons production program. The majority of weapons-grade material produced during these runs was processed in the 200-East Area at the Plutonium-Uranium Extraction Plant prior to its shutdown. The remainder is stored in the K Basins. See Section 2.3.4, "Spent Nuclear Fuel Project," for the status and details regarding the storage of spent fuel.

All of the Hanford production reactors and most of the associated facilities have been shut down and deactivated, and each 100 Area is in some stage of cleanup, decommissioning, or restoration. For example, C Reactor has been cocooned and placed into interim safe storage as a large-scale demonstration, a state that it can safely remain in for many years. Of the 24 facilities associated with the reactor, 23 have been removed. See Section 1.0.5.4, "Environmental Restoration," and Section 2.3, "Activities, Accomplishments, and Issues," for the status of various facilities.

1.0.2.3 The 200 Areas

The 200-East and 200-West Areas are located on a plateau approximately in the center of the site. These areas house facilities that received and dissolved irradiated fuel and then separated out the valuable plutonium (Figure 1.0.2). These facilities were called "separations plants." Three types of separations plants were used over the years to process irradiated fuel. Each of the plutonium production processes began with the dissolution of the aluminum or zirconium cladding material in solutions containing ammonium hydroxide/ammonium nitrate/ammonium fluoride followed by the dissolution of the irradiated fuel elements in nitric acid. All three separations plants, therefore, produced large quantities of waste nitric acid solutions that contained high levels of radioactive materials. These wastes were neutralized and stored in large underground tanks. Fumes from the dissolution of cladding and fuel and from other plant processes were discharged to the atmosphere from tall smokestacks. Filters were added to the stacks after 1950.

Both B and T Plants used a "bismuth phosphate" process to precipitate and separate plutonium from acid solutions during the early days of site operations. Leftover uranium and high-level waste products were not separated and were stored together in large, underground, "single-shell" tanks (i.e., tanks constructed with a single wall of steel). The leftover uranium was later salvaged, purified into uranium oxide powder at the Uranium-TriOxide Plant, and transported to uranium production facilities in other parts of the country for reuse. The salvage process used a solvent extraction technique that resulted in radioactive liquid waste that was discharged to the soil in covered trenches at the BC Cribs area south of the 200-East Area.

After T Plant stopped functioning as a separations facility, it was converted to a decontamination operation, where pieces of equipment and machinery could be radiologically decontaminated for reuse.

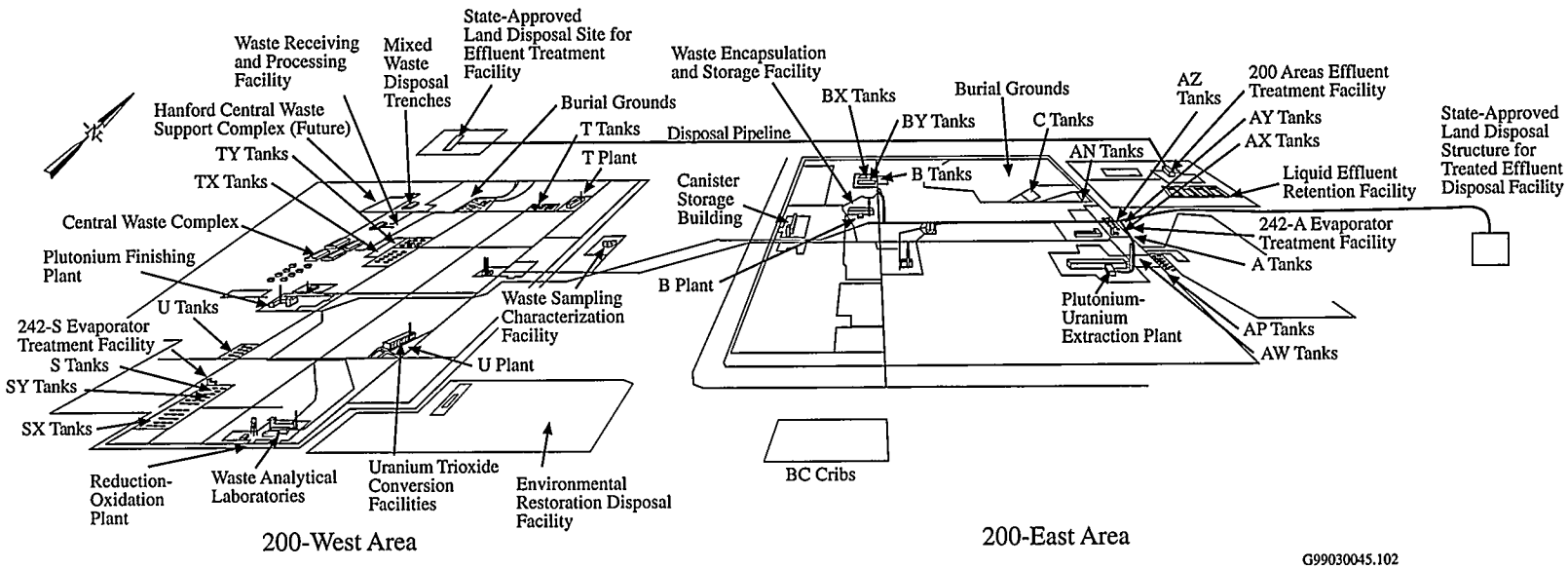


Figure 1.0.2. Waste Processing, Storage, and Disposal Facilities in the 200 Areas

B Plant was later converted into a facility to separate radioactive strontium and cesium from high-level waste. The strontium and cesium were then concentrated into a solid salt material, melted, and encapsulated at the adjacent encapsulation facility. Canisters of encapsulated strontium and cesium were stored in a water storage basin at the encapsulation facility, where many remain today.

In 1952, U Plant in the 200-West Area, built during World War II but not needed as a processing canyon, was retrofitted as the Metal Recovery Plant. Its mission was to use a new tributyl phosphate/saturated kerosene extraction technique to recover uranium from the waste stored in Hanford's tank farms. The scarcity of high-grade uranium supplies made this mission crucial and much of the United States' supply of uranium was housed in Hanford's tanks. The separated uranium was purified into uranium oxide powder at the Uranium-TriOxide Plant.

The Reduction-Oxidation and Plutonium-Uranium Extraction Plants used solvent extraction techniques to separate plutonium from leftover uranium and radioactive waste products. Most of the irradiated fuel produced at the site was processed at either of these two plants. The solvent extraction method separates chemicals based on their differing solubilities in water and organic solvents (i.e., hexone at the Reduction-Oxidation Plant and tributyl-phosphate at the Plutonium-Uranium Extraction Plant). High-level liquid wastes were neutralized and stored in single-shell tanks (Reduction-Oxidation Plant) or double-shell tanks (Plutonium-Uranium Extraction Plant). Occasionally, organic materials such as solvents and resins ended up in high-level liquid waste streams sent to the tanks. Various chemicals and radioactive materials precipitated and settled to the bottom of the tanks. This phenomenon was later used to advantage. The liquid waste was heated in special facilities (evaporators) to remove excess water and concentrate the waste into salt cake and sludge, which remained in the tanks. The evaporated and condensed water contained radioactive tritium and was discharged to cribs. Intermediate- and low-level liquid wastes discharged to the soil from the Reduction-Oxidation and Plutonium-Uranium Extraction Plants typically contained tritium and other radioactive fission products as well as nonradioactive nitrate. Intermediate-level liquid wastes discharged to cribs from the Reduction-Oxidation Plant sometimes contained hexone used in the reduction-oxidation process. Cooling water from the Reduction-Oxidation Plant was discharged to the 216-S-10 Pond. Cooling water from the Plutonium-Uranium Extraction Plant was discharged to the Gable Mountain and 216-B-3 Ponds.

The Reduction-Oxidation and Plutonium-Uranium Extraction Plants produced uranium nitrate for recycle and plutonium nitrate for weapons component production. Uranium nitrate was shipped by tank truck to the Uranium-TriOxide Plant for processing. The Uranium-TriOxide Plant used specially designed machinery to heat the uranium nitrate solution and boil off the nitric acid, which was recovered and recycled to the separations plants. The product (uranium oxide) was packaged and shipped to other facilities in the United States for recycle. Plutonium nitrate, in small quantities for safety reasons, was placed into special shipping containers (P-R cans) and hauled by truck to Z Plant (later called the Plutonium Finishing Plant) for further processing.

The purpose of Plutonium Finishing Plant operations was to convert the plutonium nitrate into plutonium metal blanks (buttons) that were shipped off the site for manufacture into nuclear components. The conversion processes used nitric acid, hydrofluoric acid, carbon tetrachloride, and other organic compounds. Varying amounts of all these materials ended up in the intermediate-level liquid wastes that were discharged to cribs. Cooling water from the Plutonium Finishing Plant was discharged via open

ditch to the 216-U-10 Pond. High-level solid wastes containing plutonium scraps were segregated and packaged for storage in special earth-covered trenches.

All of the former activities in the separations plants, the Reduction-Oxidation Plant, and the Plutonium Finishing Plant have been shut down and the facilities are in various stages of decontamination and decommissioning or alternate use. For example, the former T Plant complex now consists of two operational facilities used for waste sampling and verification, waste repackaging, equipment decontamination, and storage of a small amount of irradiated fuel from the former Shippingport, Pennsylvania reactor. See Section 1.0.5.3, "Facility Stabilization," Section 1.0.5.4, "Environmental Restoration," and Section 2.3.5, "Facility Stabilization Project," for additional information. Low-level and intermediate-level liquid wastes are no longer released to surface ponds, ditches, or cribs. These facilities are in various states of decommissioning, decontamination, and restoration. See Section 1.0.5.1, "Waste Management," and Section 2.2, "Compliance Status" (especially Table 2.2.2), for details.

1.0.2.4 The 400 Area

In addition to research and development activities in the 300 Area, the Hanford Site has supported several test facilities. The largest is the Fast Flux Test Facility, located approximately 8 km (5 mi) northwest of the 300 Area. This special nuclear reactor was designed to test various types of nuclear fuel. The facility operated for approximately 13 yr and was shut down in 1993. The reactor was a unique design that used liquid metal sodium as the primary coolant. The heated liquid sodium was cooled with atmospheric air in heat exchangers. Spent fuel from the facility resides in the 400 Area, while other wastes were transported to the 200 Areas. With the exception of the spent fuel, no major amounts of radioactive wastes were stored or disposed of at the Fast Flux Test Facility site. In January 1997, DOE made a decision to keep the Fast Flux Test Facility in standby while evaluating its potential for tritium and medical isotope production, as well as plutonium disposition. Tritium, a necessary ingredient in some nuclear weapons, decays relatively quickly so must be replenished. Medical isotopes are radioactive elements that are useful for the treatment of medical conditions such as cancer. Excess plutonium, no longer needed for national defense, could be disposed of by converting it to reactor fuel that could be burned in commercial reactors. Decisions were made in 1998 to not use the Fast Flux Test Facility for tritium production or plutonium disposition. A decision on any civilian missions for the facility, such as medical isotope production, is expected in 1999. Details can be found in Section 2.3.6, "Fast Flux Test Facility."

1.0.3 Current Site Mission

For more than 40 years, Hanford Site facilities were dedicated primarily to the production of plutonium for national defense and to the management of the resulting wastes. In recent years, efforts at the site have focused on developing new waste treatment and disposal technologies and cleaning up contamination left over from historical operations.

Site activities include two major missions: 1) environmental management and 2) science and technology. The environmental management mission includes the following:

- **management of wastes** and the handling, storage, treatment, and disposal of radioactive, hazardous, mixed, or sanitary wastes from past and current operations
- **stabilizing facilities** by transitioning them from an operating mode to a long-term surveillance and maintenance mode. This includes maintaining facilities in a safe and compliant status, deactivating primary systems to effectively reduce risks, providing

for the safe storage of nuclear materials and reducing risks from hazardous materials and contamination. These activities are intended to allow the lowest surveillance and maintenance cost to be attained while awaiting determination of a facility's final disposition.

- **maintaining the Fast Flux Test Facility** reactor and its associated support facilities while alternative future missions for the reactor are explored (e.g., medical isotope production)
- **maintenance and cleanup** of several hundred inactive radioactive, hazardous, and mixed waste disposal sites; **remediation** of contaminated groundwater; and **surveillance, maintenance, and decommissioning** of inactive facilities.

The science and technology mission includes the following:

- **research and development** in energy, health, safety, environmental sciences, molecular sciences, environmental restoration, waste management, and national security
- **developing new technologies** for environmental restoration and waste management, including site characterization and assessment methods; waste minimization, treatment, and remediation technology.

DOE has set a goal of cleaning up Hanford's waste sites and ensuring that its facilities are always in compliance with federal, state, and local environmental laws. In addition to supporting the environmental management mission, DOE is also supporting other special initiatives in accomplishing its national objective.

The highest priority of the DOE Richland Operations Office is to achieve daily excellence in protection of the worker and the public and in stewardship of the environment, both on and off the Hanford Site. By meeting the most rigorous standards, the DOE Richland Operations Office provides safe and healthful workplaces and protects the environment of all Richland Operations' activities. Fundamental to the attainment of this policy are personal commitment and accountability, mutual trust, open communications, continuous improvement, worker involvement, and full participation of all interested parties. Consistent with the strategic plan for the site (DOE/RL-96-92), the Richland Operations Office will reduce accidents, radiological and toxicological exposures, and regulatory noncompliances.

1.0.4 Site Management

Hanford Site operations and activities are managed by the DOE Richland Operations Office through the following contractors and subcontractors. Each contractor is responsible for safe, environmentally sound maintenance and management of its activities or facilities; for waste management; and for monitoring its activities and any potential effluents to ensure environmental compliance.

The principal contractors and their respective responsibilities include the following:

- Fluor Daniel Hanford, Inc., the management and integration contractor, is the prime contractor under the Project Hanford Management Contract awarded in 1996. The Project Hanford Management Contract encompasses the majority of the work under way at the Hanford Site as it relates to DOE's mission to clean up the site. Major subcontractors of Fluor Daniel Hanford, Inc. and their areas of responsibility are as follows.
  - Lockheed Martin Hanford Corporation—responsible for safely managing the underground waste containment tanks and for tank waste remediation systems. With 177 underground waste containment tanks at the site, they are evaluating tank contents, treatment alternatives, retrieval alternatives, and closure alternatives.
  - Waste Management Federal Services of Hanford, Inc.—responsible for waste management.

They use existing technology to accelerate treatment and disposal of waste, reduce the need for waste storage, and minimize waste disposition.

- Fluor Daniel Hanford Inc./DE&S Hanford, Inc.—responsible for the Spent Nuclear Fuel Project. This project addresses the cleanup efforts associated with the waste and fuel rods stored in the K Basins.
- B&W Hanford Company—responsible for the facility stabilization project and the Advanced Reactors Transition Project. The facility stabilization project is tasked with safely and cost effectively deactivating contaminated surplus facilities to a reduced cost, low-risk stabilized/shutdown condition for either long-term surveillance and maintenance or final disposition. The Advanced Reactors Transition Project maintains the Fast Flux Test Facility and its associated support facilities in a safe and stable condition while DOE explores alternative future missions.
- Numatec Hanford Corporation—responsible for technology implementation and nuclear engineering. They provide application technology as needed to all cleanup contractors.
- DynCorp Tri-Cities Services, Inc.—responsible for infrastructure services. They provide non-nuclear-related support in the areas of site operation, property management, utilities, facility maintenance, site services, and emergency preparedness.
- Protection Technology Hanford (B&W Protec, Inc. through February 1999)—provides safeguard and security services, including material control and accountability, physical security, information security, and other security activities.

- Battelle Memorial Institute operates Pacific Northwest National Laboratory, the research and development contractor, for DOE, conducting research and development in environmental restoration and waste management, environmental science, molecular science, energy, health and safety, and national security. In addition, the laboratory performs groundwater monitoring for the Hanford Groundwater Monitoring Project, which includes Resource Conservation and Recovery Act/Comprehensive Environmental Response, Compensation, and Liability Act monitoring, and surface environment surveillance, both on and around the site for the Surface Environmental Surveillance Project.
- Bechtel Hanford, Inc., the environmental restoration contractor, is responsible for surveillance and maintenance of inactive past-practice waste sites and inactive facilities; characterization and remediation of past-practice waste sites and contaminated groundwater; management of remediation waste; closure of Resource Conservation and Recovery Act land-based treatment, storage, and disposal units; decontamination and decommissioning of facilities; overall Hanford Site groundwater project management; site-wide drilling management; and coordinating and integrating work that could impact water resources through the Hanford Site Groundwater/Vadose Zone Integration Project. The Bechtel Team includes two preselected subcontractors: CH2M Hill Hanford, Inc. and ThermoHanford, Inc.
- Hanford Environmental Health Foundation is the occupational and environmental health services contractor.
- MACTEC-ERS is a prime contractor to the DOE Grand Junction Office and is performing vadose zone characterization and monitoring work beneath single-shell underground waste storage tanks in the 200 Areas.

In addition, several enterprise companies were created to provide services to Fluor Daniel Hanford, Inc. These subcontractors and their areas of responsibility include the following:

- COGEMA Engineering Corporation provides engineering and technical support in the areas of tank waste remediation systems engineering and construction, spent fuel conditioning, and engineering testing and technology.
- Lockheed Martin Services, Inc. provides telecommunications and network engineers, information systems, production computing, document control, records management, and multimedia services.

- Fluor Daniel Northwest, Inc. provides a variety of professional services to the subcontractors, including construction, engineering, finance, accounting, and materials management.
- DE&S Northwest, Inc. provided nuclear and non-nuclear services in the area of quality assurance and related activities through the end of calendar year 1998.
- Waste Management Federal Services, Inc., Northwest Operations provides waste transportation services, waste packaging systems engineering, environmental monitoring and investigations, groundwater well services, sampling and mobile laboratory services, and nuisance wildlife and vegetation management.

British Nuclear Fuels Limited, Inc. was authorized by DOE in 1998 to proceed with their contract to provide services to treat and immobilize an initial portion of Hanford's radioactive underground tank wastes. The proof of concept, commercial demonstration phase will cover a 10- to 14-yr period, after which a full-scale production phase may be authorized.

1.0.5 Major Site Activities

1.0.5.1 Waste Management

Current activities at the site include the management of high- and low-level defense wastes in the 200-East and 200-West Areas (see Figure 1.0.2) and the storage of irradiated fuel in the 100-K Area. Major facilities are discussed below.

Waste management activities involving single-shell and double-shell tanks include ensuring safe storage of wastes through surveillance and monitoring of the tanks, upgrading monitoring instrumentation, and imposing strict work controls during intrusive operations. Concerns had been raised about the potential for explosions from ferrocyanide and/or organic fuels or hydrogen gas accumulation in the waste tanks. DOE and external oversight groups have concluded that there is no imminent danger to the public from either situation. Details concerning these tank wastes are in Section 2.3.8, "Tank Waste Remediation System Activities."

Liquid wastes on the Hanford Site are managed in treatment, storage, and disposal facilities. Details on these facilities are provided in Section 2.3.10, "Liquid Effluent Activities."

Solid waste is received at the low-level burial grounds in the 200-East and 200-West Areas and the Central Waste Complex in the 200-West Area from all radioactive waste generators on the site and any offsite generators authorized by DOE to ship waste to the Hanford Site for treatment, storage, and disposal. In addition, reactor compartments are being received from the United States Navy for disposal in a special trench in the 200-East Area. The Waste Receiving and Processing Facility (operations began in March 1997) has the capability to process retrieved, suspect, transuranic, solid waste (waste that may or may not meet transuranic criteria); certify newly generated and stored transuranic solid and low-level wastes for disposal at the Waste Isolation Pilot Plant in New Mexico (transuranic only) or the low-level burial grounds (low-level waste only); and process small quantities of radioactive mixed low-level waste for permanent disposal. Details on these and other facilities for the management of solid waste are provided in Section 2.3.9, "Solid Waste Management Activities."

The Environmental Restoration Disposal Facility, near the 200-West Area, was opened in July 1996 to accept waste generated during the Hanford Site cleanup activities. This facility serves as the central disposal site for contaminated soil and other waste removed under the Environmental Restoration Program. Additional details about this facility are provided in Section 2.3.12.1, "Environmental Restoration Disposal Facility."

1.0.5.2 Spent Nuclear Fuels Project

The Spent Nuclear Fuels Project supports the Hanford mission to clean up the site by managing and reducing hazards associated with its spent nuclear fuel inventory. Spent nuclear fuel stored on the site varies in condition and level of vulnerability and is stored in both wet and dry configurations. Potential risks to workers, assurance of public health and safety, and protection of the environment led to a decision to proceed immediately with the removal of spent nuclear fuel stored in the K Basins. Refer to Section 2.3.4, "Spent Nuclear Fuel Project," for further details.

1.0.5.3 Facility Stabilization

The Facility Stabilization Project's mission is to transition those Hanford Site facilities, for which it has responsibility, from an operating mode to a long-term surveillance and maintenance mode. This includes maintaining facilities in a safe, compliant status; providing for the safe storage of nuclear materials; and reducing risks from hazardous materials and contamination. Under the project, the deactivation of primary systems to effectively reduce risks to human health and the environment will also be conducted. These activities will allow the lowest surveillance and maintenance costs to be attained while awaiting determination of a facility's final disposition and possible turnover to the DOE Environmental Restoration Program.

The Facility Stabilization Project is engaged in five major deactivation efforts at the Hanford Site. The major efforts are B Plant, the Facility Stabilization and Environmental Restoration Team, the 300 Area Stabilization Project, the Waste Encapsulation and Storage Facility, and the Plutonium Finishing Plant. In addition, surveillance and maintenance of the Plutonium-Uranium Extraction Plant continued, following the completion of deactivation activities. The mission of each of these projects and related accomplishments during 1998 are provided in Section 2.3.5, "Facility Stabilization Project."

1.0.5.4 Environmental Restoration

The Environmental Restoration Project activities include decontamination and decommissioning of inactive facilities, surveillance and maintenance of deactivated facilities, transition of deactivated facilities and waste sites to the Environmental Restoration Program, characterization and cleanup of inactive waste sites, monitoring and remediation of contaminated groundwater, management of site-wide drilling, integrating groundwater and vadose zone activities that could impact water resources, and management of remediation waste. Refer to Section 2.3.12, "Environmental Restoration Project," for details.

1.0.5.5 Research and Technology Development

Research and technology development activities are conducted in the 200, 300, 400, and Richland North Areas. Many of these activities are intended to improve the techniques and reduce the costs of waste management, cleanup, environmental protection, and site restoration. Refer to Section 2.3.15, "Research and Technology Development Activities," for details.

1.0.6 Site Environmental Programs

1.0.6.1 Effluent Monitoring, Waste Management, and Chemical Inventory Programs

Liquid and airborne effluents are monitored or managed through contractor effluent monitoring programs. These programs are designed to monitor effluents at their point of release into the environment whenever possible. Waste management and chemical inventory programs document and report the quantities and types of solid waste disposed of at the Hanford Site and the hazardous chemicals stored across the site. Results for the 1998 effluent monitoring and waste management and chemical inventory programs are summarized in Section 2.5, "Waste Management and Chemical Inventories," and Section 3.1, "Facility Effluent Monitoring."

1.0.6.2 Near-Facility Environmental Monitoring Program

This program provides facility-specific environmental monitoring immediately adjacent to onsite facilities. Monitoring is conducted to comply with DOE and contract requirements and local, state, and federal environmental regulations. The program is also designed to evaluate the effectiveness of effluent treatments and controls and waste management and restoration activities and to monitor emissions from diffuse/fugitive sources. Results for the 1998 programs are summarized in Section 3.2, "Near-Facility Environmental Monitoring."

1.0.6.3 Sitewide Environmental Surveillance

The main focus of sitewide environmental surveillance is on assessing the impacts of radiological and chemical contaminants on the environment and human health and confirming compliance with pertinent federal and state environmental regulations and policies. Surveillance activities are conducted both on and off the site to monitor for contaminants from the entire Hanford Site rather than from specific contractor-owned or -managed facilities. Results for the 1998 sitewide environmental surveillance program are summarized in Section 4.0, "Environmental Surveillance Information."

1.0.6.4 Groundwater Monitoring and Vadose Zone Baseline Characterization

Extensive groundwater monitoring is conducted onsite to document the distribution and movement of groundwater contamination, to assess the movement of contamination into previously uncontaminated areas, to protect the unconfined aquifer from further contamination, and to provide an early warning when contamination of groundwater does occur. Sampling is also conducted to comply with federal and state requirements. A description of the monitoring program and a summary of the monitoring results for 1998 are described in Section 6.1, "Hanford Groundwater Monitoring Project."

Vadose zone baseline characterization is being conducted to establish baseline levels of manmade radionuclides in the vadose zone beneath the single-shell tanks in the 200 Areas and beneath selected cribs and trenches used for waste disposal. The primary objective of these efforts is to detect and identify gamma-emitting radionuclides and determine their activities and distributions. Other significant vadose zone activities that occurred in 1998 include spectral gamma-ray logging of boreholes at past-practice liquid waste disposal facilities associated with the Plutonium Finishing Plant. Results for these vadose zone activities in 1998 are summarized in Section 6.2, "Vadose Zone Characterization and Monitoring."

1.0.6.5 Other Environmental Programs

Other aspects of the environment are studied for reasons other than specific impacts from possible contamination. These aspects include climate, wildlife, and cultural resources. These studies are summarized in Section 7.0, "Other Hanford Site Environmental Programs."

1.0.7 References

40 CFR 122. U.S. Environmental Protection Agency. "EPA Administered Permit Programs: The National Pollutant Discharge Elimination System." *Code of Federal Regulations*.

Clean Air Act. 1986. Public Law 88-206, as amended, 42 USC 7401 et seq.

Comprehensive Environmental Response, Compensation, and Liability Act. 1980. Public Law 96-150, as amended, 94 Stat. 2767, 42 USC 9601 et seq.

DOE/RL-91-50, Rev. 2. 1997. *Environmental Monitoring Plan, United States Department of Energy Richland Operations Office*. U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-96-92. 1996. *Hanford Strategic Plan*. U.S. Department of Energy, Richland Operations Office, Richland, Washington. Also available at URL: http://www.hanford.gov/hsp/index.html

Fitzgerald, J. J. 1970. *Applied Radiation Protection and Control*. Gordon and Breach Science Publishers. New York.

PNL-8506. 1993. *Arid Lands Ecology Facility Management Plan*. Pacific Northwest Laboratory, Richland, Washington.

PNNL-6415, Rev. 10. 1998. *Hanford Site National Environmental Policy Act (NEPA) Characterization*. D. A. Neitzel (ed.), and C. J. Fosmire, R. A. Fowler, S. M. Goodwin, D. W. Harvey, P. L. Hendrickson, D. J. Hoitink, T. M. Poston, A. C. Rohay, P. D. Thorne, and M. K. Wright, Pacific Northwest National Laboratory, Richland, Washington.

Resource Conservation and Recovery Act. 1976. Public Law 94-580, as amended, 90 Stat. 2795, 42 USC 6901 et seq.

Washington State Office of Financial Management. 1997a. *1997 Data Book, State of Washington*. Forecasting Division, Olympia, Washington.

Washington State Office of Financial Management. 1997b. *Inter-Censal and Post-Censal Estimates of County Populations by Age and Sex: State of Washington 1980-1997*. Forecasting Division, Olympia, Washington.

U.S. Bureau of the Census. 1994. *County and City Data Book*. U.S. Government Printing Office, Library of Congress, No. 52-4576, Washington, D.C.

2.0 Environmental and Regulatory Compliance Summary

This section describes how environmental compliance is achieved for the Hanford Site. Included are sections describing 1) stakeholder and tribal involvement in the environmental restoration and waste management missions at the Hanford Site, 2) the current status of the site's compliance with principal regulations, 3) issues and actions arising from these compliance efforts, 4) an annual summary of environmentally significant occurrences, and 5) waste management and chemical inventory information.

It is the stated policy of the U.S. Department of Energy (DOE) that all activities be carried out in compliance with all applicable federal, state, and local environmental laws and regulations, DOE Orders, Secretary of Energy Notices, DOE Headquarters and Richland Operations Office directives, policies and guidance. This includes those specific requirements, actions, plans, and schedules identified in the Hanford Federal Facility Agreement and Consent Order (also known as the Tri-Party Agreement; Ecology et al. 1989) and other compliance or consent agreements. The DOE Richland Operations Office recognizes the importance of maintaining a proactive program of self-assessment and regulatory reporting to ensure that environmental compliance is achieved and maintained at the Hanford Site.

2.1 Stakeholder and Tribal Involvement

D. G. Black

Many entities have a role in DOE's mission of environmental restoration and waste management at Hanford. Stakeholders include federal, state, and local regulatory agencies; environmental groups; regional communities; and the public. Indian tribes also have a special and unique involvement with the Hanford Site. The following sections describe the roles of the principal agencies, organizations, and public in environmental compliance and cleanup of the Hanford Site.

2.1.1 Regulatory Oversight

Several federal, state, and local government agencies are responsible for monitoring and enforcing compliance with applicable environmental regulations at the Hanford Site. The major agencies include the U.S. Environmental Protection Agency (EPA), Washington State Department of Ecology, Washington State Department of Health, and Benton Clean Air Authority. These agencies issue permits, review compliance reports, participate in joint monitoring programs, inspect facilities and operations, and/or oversee compliance with applicable regulations. DOE, through compliance audits and directives, initiates and assesses actions for compliance with environmental requirements. The primary requirements address air quality, water quality, land use, cultural resources, and waste management.

EPA is the principal federal regulator that develops, promulgates, and enforces environmental protection regulations and standards as directed by statutes passed by Congress. In some instances, EPA has delegated environmental regulatory authority to the state or authorized the state program to operate in lieu of the federal program when the state's program meets or exceeds EPA's requirements. For instance, EPA has delegated or authorized certain enforcement authorities to the Washington State Department of Ecology for air pollution control and hazardous waste management. In other activities, the state program is assigned direct oversight over the DOE Richland Operations Office as provided by federal law. For example, the Washington State Department of Health has direct authority under the Clean Air Act of 1986 to enforce the standards and requirements under a statewide program for regulating radionuclide air emissions at applicable facilities (e.g., the Hanford Site). Where federal regulatory authority is not delegated or only partially authorized to the state, EPA Region 10 is responsible for reviewing and enforcing compliance with EPA regulations as they pertain to the Hanford Site. In addition, EPA periodically reviews the adequacy of various state environmental programs and reserves the right to directly enforce federal environmental regulations.

Although the state of Oregon does not have direct regulatory authority at the Hanford Site, DOE recognizes its interest in Hanford Site cleanup because of Oregon's location downstream along the Columbia River. There is also the potential for shipping radioactive wastes to or from the Hanford Site through Oregon by rail, truck, or barge. Oregon participates in the State and Tribal Government Working Group for the Hanford Site, which reviews the site's cleanup plans.

2.1.2 Hanford Federal Facility Agreement and Consent Order

This order (also known as the Tri-Party Agreement; Ecology et al. 1989) is an agreement among the Washington State Department of Ecology, EPA, and DOE for achieving environmental compliance at the Hanford Site with the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), including the Superfund Amendments and Reauthorization Act of 1986 remedial action provisions, and with Resource Conservation and Recovery Act (RCRA) treatment, storage, and disposal unit regulation and corrective action provisions. The Tri-Party Agreement 1) defines the RCRA and the CERCLA cleanup commitments, 2) establishes responsibilities, 3) provides a basis for budgeting, and 4) reflects a concerted goal of achieving regulatory compliance and remediation with enforceable milestones in an aggressive manner. Also, the Tri-Party Agreement was established with input from the public.

The Tri-Party Agreement has continued to evolve as cleanup of the Hanford Site has progressed. Significant changes to the agreement have been negotiated between the Washington State Department of Ecology, EPA, and DOE to meet the changing conditions and needs of the cleanup. The most complex changes were worked out in 1993 with further modifications each year since. All significant changes to the agreement undergo a process of public involvement that ensures communication and addresses the public's values prior to final approvals. Copies of the agreement are publicly available at the DOE's Hanford Reading Room located in the Consolidated Information Center on the campus of Washington State University at Tri-Cities, Richland, Washington, and at information repositories in Seattle and Spokane, Washington, and Portland, Oregon. To get on the mailing list to obtain Tri-Party Agreement information, contact the EPA or DOE directly, or call the Washington State Department of Ecology at 1-800-321-2008. Requests by mail can be sent to:

Hanford Mailing List: Informational Mailings
Mail Stop B3-35
P.O. Box 1000
Richland, WA 99352

or

Hanford Update
Department of Ecology
P.O. Box 47600
Olympia, WA 98504-7600

2.1.3 The Role of Indian Tribes

The Hanford Site is located on land ceded to the United States government by the Yakama Indian Nation and the Confederated Tribes of the Umatilla Indian Reservation in the Treaties of 1855. These two tribes, as well as the Nez Perce Tribe, have treaty fishing rights on portions of the Columbia River. The tribes reserved the right to fish "at all usual and accustomed places" and the privilege to hunt, gather roots and berries, and pasture horses and cattle on open and unclaimed land. The Wanapum are not a federally recognized tribe; however, they have historic ties to the Hanford Site and are routinely consulted regarding cultural and religious freedom issues.

The Hanford Site environment supports a number of Native American foods and medicines and contains sacred places that are important in sustaining tribal cultures. The tribes hope to use these resources in the future and want to assure themselves that the Hanford environment is clean and healthy.

The DOE American Indian policy (DOE Order 1230.2) states, "American Indian Tribal Governments have a special and unique legal and political relationship with the Government of the United States, defined by history, treaties, statutes, court decisions, and the U.S. Constitution." In recognition of this relationship, DOE and each tribe interact and consult directly. The three tribes belong to DOE groups such as the State and Tribal Government Working Group and the Hanford Natural Resources Trustee Council. They actively participate in many projects, including the Hanford Site Groundwater/ Vadose Zone Integration Project and the Cultural Resources Program. The three tribes have made presentations to DOE and the contractors on treaty rights, tribal sovereignty, the United States government trust responsibility, and the unique status of tribal governments.

DOE interaction with tribes in Hanford plans and activities is guided by the DOE American Indian policy (DOE Order 1230.2), which states, among other things, "The Department shall: Consult with Tribal governments to assure that Tribal rights and concerns are considered prior to DOE taking actions, making decisions, or implementing programs that may affect Tribes." In addition to the American Indian policy, laws such as the American Indian Religious Freedom Act of 1978, the Archaeological Resources Protection Act of 1979, the National Historic Preservation Act of 1966, and the Native American Graves Protection and Repatriation Act of 1990 require consultation with tribal governments. It is the combination of the Treaties of 1855, federal policy, executive orders, laws, and regulations that provide the basis for tribal participation in Hanford Site plans and activities.

DOE provides financial assistance through cooperative agreements with the Yakama Indian Nation, the Confederated Tribes of the Umatilla Indian Reservation, and the Nez Perce Tribe to support their involvement in environmental management activities of the Hanford Site.

2.1.4 Hanford Natural Resource Trustee Council

The President is required by CERCLA to appoint federal officials to act on behalf of the public as trustees for natural resources when natural resources may be injured, destroyed, lost, or threatened as a result of a release of hazardous substances. The President appointed the Secretary of Energy as the primary federal natural resource trustee for all natural resources located on, over, or under land administered by DOE.

The National Contingency Plan in Title 40, Code of Federal Regulations, Part 300, Subpart 605 (40 CFR 300.605) authorizes state governors to designate a state lead trustee to coordinate all state trustee responsibilities. The National Contingency Plan also states that chairmen (or heads of governing bodies) of Indian tribes have essentially the same trusteeship over natural resources belonging to or held in trust for the tribe as state trustees have. In addition to DOE, organizations that have been designated as natural resource trustees for certain natural resources at or near Hanford include: the Yakama Indian Nation, the Confederated Tribes of the Umatilla Indian Reservation, the Nez Perce Tribe, the state of Washington represented by the Washington State Department of Ecology and the Washington State Department of Fish and Wildlife, the state of Oregon represented by the Oregon Department of Energy, the U.S. Department of the Interior represented by the U.S. Fish and Wildlife Service and the Bureau of Land Management, and the U.S. Department of Commerce represented by the National Oceanic and Atmospheric Administration.

To better address their responsibilities, the trustees have signed a memorandum of agreement (1996) formally establishing the Hanford Natural Resource Trustee Council. The primary purpose of the council is to facilitate the coordination and cooperation of the member trustees in their efforts in mitigating impacts to natural resources that result from hazardous substance releases from within the Hanford Site or the remediation of those releases. The council also adopted by-laws to direct the process of arriving at consensus agreements.

The council is overseeing an assessment of potential injury to Columbia River aquatic resources that resulted from the release of hazardous substances from within the 100 Areas. The initial phase of this assessment involved preparation of an aquatic resources assessment plan by the U.S. Fish and Wildlife Service. The U.S. Fish and Wildlife Service used the natural resource damage assessment regulations in 43 CFR 11 as guidance in preparing the plan. The assessment plan addresses current exposure pathways and potential injury to aquatic resources from releases within the 100 Areas. The plan also addresses potential injury to fall chinook salmon from chromium releases within the 100 Areas that have migrated to the Columbia River. The results of the overall assessment will aid the trustees, regulators, and DOE in developing, evaluating, and selecting remedial actions that minimize or eliminate any injury to aquatic resources.

2.1.5 Public Participation

Individual citizens of the state of Washington and neighboring states may influence Hanford Site cleanup decisions through public participation activities. The public is provided opportunities to contribute their input and influence decisions through many forums, including Hanford Advisory Board meetings, Tri-Party Agreement activities, National Environmental Policy Act of 1969 public meetings on various environmental impact statements and environmental assessments, and many other outreach programs.

A framework for integrated communications and public involvement for the Hanford Site outlines the DOE commitment to and plan for involving the public in decisions. The Office of External Affairs (DOE Richland Operations Office) is responsible for establishing the planning and scheduling of public participation activities for the Hanford Site.

The Tri-Party Agreement provides a means for Hanford to become compliant with environmental regulatory requirements. The Community Relations Plan, a companion to the Tri-Party Agreement, describes how public information and involvement activities are conducted for Tri-Party Agreement decisions. The plan was developed and negotiated among DOE, Washington State Department of Ecology, and EPA Region 10 with public comment and was jointly approved in 1990. The plan is updated on an as-needed basis, the most recent revision occurring in February 1997 (Ecology et al. 1997).

Before each public participation activity, the press is informed of the issues to be discussed, and notices are sent to elected officials, community leaders, and special interest groups. A mailing list of approximately 3,800 individuals who have indicated an interest in participating in Hanford Site decisions is maintained and kept current. The mailing list is also used to send topic-specific information to those people who have requested it.

To apprise the public of upcoming opportunities for public participation, the *Hanford Update*, a synopsis of all ongoing and upcoming Tri-Party Agreement public involvement activities, is published bimonthly. In addition, the *Hanford Happenings* calendar, which

highlights Tri-Party Agreement scheduled meetings and comment periods, is distributed each month to the entire mailing list.

Most of Hanford's stakeholders reside in Washington, Oregon, and Idaho. To allow them better access to up-to-date Hanford Site information, four information repositories have been established. They are located in Richland, Seattle, and Spokane, Washington, and Portland, Oregon.

The three parties respond to questions that are received via a toll-free telephone line (800-321-2008). Members of the public can request information about any public participation activity and receive a response by contacting the Office of External Affairs (DOE Richland Operations Office) at (509) 376-7501.

Also, there is a calendar of public involvement opportunities on the Internet: http://www.hanford.gov/whc/cal/cal.html.

2.1.6 Hanford Advisory Board

The Hanford Advisory Board was chartered in January 1994 to advise DOE on major Hanford Site cleanup policy questions. The board was the first of many such advisory groups created by DOE at weapons production cleanup sites across the national DOE complex. The board comprises 32 members (stakeholders) who represent a broad cross section of interests: environmental, economic development, tribes and other governments, and the public. Each board member has at least one alternate. Merilyn Reeves, of Amity, Oregon, is the chairperson.

The board has five standing committees: 1) Dollars and Sense, which deals with DOE budget issues; 2) Health, Safety, and Waste Management; 3) Environmental Restoration; 4) the board's internal executive committee; and 5) the Public Involvement committee. Committees study issues and develop policy recommendations for board action. In addition, special groups or ad hoc committees are formed on an as-needed basis and have a limited life span.

The board held six 2-d meetings in 1998. Members received in-depth briefings from the Tri-Party Agreement agencies, reviewed technical reports and proposed budgets, and sought out more information on major public policy issues. From October 1997 through September 1998, the board produced 11 new pieces of consensus advice (making a total of 87), cosponsored several public meetings, produced numerous pieces of "sounding board" advice, and engaged in an ongoing dialogue with the Tri-Party Agreement agencies. The board's advice, and responses to that advice, can be found on the Internet at http://www.hanford.gov/boards/hab/advice/adviceindex.htm.

Values adopted by the board provide a basis for its current work in promoting cleanup. These values are simplified into the following 10 key principles:

- protect public and worker health and safety
- protect the Columbia River - stop actual and potential contamination of the Columbia River and prevent migration of contamination off the site
- avoid further harm - minimize use of land for waste management, avoid contaminating uncontaminated land, and avoid further damage to critical resources, especially cultural resources, habitat, and groundwater
- dilution is not the solution - all liquid wastes need to be treated according to applicable regulations prior to discharge or disposal
- treaty rights - preserve natural resource rights embodied in treaties, and enforce laws protecting natural and cultural resources
- regional importance - the Hanford Site has ecological, economic, and human resources of regional importance
- vision - an understanding of possible future uses of the Hanford Site can focus decisions about what manner of cleanup is needed and what is most important to accomplish over time; the public, the

agencies, and the workers should be able to see the end of the cleanup, if not predict its exact date

- "get on with it" - demonstrate substantive progress on cleanup to ensure continued public support and funding
- public involvement and accountability - involve the public and respect tribal rights in development of the goals, scope, pace, and oversight of cleanup, and establish management practices that ensure accountability, efficiency, and allocation of funds to high-priority items
- compliance culture - there should be a cooperative commitment to comply with environmental laws; the Tri-Party Agreement should not become a shield against enforcement of other laws.

2.1.7 Hanford Site Technology Coordination Group

The Hanford Site Technology Coordination Group structure implemented at Hanford in 1994 consists of a Management Council and four subgroups aligned with four Environmental Management Focus Areas: 1) decontamination and decommissioning, 2) mixed waste, 3) subsurface contaminants, and 4) tanks. The Management Council focuses on Hanford Site policy issues related to technology development and deployment. Subgroups of the Site Technology Coordination Group identify and prioritize the site's science and technology needs, identify technology demonstration opportunities, interface with the Environmental Management Focus Areas, and ensure that demonstrated technologies are deployed.

During 1998, the Management Council endorsed four science and technology needs packages developed by the subgroups for submittal to the four Environmental Management Focus Areas and the Environmental Management Science Program. These needs can be found on the Internet at http://www.pnl.gov/stcg/needs.stm. In addition, they endorsed five accelerated site technology deployment proposals and heard presentations on a number of new technologies being demonstrated and/or deployed on the Hanford Site.

The Management Council is chaired by the DOE Richland Operations Office Deputy Manager and includes 16 voting members: 5 DOE Richland Operations Office Assistant Managers (Tank Waste Remediation System, Environmental Restoration, Waste Management, Facility Transition, and Technology); 2 representatives from the EPA; 2 from the Washington State Department of Ecology; 1 from the Oregon Office of Energy; 3 from the Hanford Advisory Board; and 3 from American Indian tribes (Yakama Indian Nation, Nez Perce Tribe, and Confederated Tribes of the Umatilla Indian Reservation). Each of the Hanford Site contractors has one ex-officio member on the Management Council, and the Site Technology Coordination Group Subgroup leads also attend.

The elements of the Hanford Site Technology Coordination Group mission statement are as follows:

- function by involving user organizations (both DOE and the contractors), technology providers, regulators, American Indian tribes, and stakeholders, and promoting broad information exchange among all interested parties; maintain a helpful attitude and serve as a conscience for technology improvement at Hanford; contribute to DOE-wide communications and lessons learned
- identify, prioritize using systems analysis, and seek consensus on Hanford Site and program-specific problems, science and technology needs, and requirements; recognize baseline schedule insertion points for technology; focus on the baseline, but also identify technologies to support potential baseline alternatives if they offer risk reduction benefits or high

financial return on investment by improvements in environmental, safety, or health protection; devote 20% of the effort to science needs and 80% to technology needs and deployment

- be a forum for assessing and recommending potential technologies for application at Hanford; look for technologies that provide improved end results, improved effectiveness, improved schedules, or improved costs in accomplishing the required results; look for technologies to reduce surveillance and maintenance costs while maintaining safe operations; focus on life-cycle costs and benefits, improvements in environmental, safety, or health protection, and improvements in performance, pollution prevention, and waste minimization relative to alternative remedies; make appropriate referrals for vendors (e.g., to DOE or the contractors)
- champion and facilitate demonstration and deployment of innovative, modified, or existing technologies that are new to Hanford and share information with other sites to best leverage all available resources
- create a viable market for technology with the DOE Richland Operations Office and contractors and eliminate barriers (e.g., "not invented here," resistance to change)
- promote competitive privatization and commercialization by communicating information on Hanford's science and technology needs and schedule insertion points, as well as demonstration and deployment opportunities, to commercial technology providers; help break barriers to involvement by companies new to Hanford
- provide input to decision makers (e.g., DOE Richland Operations Office, DOE Headquarters, Congress, and heads of regulatory agencies) on Hanford's highest-priority science and technology needs to ensure critical needs are funded; provide feedback to them on the site's accomplishments.

2.2 Compliance Status

D. G. Black

This section summarizes the activities conducted to ensure that the Hanford Site is in compliance with federal environmental protection statutes and related state and local environmental protection regulations. Also discussed is the status of compliance with these requirements. Environmental permits required under the environmental protection regulations are discussed under the applicable statute.

2.2.1 Hanford Federal Facility Agreement and Consent Order, 1998 Performance

The Tri-Party Agreement (Ecology et al. 1989) commits DOE to achieve compliance with the remedial action provisions of CERCLA and with the treatment, storage, and disposal unit regulations and corrective action provisions of RCRA, including the state's implementing regulations.

From 1989 through 1998, a total of 597 enforceable milestones and 246 unenforceable target dates were completed on or ahead of schedule.

In 1998, there were 70 specific cleanup milestones and target dates scheduled for completion: 58 were completed on or before their required due dates and 12 were delayed because of safety issues and future Fast Flux Test Facility usage issues.

Highlights of the work accomplished in 1998 are listed in Section 2.3, "Activities, Accomplishments, and Issues."

2.2.2 Environmental Management Systems Development

The International Organization for Standardization was founded in 1947 and promotes the development of international manufacturing, trade, and communication standards. In 1996, the organization issued an international voluntary consensus standard ISO 14001, *Environmental Management Systems – Specifications with Guidance for Use*. This industry-driven standard represents the culmination of international environmental standardization efforts spanning nearly two decades.

The ISO 14000-series of standards (Cascio 1996) are based on the following five guiding principles:

- An organization should define its environmental policy and ensure commitment to its environmental management system.
- An organization should formulate a plan to fulfill its environmental policy.
- For effective implementation, an organization should develop the capabilities and support mechanisms necessary to achieve its environmental policy, objectives, and targets.
- An organization should measure, monitor, and evaluate its environmental performance.
- An organization should review and continually improve its environmental management system, with the objective of improving its overall environmental performance.

The basis for any environmental management system is compliance with applicable environmental laws, regulations, permits, and other requirements.

An effective system goes beyond compliance and provides an organization with a systematic approach to the development, implementation, and maintenance of an environmental policy. The precept is that through planning, implementation, checking, management review, and continuous improvement, organizations become more effective and efficient in the management of their activities and the impacts of those activities on the environment.

During 1998, the environmental management system at Pacific Northwest National Laboratory was reviewed and approved by DOE Headquarters. This environmental management system was the first among national laboratories to receive this approval.

Fluor Daniel Hanford, Inc., the site management and integration contractor, issued in June 1997 HNF-EP-925, *Environmental Management System Implementation Plan*. At that time, a decision was made to include ISO 14001 in developing an integrated safety management system. During development, the name of the management system was changed.

HNF-MP-003, *Integrated Environment, Safety and Health Management System Plan*, establishes a single, defined safety and environmental management system that integrates environment, safety, and health requirements into the work planning and execution processes to effectively protect the workers, public, and environment. That plan specifically addresses the Project Hanford Management Contract requirements for a safety and environmental management system that satisfies Defense Nuclear Facilities Safety Board recommendations, addresses implementation of an environmental management system consistent with the principles of the ISO 14001 standard, and supports radiological control considerations. The Fluor Daniel Hanford, Inc. integrated environment, safety, and health management system is primarily based on the philosophies, principles, and requirements of DOE P 450.4, *Safety Management System Policy*, and the ISO 14001 standard and also incorporates the best practices of the following policies, standards, and initiatives: Voluntary Protection Program, Responsible Care® of the Chemical Manufacturer's Association, and Enhanced Work Planning/ Hanford Occupational Health Process.

Five safety management core functions defined in DOE P 450.4 provide the necessary planning, checks, and controls for any work that could potentially affect the workers, public, or environment. An environmental management system is defined in the ISO 14001 standard as "the part of the overall management system that includes organizational structure, planning activities, responsibilities, practices, procedures, processes, and resources for developing, implementing, achieving, reviewing, and maintaining the environmental policy."

The Fluor Daniel Hanford, Inc. integrated environment, safety, and health management system consists of seven core functions that capture both DOE P 450.4 and ISO 14001 elements:

- establish environment, safety, and health policy
- define scope of work
- identify hazards and requirements
- analyze hazards and implement controls
- perform work within controls
- provide feedback and process improvement
- perform management review.

A deliberate, careful comparison and integration of DOE P 450.4 and the ISO 14001 standard resulted in the development of the guiding principles and core functions identified in HNF-MP-003. These guiding principles and core functions are the cornerstones for development of the Fluor Daniel Hanford, Inc. integrated environment, safety, and health management system. Provided in HNF-MP-003 is an appendix that cross references the elements of ISO 14001 and the guiding principles and core functions. A person familiar with ISO 14001 can use this appendix as a cross-reference to identify sections that correlate to ISO 14001 standard elements.

The final plan was issued in September 1997. Planning for implementation of the system at Fluor Daniel Hanford, Inc.-managed facilities was in place by September 1998.

Integrated environmental, health, and safety system implementation is proceeding throughout the Project Hanford Management Contract team. Environmental management is being infused at all levels. During the past year, enhanced work planning was targeted to focus integrated environmental, health, and safety system implementation at the "activity" level. Environmental considerations have been incorporated into the enhanced work planning effort.

2.2.2.1 Chemical Management System

The Hanford Site, with its numerous contractors, facilities, and processes uses a variety of approaches for chemical management. In an effort to develop a uniform set of requirements for managing chemicals on the Hanford Site, the prime contractors initiated a coordinated effort to create a joint plan of action for chemical management on the Hanford Site. A multicontractor chemical management system working group was formed, and a strategy for chemical management was developed.

As part of the strategy, the prime contractors developed chemical management system requirements for the Hanford Site. The requirements were approved by the prime contractors on November 25, 1997 and transmitted to the DOE Richland Operations Office. These requirements are applicable within the Hanford Site to the acquisition, use, storage, transportation, and final disposition of chemicals, including hazardous chemicals as defined in the Occupational Safety and Health Administration's hazard communication standard (29 CFR 1910.1200, Appendixes A and B).

The prime contractors used these requirements to evaluate the adequacy of their chemical management programs, identify opportunities for improvement, implement changes as appropriate, and drive the day-to-day management of chemicals. It was recognized, based on the complexity of chemical management operations and the nature and severity of associated hazards, that these chemical management system requirements would be applied using a graded approach.

During the first quarter of 1998, each contractor performed a gap analysis of their chemical operations against the chemical management system requirements. The gaps identified, including procedure development and/or modifications, were translated into needs. These were then evaluated, using a graded approach that considered complexity of operations and associated hazards. The outcome of the gap analysis was identification of actions for each of the prime contractors to obtain conformance with the chemical management system requirements. For the remainder of 1998 and during the first quarter of 1999, the prime contractors worked toward conformance with the established requirements. Completion of conformance is scheduled for 1999, and further enhancements to contractor chemical management systems will be implemented in 2000 and beyond.

The chemical management system requirements incorporate best industry practices, drive continuous improvement, and will be incorporated into the integrated environmental, safety, and health management system of the prime contractors. Discussions with the EPA and affected stakeholders are ongoing. These discussions include the designs for chemical management systems.

2.2.3 Comprehensive Environmental Response, Compensation, and Liability Act

In 1980, CERCLA was enacted to address past releases or potential releases of hazardous substances, pollutants, and contaminants to the environment. The EPA is the federal agency responsible for oversight of DOE's implementation of CERCLA. There is significant overlap between the state RCRA corrective action program (see Section 2.2.5) and CERCLA, and many waste management units are subject to remediation under both programs. The CERCLA program is implemented via 40 CFR 300, National Oil and Hazardous Substances Pollution Contingency Plan, which establishes procedures for characterization, evaluation, and remediation. The Tri-Party Agreement addresses CERCLA implementation at Hanford and is generally consistent with the contingency plan process.

There are several remediation activities under way at Hanford that are being accomplished using the CERCLA process (e.g., remedial investigation in the 200 and 300 Areas, cleanup in the 100 and 300 Areas). Specific project activities and accomplishments are described in Section 2.3.12, "Environmental Restoration Project."

2.2.4 Emergency Planning and Community Right-To-Know Act

This Act requires states to establish a process for developing chemical emergency preparedness programs and to distribute within communities information on hazardous chemicals present in facilities. The Act has two subtitles: Subtitle A includes requirements for emergency planning (Sections 301-303) and emergency release notification (Section 304); Subtitle B requires periodic reporting of chemical inventories and associated hazards (Sections 311-312), releases, and waste management activities (Section 313).

Sections 301-303 require states to establish a state emergency response commission and local emergency planning committees. These organizations are tasked to gather information and develop emergency plans for local planning districts in the state. Facilities that produce, use, or store extremely hazardous substances in quantities above threshold planning quantities must identify themselves to the state emergency response commission and local emergency planning committee, provide any additional information the local emergency planning committee requires for development of the local emergency response plan, and notify the committee of any changes occurring at the facility that may be relevant to emergency planning. It should be noted that the entire Hanford Site is considered a facility for the purpose of determining threshold planning and reporting quantities. This does not include, however, activities conducted by others on Hanford Site lands covered by leases, use permits, easements, and other agreements whereby land is used by parties other than DOE.

Under Section 304, facilities must also notify the state emergency response commission and the local emergency planning committee immediately after an accidental release of an extremely hazardous substance over the reportable quantity established for that substance, and follow up the notification with a written report. Extremely hazardous substances are listed in 40 CFR 355 (Appendixes A and B) along with the applicable threshold planning quantity and reportable quantity.

Sections 311-312 require facilities that store hazardous chemicals in amounts above minimum threshold levels to report information regarding those chemicals to the state emergency response commission, local emergency planning committee, and local fire department. Both sections cover chemicals that are considered physical or health hazards by the Occupational Safety and Health Act of 1970 Hazard Communication Standard (29 CFR 1910.1200). The minimum threshold level is 4,545 kg (10,000 lb) for hazardous chemicals. If the chemical is an extremely hazardous substance, the minimum threshold level is 277 kg (500 lb) or the listed threshold planning quantity, whichever is less. Section 311 calls for the submittal of a material safety data sheet for each hazardous chemical present above minimum threshold levels or a listing of such chemicals with associated hazard information. The listing must be updated within 3 mo of any change to the list, including receipt of new chemicals above minimum threshold levels or discovery of significant new hazard information regarding existing chemicals. Section 312 requires annual submittal of more-detailed quantity and storage information regarding the same list of chemicals in the form of a tier one or tier two emergency and hazardous chemical inventory report. These minimum threshold levels apply to the total quantities of such chemicals that are stored or received in aggregate at the Hanford Site, not to individual facilities at the site.

The Hanford Site provides appropriate hazardous chemical inventory information to the Washington State Department of Ecology Community Right-To-Know Unit; local emergency planning committees for Benton, Franklin, and Grant Counties; and to both the Richland and Hanford Site fire departments. Updated material safety data sheet listings were issued in April 1998, January 1999, and March 1999, covering chemical inventory changes occurring during 1998. During 1998, these listings averaged 39 to 42 hazardous chemicals present in quantities exceeding minimum threshold levels, 3 to 4 of which were extremely hazardous. The 1998 Hanford Site tier two emergency and hazardous chemical inventory (DOE/RL-99-16) was issued in February 1999.

Under Section 313, facilities must report total annual releases of certain listed toxic chemicals. The Pollution Prevention Act requires additional information with the report, and Executive Order 12856 (EPA 100-K-93-001) extends the requirements to all federal facilities, regardless of the types of activities conducted.

The 1997 Hanford Site toxic chemical release inventory (DOE/RL-98-39) was issued in June 1998. Two listed toxic chemicals were used at the Hanford Site in amounts above established activity thresholds: phosphoric acid and chlorine. Because the total quantity of chlorine released and managed as waste amounted to <277 kg (500 lb), the Hanford Site qualified for the alternate 455,000-kg (1,000,000-lb) activity threshold for chlorine. Accordingly, the 1997 toxic chemical release inventory included information regarding releases of phosphoric acid and other related waste management information and a signed certification that Hanford qualified for the alternate threshold for chlorine.

Based on evaluation of 1998 Hanford Site toxic chemical usage data, chlorine was the only chemical used in quantities exceeding applicable activity thresholds that require reporting under Section 313. Because the associated activities resulted in minimal quantities of chlorine released to the environment or entering waste streams, the site was eligible to apply the alternate 455,000-kg (1,000,000-lb) threshold for manufacture, process, or other use of the chemical. Accordingly, the site submitted the required forms for chlorine, certifying that the criteria for applying the alternate threshold were met.

Table 2.2.1 provides an overview of 1998 Emergency Planning and Community Right-To-Know Act of 1886 reporting.

Table 2.2.1. Emergency Planning and Community Right-to-Know Act Compliance Reporting, 1998[a]

Sections of the Act	Yes	No	Not Required
302-303: Planning notification	X[b]		
304: Extremely hazardous substances release notification			X
311-312: Material safety data sheet/chemical inventory (for calendar year 1998)	X		
313: Toxic chemical release inventory reporting (for calendar year 1998)	X		

(a) "Yes" indicates that notifications were provided and/or reports were issued under the applicable provisions. "No" indicates that notifications or reports should have been provided but were not. "Not Required" indicates that no actions were required under the applicable provisions, either because triggering thresholds were not exceeded or no releases occurred.
(b) These notifications apply to the Hanford Site but were completed prior to 1998.

2.2.5 Resource Conservation and Recovery Act

2.2.5.1 Hanford Facility RCRA Permit

The Hanford Facility RCRA Permit (#WA7890008967), Dangerous Waste Portion, that was issued by the Washington State Department of Ecology has been in effect since late September 1994 (DOE/RL-91-28, Rev. 3). The permit provides the foundation for all future RCRA permitting on the Hanford Site in accordance with provisions of the Tri-Party Agreement (Ecology et al. 1989).

2.2.5.2 RCRA/Dangerous Waste Permit Applications and Closure Plans

For purposes of the RCRA and the Washington State dangerous waste regulations (Washington Administrative Code [WAC] 173-303), the Hanford Site is considered to be a single facility that encompasses over 60 treatment, storage, and disposal units. The Tri-Party Agreement recognized that all of the treatment, storage, and disposal units could not be permitted simultaneously and a schedule was established for submitting unit-specific Part B dangerous waste permit applications and closure plans to the Washington State Department of Ecology.

During 1998, nine Part A, Form 3, revisions and one new Part A, Form 3, were certified and submitted to the Washington State Department of Ecology. In 1998, two Part B permit applications for final status were certified and submitted. In addition, two Notices of Intent for interim-status expansion and 11 closure-related documents were filed with the Washington State Department of Ecology.

2.2.5.3 RCRA Groundwater Monitoring Project Management

Table 2.2.2 lists the facilities and units (or waste management areas) that require groundwater monitoring and notes their monitoring status. Samples were collected from approximately 244 RCRA wells sitewide in 1998; approximately the same number of wells sampled during 1997.

Table 2.2.2. RCRA Interim- and Final-Status Groundwater Monitoring Projects, as of September 1998

TSD Units, date initiated (associated [CERCLA] groundwater operable units)	Interim-Status TSD Unit Groundwater Monitoring: Indicator Parameter Evaluation, date initiated[a]	Interim-Status TSD Unit Groundwater Monitoring: Groundwater Quality Assessment, date initiated	Final-Status TSD Unit Groundwater Monitoring: Detection Evaluation	Final-Status TSD Unit Groundwater Monitoring: Corrective Action, date initiated	Regulations	Year Scheduled for Part B or Closure
1301-N LWDF, December 1987 (100-NR-2)	X				40 CFR 265.93(b) WAC 173-303-400	1999[b]
1324-N/NA LWDF, December 1987 (100-NR-2)	X				40 CFR 265.93(b) WAC 173-303-400	1998[b]
1325-N LWDF, December 1987 (100-NR-2)	X				40 CFR 265.93(b) WAC 173-303-400	1999[b]
120-D-1 ponds, April 1992 (100-HR-3)	X, clean closure in FY 1999				40 CFR 265.93(b) WAC 173-303-400	1998[c]
183-H solar evaporation basins, June 1985 (100-HR-3)				X, 1998	40 CFR 264 WAC 173-303-645(10)	1994[b]
216-S-10 pond and ditch, August 1991	X				40 CFR 265.93(b) WAC 173-303-400	>2000[b]
216-U-12 crib, September 1991 (200-UP-1)		X, 1993			40 CFR 265.93(d) WAC 173-303-400	>2000[b]
216-B-3 pond, November 1988 (200-PO-1)	X, January 1998[d]				40 CFR 265.93(b) WAC 173-303-400	2000[b]
216-A-29 ditch, November 1988 (200-PO-1)	X				40 CFR 265.93(b) WAC 173-303-400	2000[b]
PUREX cribs[e] 1988 (200-PO-1)		X, 1997			40 CFR 265.93(d) WAC 173-303-400	>2000[b]

Table 2.2.2. (contd)

TSD Units, date initiated (associated [CERCLA] groundwater operable units)	Interim-Status TSD Unit Groundwater Monitoring: Indicator Parameter Evaluation, date initiated[a]	Interim-Status TSD Unit Groundwater Monitoring: Groundwater Quality Assessment, date initiated	Final-Status TSD Unit Groundwater Monitoring: Detection Evaluation	Final-Status TSD Unit Groundwater Monitoring: Corrective Action, date initiated	Regulations	Year Scheduled for Part B or Closure
216-B-63 trench, August 1991 (200-PO-1)	X				40 CFR 265.93(b) WAC 173-303-400	>2000[b]
LERF, July 1991			X, 1998[f]		40 CFR 265.93(b) WAC 173-303-400	1998[g]
LLWMA 1, September 1988	X				40 CFR 265.93(b) WAC 173-303-400	TBD[g,h]
LLWMA 2, September 1988	X				40 CFR 265.93(b) WAC 173-303-400	TBD[g,h]
LLWMA 3, October 1988	X				40 CFR 265.93(b) WAC 173-303-400	TBD[g,h]
LLWMA 4, October 1988 (200-ZP-1)	X				40 CFR 265.93(b) WAC 173-303-400	TBD[g,h]
WMA A-AX, February 1990	X				40 CFR 265.93(b) WAC 173-303-400	>2000[b]
WMA B-BX-BY, February 1990		X, 1996			40 CFR 265.93(d) WAC 173-303-400	>2000[b]
WMA C, February 1990 (200-PO-1)	X				40 CFR 265.93(b) WAC 173-303-400	>2000[b]
WMA S-SX October 1991 (200-UP-1)		X, 1996			40 CFR 265.93(d) WAC 173-303-400	>2000[b]
WMA T, February 1990 (200-ZP-1)		X, 1993			40 CFR 265.93(d) WAC 173-303-400	>2000[b]
WMA TX-TY, September - October 1991 (200-ZP-1)		X, 1993			40 CFR 265.93(d) WAC 173-303-400	>2000[b]

Table 2.2.2. (contd)

TSD Units, date initiated (associated [CERCLA] groundwater operable units)	Interim-Status TSD Unit Groundwater Monitoring: Indicator Parameter Evaluation, date initiated[a]	Interim-Status TSD Unit Groundwater Monitoring: Groundwater Quality Assessment, date initiated	Final-Status TSD Unit Groundwater Monitoring: Detection Evaluation	Final-Status TSD Unit Groundwater Monitoring: Corrective Action, date initiated	Regulations	Year Scheduled for Part B or Closure
WMA U, October 1990 (200-ZP-1)	X				40 CFR 265.93(b) WAC 173-303-400	>2000[b]
NRDWL, October 1986 (200-PO-1)	X				40 CFR 265.93(b) WAC 173-303-400	>2000[b]
316-5 process trenches, June 1985 (300-FF-5)				X, 1996	40 CFR 264 WAC 173-303-645(10)	1996[b,i]

(a) Specific parameters (pH, specific conductance, total organic carbon, and total organic halides) used to determine if a facility is affecting groundwater quality. Exceeding the established limits means that additional evaluation and sampling are required (groundwater quality assessment). An X in the assessment column indicates whether an evaluation was needed or an assessment was required.
(b) Closure/postclosure plan; TSD unit will close under final status.
(c) Closure plan approval expected in fiscal year 1999; facility groundwater monitoring not required after clean closure.
(d) Reverted to indicator parameter evaluation following assessment.
(e) 216-A-10, -A-36B, and A-37-1 combined into one RCRA monitoring unit. RCRA monitoring will be performed according to interim-status groundwater quality assessment requirements.
(f) Will monitor groundwater under interim status until final-status groundwater monitoring plan is approved.
(g) Part B permit; TSD unit scheduled to operate under final-status regulations beginning in year indicated.
(h) Facility Part B permit and final-status groundwater monitoring plan contingent on completion of solid waste environmental impact statement.
(i) Closure plan pending Washington State Department of Ecology approval.

CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act of 1980.
LERF = Liquid effluent retention facility.
LLWMA = Low-level waste management area.
LWDF = Liquid waste disposal facility.
NRDWL = Nonradioactive Dangerous Waste Landfill.
PUREX = Plutonium-uranium extraction (plant).
RCRA = Resource Conservation and Recovery Act of 1976.
TBD = To be determined.
TSD = Treatment, storage, or disposal (unit).
WMA = Waste management area (single-shell tank farm).
> = Beyond the year 2000.

Groundwater samples were analyzed for a variety of dangerous waste constituents and site-specific constituents, including selected radionuclides. The constituent lists meet the minimum RCRA regulatory requirements and are integrated to supplement other groundwater project requirements (e.g., CERCLA) at the Hanford Site.

During 1998, 11 new RCRA wells were installed (Table 2.2.3); 10 to fulfill requirements of the Tri-Party Agreement and 1 as part of the proposed immobilized low-activity waste disposal site in support of performance assessment activities.

Milestone M-24-00J (Ecology et al. 1989) required the installation of 10 new RCRA groundwater monitoring wells. The installation of these 10 wells was successfully completed in November 1998. Of these, seven were installed as new assessment wells to replace those going dry at Waste Management Areas T and TX-TY and at the 216-U-12 Crib in the 200-West Area. One new assessment well was installed at Waste Management Area B-BX-BY in the 200-East Area, and two detection groundwater monitoring wells were installed at Waste Management Area U in the 200-West Area. The nine new 200-West Area wells have well screens intended to extend their useful life. Of the 10 wells, 2 were drilled deep in the aquifer to characterize the vertical extent of known groundwater contaminants and define aquifer flow boundaries before being completed as shallow wells. Well data reports (PNNL-11957, PNNL-12124, PNNL-12125, PNNL-12126, PNNL-12127, and PNNL-12128) contain more-detailed information about these new wells, including the detailed geologic and geophysical descriptions and a complete set of sample data results.

Table 2.2.3. RCRA Well Installation Summary, 1998

Well Number[a]	Well Identification	Location
299-W10-23	B8545	T[b]
299-W10-24	B8546	T
299-W14-14	B8547	TX-TY
299-W10-26	B8548	TX-TY
299-W14-13	B8549	TX-TY
299-W15-40	B8550	TX-TY
299-W19-41	B8551	U
299-W19-42	B8553	U
299-W22-79	B8552	216-U-12 Crib
299-E33-44	B8554	B-BX-BY[b]
299-E17-21	B8500	ILAW

(a) "W" in number indicates 200-West Area; "E" 200-East Area. Well number is an older identification number that is used to locate the well in the field. The separate well identification is a newer identification number that is used to track the wells in electronic databases.
(b) Waste management area (single-shell tank farm).
ILAW = Immobilized low-activity waste site.

At the end of 1998, 17 RCRA waste management areas were monitored, and no evidence was found that they were adversely affecting groundwater quality. Other waste management areas were monitored for assessment or compliance programs to determine the impacts of contamination detected in groundwater at those areas. Highlights of 1998 RCRA monitoring activities are summarized below.

Interim-status assessment monitoring programs continued at four single-shell tank waste management areas in 1998 primarily to determine the source of contamination detected in downgradient and surrounding wells. Contamination from chemically similar sources (e.g., cribs, trenches) near the tank farms made it difficult to differentiate whether the waste management areas (tank farms, transfer lines, diversion boxes) were the source. The ongoing assessment investigations indicate that the waste management areas are the true source. The T and TX-TY single-shell tank farms (200-West Area) have been monitored under an assessment program since 1993 because of elevated specific conductance. An assessment report (PNNL-11809) concluded that the tanks or associated structures probably have contaminated the groundwater with technetium-99. An assessment management program at Waste

Management Area S-SX (200-West Area) began in 1996. It appears that this waste management area contaminated the groundwater with technetium-99, nitrate, and hexavalent chromium. Waste Management Area B-BX-BY (200-East Area) appears to have contaminated the groundwater with technetium-99.

The 183-H Solar Evaporator Basins (100-H Area) and the 316-5 Process Trenches (300 Area) were monitored under final-status regulations during 1998. The 183-H Basins have contaminated the groundwater with technetium-99, uranium, nitrate, and chromium at levels exceeding applicable limits. The CERCLA program is addressing corrective action, and an interim remedial action (pump-and-treat system) for chromium continued operation in 1998. Groundwater monitoring to meet RCRA requirements is continuing during the remediation.

The 316-5 Process Trenches and other nearby sources contaminated the groundwater with cis-1,2-dichloroethylene, trichloroethylene, and uranium at levels above their respective concentration limits. However, a corrective action monitoring plan has not been approved for these waste sites, and monitoring is continuing under an existing compliance plan. Natural attenuation of the contaminants is the corrective action chosen. Groundwater monitoring is continuing in accordance with RCRA to monitor the decline in contaminant concentrations.

The results of groundwater monitoring are discussed in detail in Section 6.1, "Hanford Groundwater Monitoring Project."

2.2.5.4 RCRA Inspections

DOE and its contractors are working to resolve outstanding notices of violation and warning letters of noncompliance from the Washington State Department of Ecology that were received during 1998. Each of these notices lists specific violations. RCRA noncompliance events for 1998 are detailed below.

- The Washington State Department of Ecology issued a Notice of Correction in response to a dangerous waste compliance inspection of tank 241-SX-104 in the 200-West Area. Corrective actions are being negotiated under the Tri-Party Agreement.
- The Washington State Department of Ecology issued a Notice of Correction, Notice of Penalty, and Administrative Order in response to a dangerous waste compliance inspection at the SY double-shell tank farm in the 200-West Area. Alleged violation #2 of the Notice of Correction, Notice of Penalty, and Administrative Order was challenged and resulted in a settlement agreement that defined the leak detection system for Hanford's double-shell tanks.
- The Washington State Department of Ecology issued a Notice of Correction in response to a dangerous waste compliance inspection of the 324 Building in the 300 Area. Corrective actions were completed, and responses to the items in the Notice of Correction were provided.
- The Washington State Department of Ecology issued a Notice of Intent to Sue for missed Tri-Party Agreement milestones associated with Hanford's single-shell tank stabilization program. After intensive negotiations, the notice resulted in a Consent Decree that expedited the completion of Hanford's single-shell tank stabilization.
- The Washington State Department of Ecology issued a letter that required the development of a single-shell tank corrective action program. An agreement was reached by which the original corrective action plan requirement and subsequent dispute resolution process were suspended, pending further negotiations.
- The Washington State Department of Ecology and the U.S. Environmental Protection Agency issued a Notice of Violation against the Environmental Restoration Disposal Facility in the 200-West Area, the 200-UP-1 Operable Unit pump-and-treat project in the 200-West Area, and the 100-B,C Area remedial action project. There were two violations and one item of concern that required correction pertaining to RCRA as an applicable or relevant and appropriate requirement. In addition to the RCRA issues, there were three items of concern that required

action related to strategy for management of investigation-derived waste and waste control planning in the 200-UP-1 Operable Unit. The notice also included a violation and an item of concern relating to WAC 246-247 and 40 CFR 61, Subpart H (air emissions). The notice required four actions be taken to resolve the identified issues and violations. The issues and required actions identified in the notice have been addressed.

2.2.6 Clean Air Act

Federal, state, and local agencies enforce Clean Air Act of 1986 (Section 118) standards and requirements for regulation of air emissions at facilities such as the Hanford Site. A summary of the major agency interfaces and applicable regulations for the Hanford Site is provided in the following paragraphs.

The Washington State Department of Health's Division of Radiation Protection regulates radioactive air emissions statewide through delegated authority from EPA and its implementing regulation (WAC 246-247). Prior to commencing any work that would result in creating a new or modified source of radioactive airborne emissions, a notice of construction application must be submitted to the Washington State Department of Health by the DOE Richland Operations Office, and usually the EPA, for review and approval. Applicable controls and annual reporting of all radioactive air emissions are standard requirements. The Hanford Site operates under state license FF-01 for such emissions. The conditions specified in the license will be incorporated into the Hanford Site air operating permit, scheduled to be issued in late 1999 in accordance with Title V of the Clean Air Act and Amendments of 1990 and the federal and state programs under 40 CFR 70 and WAC 173-401, respectively. The Hanford Site air operating permit will include a compilation of requirements for both radioactive emissions now covered by the existing state license and nonradioactive emissions. The permit requires the owner (DOE Richland Operations Office) to submit periodic reports and an annual compliance certification to the state.

Revised requirements for radioactive air emissions were issued in December 1989 under 40 CFR 61, Subpart H. The total emissions from the Hanford Site's DOE operations result in offsite exposures that remain well below the state and EPA offsite emission standard of 10 mrem/yr. Reporting and monitoring requirements necessitate routine evaluation of all radionuclide emission points on the Hanford Site to determine those subject to the continuous emission measurement requirements in 40 CFR 61, Subpart H, reflected in both federal and state regulations. The 1989 requirements for flow and emissions measurements, quality assurance, and sampling documentation have been implemented at all Hanford Site sources and/or are tracked for milestone progress, as discussed below, in accordance with a schedule approved by the EPA and monitored by the Washington State Department of Health.

The *Federal Facility Compliance Agreement for Radionuclide NESHAP* (1994) was signed by EPA Region 10 and DOE and provides a compliance plan and schedule that are being followed to bring the Hanford Site into compliance with the Clean Air Act of 1986, as amended, and its implementing regulations in 40 CFR 61, Subpart H that address sampling of airborne emissions. All 1998 federal facility compliance agreement milestones were met, and Hanford Site air emissions remained well below all regulatory limits set for radioactive and other pollutants.

The Washington State Department of Ecology enforces state regulatory controls for air contaminants as allowed under the Washington Clean Air

Act (Revised Code of Washington [RCW] 70.94). The implementing requirements (e.g., WAC 173-400, 173-460) specify applicable controls, reporting, notifications, permitting, and provisions of compliance with the general standards for applicable Hanford Site sources.

Pursuant to 40 CFR 61, Subpart M, EPA promulgated regulations specifically addressing asbestos emissions. These regulations apply at the Hanford Site in building demolition and/or renovation and waste disposal operations. Asbestos at Hanford is handled in accordance with EPA regulations and approved contractor procedures.

Title VI of the Clean Air Act Amendments of 1990 require regulation of the service, maintenance, repair, and disposal of appliances containing Class I and Class II ozone-depleting substances (refrigerants) through implementation of the requirements in 40 CFR 82. Implementation of the EPA requirements for ozone-depleting substance management on the Hanford Site is administered through a sitewide implementation plan (DOE/RL-94-86). The continued need for this implementation plan is being evaluated by the DOE Richland Operations Office to determine if it should be updated to reflect changes in Hanford Site contractor relationships and applicable federal regulations.

The Benton Clean Air Authority enforces Regulation 1, which pertains to open burning and asbestos handling. The Benton Clean Air Authority has been delegated the authority to enforce EPA asbestos regulations under the national emission standards for hazardous air pollutants (40 CFR 61, Subpart M). There was one asbestos compliance issue identified and resolved at a Bechtel Hanford Inc. project during 1998.

During 1998, routine reporting and/or notification of air emissions was provided to each air quality agency in accordance with requirements.

2.2.6.1 Clean Air Act Enforcement Inspections

DOE and its contractors are working to resolve outstanding compliance findings from the Washington State Departments of Health and Ecology inspections. The noncompliance events in 1998 are listed below.

- The Washington State Department of Health issued a Notice of Correction in response to a compliance inspection of the 296-S-25 and 296-S-22 Emission Units (stacks) on waste receiving tanks associated with underground storage tanks in the 200-West Area. The inspection concluded that the emission units were not maintained and operated in compliance with technology standards required by regulation. The notice identified two corrective actions that have been responded to.
- The Washington State Department of Health issued a Notice of Violation/Notice of Correction in response to a tritium release event at the 324 Building in the 300 Area. The regulator concluded that the release event violated sampling requirements and the approved Notice of Construction for the activities associated with the release. The notice identified two violations and three corrective actions. The corrective actions were addressed during a number of meetings held with the regulator.
- The Washington State Department of Health issued a Notice of Correction in response to an inspection at the 200 Areas Effluent Treatment Facility in the 200-East Area. The inspection concluded that reporting and monitoring requirements were not met regarding a spill of contaminated waste water at the facility. The notice identified seven corrective actions that have been responded to.
- The Washington State Department of Health issued a Notice of Violation/Notice of Correction in response to an inspection at the 200 Areas Effluent Treatment Facility. Violations of approved controls and reporting requirements were identified. The notice identified two violations and three corrective actions that have been responded to.
- The Washington State Department of Health issued a Notice of Correction for the 105-C Building in

the 100-B,C Area and the Radiological Counting Facility in the 100-N Area. The 105-C Building is a deactivated reactor that has been placed in interim safe storage, and the Radiological Counting Facility performs screening analysis for Environmental Restoration Project samples. Air monitoring samples from the 105-C Building interim safe storage project were analyzed at a facility with quality control procedures that did not meet the state's regulatory requirements and results of air emissions sampling were not individually reported in the annual radionuclide air emission report. A required annual test was not conducted at the Radiological Counting Facility in 1996 and 1997. A letter response was transmitted to the Washington State Department of Health in September 1998 to close out these issues.

- The Washington State Department of Health issued a Notice of Correction in response to an inspection at the AP double-shell tank farm in the 200-East Area. The inspection concluded that calibration requirements were not met. The notice identified four corrective actions that have been responded to.
- The Washington State Department of Health issued a Notice of Correction in response to a review of a 10-d report associated with a radiological release from the 152-ER Diversion Box, used for transfers of underground tank waste in the 200-East Area. The review concluded that additional controls were required to prevent the release of contamination. The notice identified three corrective actions that have been responded to.
- The Washington State Department of Health issued a Notice of Correction in response to a sitewide inspection. The regulator concluded that the lack of documentation provided during the inspection demonstrated that technology standards were not being met in accordance with approved Notices of Construction. The Notice of Correction identified three corrective actions that have been responded to.
- As a result of work being performed in the 325 Building by the Tritium Target Qualification Project, an unplanned release of tritium occurred on December 9, 1998. Although the released quantity of tritium was below existing permit limitations, the Washington State Department of Health issued a Stop Work Order for the 325 Building project. In response to the Stop Work Order, corrective actions were implemented to improve work processes and modify research equipment to reduce the potential for unplanned releases. The regulator concurred with the corrective measures and subsequently lifted the Stop Work Order (February 10, 1999). Work has continued without further incident. The objective of this project is to assess the tritium yield from tritium target rods irradiated at the Idaho National Engineering and Environmental Laboratory.

2.2.7 Clean Water Act

The Clean Water Act of 1997 applies to point source discharges to waters of the United States. At the Hanford Site, the regulations are applied through National Pollutant Discharge Elimination System (40 CFR 122) permits that govern effluent discharges to the Columbia River.

There are two National Pollutant Discharge Elimination System permits for the site. Permit #WA-000374-3 includes four inactive outfalls (005, 006, 007, and 009 in the 100-N Area) and three active outfalls (003 and 004 in the 100-K Area and 013 in the 300 Area). There were two instances of noncompliance for these outfalls in 1998. Permit #WA-002591-7 governs outfall 001A, located at the 300 Area Treated Effluent Disposal Facility.

An application for a permit modification for the 300 Area Treated Effluent Disposal Facility (permit #WA-002591-7) was submitted to the EPA in November 1997. The application requested the transfer of outfalls 003 and 004 (100-K Area) from existing permit #WA-000374-3 to permit #WA-002591-7. The 100-N outfalls (005, 006, 007, 009, and N Springs) identified in permit #WA-000374-3 were not included in the application because active discharges to these outfalls have ceased. N Springs may have some residual seepage from the ground and

this is being addressed under the CERCLA program. A summary discussing why another outfall (013A in the 300 Area) should be exempt from permitting was also attached to the application. The revised permit was issued in early 1999.

Permit #WA-002591-7 had 14 permit infractions in 1998. All were the result of contaminant levels in effluents exceeding the permit limits. The facility was in normal operation and meeting design specifications at the time of these events. All indications suggest that the facility is unable to consistently meet the restrictions of the permit despite the use of the best available technology.

The Hanford Site was covered by two stormwater permits (WAR-00-000F, WAR-10-000F) in 1998. In compliance with the industrial stormwater discharge permit, an annual comprehensive site compliance evaluation was performed and documented in 1998 (HNF-3100). In accordance with the September 30, 1998 Federal Register (63 FR 52430), the stormwater general permit for industrial activity (WAR-00-000F) was terminated and replaced by the multisector general stormwater permit (WAR-10-000F). On December 28, 1998, a Notice of Intent was submitted to EPA for coverage under the National Pollutant Discharge Elimination System multisector general stormwater permit (WAR-10-000F).

DOE Richland Operations Office has a pretreatment permit (CR-IU005) from the city of Richland for the discharge of wastewater from the William R. Wiley Environmental Molecular Sciences Laboratory in the Richland North Area. Also, there are numerous sanitary waste discharges to the ground, as well as 400 Area sanitary waste discharge to the Energy Northwest (formerly known as the Washington Public Power Supply System) treatment facility (see Figure 1.0.1 for Energy Northwest location). Sanitary waste from the 300 Area, the former 1100 Area, and other facilities north of, and in, Richland discharge to the city of Richland treatment facility.

Noncompliance events in 1998 related to these permits are listed below.

- Temperature limits were exceeded for outfall 004 in the 100-K Area on one occasion. This was caused by the solar heating of water inventories and sand beds at the 183-KE Water Treatment Plant.
- Because of a very low water table at the 1301-N Liquid Waste Disposal Facility, samples could not be obtained for analyzing the required parameters (oil and grease, iron, ammonia, chromium, and pH) and was considered a noncompliance.
- At the 300 Area Treated Effluent Disposal Facility, concentration limits for copper were exceeded 10 times. A more-suitable limit for the treatment technology but still protective of the environment was established in the recently issued National Pollutant Discharge Elimination System permit (permit #WA-002591-7). Also, concentration limits for methylene chloride were exceeded twice. The cause was sample blank contamination rather than an effluent problem. Further, concentration limits for bis(2-ethylhexyl)phthalate were exceeded twice. A more-suitable limit has been established.

2.2.7.1 Liquid Effluent Consent Order

The Washington State Department of Ecology liquid effluent consent order (DE91NM-177), which regulates Hanford Site liquid effluent discharges to the ground, contains compliance milestones for Hanford Site liquid effluent streams designated as Phase I, Phase II, and Miscellaneous Streams. All state waste discharge permit applications have been submitted to the Washington State Department of Ecology for liquid effluent streams subject to regulation by the consent order. One new state waste discharge permit was issued on May 1, 1998 by the Washington State Department of Ecology: Permit ST 4509 for Hanford Site cooling water and condensate discharges.

The first Hanford Site miscellaneous streams categorical permit was issued by the Washington

State Department of Ecology for hydrotest, maintenance, and construction discharges. The permit became effective May 30, 1997 and expires on May 30, 2002. A second miscellaneous streams categorical permit for cooling water and condensate discharges was issued on May 1, 1998. An application for the third, and last, miscellaneous streams categorical permit for stormwater discharges was submitted to the Washington State Department of Ecology in August 1998; issuance is pending.

In 1998, there were eight noncompliances in three of the seven state waste discharge permits in place at the Hanford Site. Details are listed below.

- State waste discharge permit ST 4507, 100-N Area Sewage Lagoon - The effluent discharge limit for total suspended solids was exceeded and was attributed to an algae bloom. Engineered upgrades are being implemented to mitigate future recurrences. The effluent flow meter failed twice, violating continuous flow monitoring requirements. The first was attributed to a loss of power. When power was restored, the flow meter was restarted. The second was attributed to sub-zero weather, which resulted in damage to the equipment. The flow meter was replaced with a unit designed to function in adverse conditions. The operations and maintenance manual was not submitted to the Washington State Department of Ecology within the specified time frame and was attributed to an administrative error. Training to the permit requirements was provided to personnel to prevent a recurrence.
- State waste discharge permit ST 4501, 400 Area secondary cooling water - The effluent discharge limit for manganese was exceeded and it was attributed to the high concentration of manganese that occurs naturally in the source water. The sample pump failed, violating composite sampling requirements. Simple mechanical failure was the cause, and the pump was repaired. The effluent discharge limit for total suspended solids was exceeded. The cause was attributed to incorrect laboratory analysis, following reanalysis of the effluent.
- State waste discharge permit ST 4508, hydrotest, maintenance, and construction discharges - The 20-min-duration limit for drinking water line flushing activities was exceeded bimonthly for several months. The cause was an administrative discrepancy between discharge limits and flushing procedures.

2.2.8 Safe Drinking Water Act

There are 12 public water systems on the Hanford Site. All public water systems are required to meet the Safe Drinking Water Act of 1974, the Safe Drinking Water Act Amendments of 1986, and the Safe Drinking Water Act Amendments of 1996. Specific performance requirements are defined within the federal regulations (40 CFR 141, EPA-570/9-76-003, EPA 822-R-96-001) and the Washington Administrative Code (WAC 246-290).

Radionuclides, inorganics, synthetic and volatile organics, lead and copper, and coliform bacteria are monitored in Hanford Site drinking water. All sampling results for 1998 were well below established maximum contaminant levels and action levels set by the Washington State Department of Health, with the exception of one positive sample from the 100-N Area water system that was positive for total coliform bacteria. This sample was negative for E. coli. All follow-up sampling indicated satisfactory results.

During 1998, the 283-W Water Treatment Plant in the 200-West Area was operated in a manner that exceeded Washington state requirements. This water system uses a surface-water source, the Columbia River. Water systems that have surface-water sources must comply with the minimum requirements for removal or inactivation of pathogenic organisms. There are provisions embodied in the National Primary Drinking Water Regulations (40 CFR 141) for water systems that for 12 consecutive months

consistently perform above the requirements to apply for additional treatment credit. As a result of the excellent performance record established by the 283-W Water Treatment Plant, the Washington State Department of Health has been requested to evaluate the operating data and award the additional credit. Because of the plant's demonstrated ability to remove pathogenic organisms, the additional credit allows the plant to not overtreat by vigorous disinfection. The result of the treatment credit is that less chlorine must be added to the water. The overall quality of the water is not changed.

Radionuclide activities in drinking water are discussed in Section 4.3, "Hanford Site Drinking Water Surveillance."

2.2.9 Toxic Substances Control Act

Requirements of this Act applied to the Hanford Site primarily involve regulation of polychlorinated biphenyls. Federal regulations for use, storage, and disposal of polychlorinated biphenyls are found in 40 CFR 761. The EPA issued a revision to these regulations, the disposal amendments, which became effective in August 1998 (63 FR 35383). The impacts of these new regulations to Hanford have been analyzed, and the necessary changes have been implemented. The state of Washington also regulates certain classes of polychlorinated biphenyls through the dangerous waste regulations in WAC 173-303-170.

Electrical transformers on the site have been sampled and characterized. Fourteen transformers with polychlorinated biphenyl concentrations >500 ppm remain in service. The timing of the replacement and disposal of these transformers will be based on the operational status decision for the Fast Flux Test Facility. The transformers will be needed if the facility is restarted.

Defueled, decommissioned, naval reactor compartments shipped by the United States Navy to the Hanford Site for disposal contain small quantities of polychlorinated biphenyls, which are tightly bound in materials such as thermal insulation, cable coverings, and rubber. Because polychlorinated biphenyls are present, the reactor compartments are regulated under this Act. A compliance agreement between EPA and DOE defines the process by which a chemical waste landfill approval under this Act will be issued for the reactor compartment disposal trench.

Nonradioactive polychlorinated biphenyl waste is stored and disposed of in accordance with 40 CFR 761. Radioactive polychlorinated biphenyl waste remains in storage onsite, pending the development of adequate treatment and disposal technologies and capacities. Requirements for the storage of radioactive polychlorinated biphenyl wastes were included in the disposal amendments (63 FR 35383) and have effectively removed the need for a compliance agreement between DOE and EPA, which previously provided a mechanism for the storage of these wastes. DOE is working with EPA to cancel the agreement and is managing radioactive polychlorinated biphenyl wastes in compliance with the new requirements. Pacific Northwest National Laboratory continues to conduct research on the degradation of polychlorinated biphenyls in waste matrices under an alternative treatment technology approval from the EPA.

2.2.10 Federal Insecticide, Fungicide, and Rodenticide Act

This Act is administered by EPA. The standards administered by the Washington State Department of Agriculture to regulate the implementation of the Act in Washington State include: Washington

Pesticide Control Act (RCW 15.58), Washington Pesticide Application Act (RCW 17.21), and rules relating to general pesticide use codified in WAC 16-228. At the Hanford Site, all pesticides are applied by commercial pesticide operators who are listed on one of two commercial pesticide applicator licenses. In 1998, the Hanford Site was in compliance with the federal and state standards.

2.2.11 Endangered Species Act

Many rare species of native plants and animals are known to exist on the Hanford Site. Five species that may occur onsite (the bald eagle, peregrine falcon, Aleutian Canada goose, steelhead trout, and spring chinook salmon) are listed by the U.S. Fish and Wildlife Service as either endangered or threatened. Others are listed by the Washington State Department of Fish and Wildlife as endangered, threatened, or sensitive species (Appendix F). The site wildlife monitoring program is discussed in Section 7.2, "Ecosystem Monitoring (Plants and Wildlife)."

Bald eagles, a threatened species, are seasonal visitors to the Hanford Site. Several nesting attempts along the Hanford Reach were documented by Pacific Northwest National Laboratory in the 1990s. In compliance with the Endangered Species Act, the Hanford Site bald eagle management plan (DOE/RL-94-150) was finalized in 1994. That plan established seasonal 800-m (2,600-ft) restricted access zones around all active nest sites and five major communal roosting sites. If nesting activities at the historical nesting sites are observed in January and early February, all Hanford-related activities are restricted until the pair abandons nesting or successfully rears young. In 1997, nests were built by two pairs of eagles. The nesting eagles eventually left the area without successfully producing offspring. The pairs attempted to nest again in 1998, but it is not yet known if offspring were produced.

The peregrine falcon and the Aleutian Canada goose are rarely observed on the site. Steelhead and salmon are regulated as evolutionary significant units by the National Marine Fisheries Service based on their historical geographic spawning areas. The upper Columbia River evolutionary significant unit was listed as threatened in August 1997. In March 1999, the mid-Columbia River evolutionary significant units for steelhead and upper Columbia River spring-run chinook salmon were listed as threatened and endangered, respectively. A Hanford Site steelhead management plan is being prepared that will serve as the formal consultation with the National Marine Fisheries Service as required under the Endangered Species Act of 1973. Like the bald eagle management plan, the steelhead management plan will discuss mitigation strategies and will list activities that can be conducted without impacting steelhead trout or their habitats.

As part of the National Environmental Policy Act of 1969 review process, an ecological review was conducted on all projects to evaluate their potential of affecting federal- and/or state-listed species within the proposed project area (PNNL-6415, Rev. 10). The ecological review included quantifying impacts that might result and identifying mitigation strategies to minimize or eliminate such impacts.

2.2.12 National Historic Preservation Act, Archaeological Resources Protection Act, Native American Graves Protection and Repatriation Act, and American Indian Religious Freedom Act

Cultural resources on the Hanford Site are subject to the provisions of these four Acts. Compliance with the applicable regulations is accomplished through an active management and monitoring program that includes a review of all proposed projects to assess potential impacts on cultural resources, periodic inspections of known archaeological and historic sites to determine their condition and eligibility for listing on the National Register of Historic Places, determination of the effects of land management policies on the sites and buildings, and management of a repository for federally owned archaeological collections. In 1998, 150 reviews were requested and conducted on the Hanford Site.

The American Indian Religious Freedom Act of 1978 requires federal agencies to help protect and preserve the rights of Native Americans to practice their traditional religions. DOE cooperates with Native Americans by providing site access for organized religious activities.

2.2.13 National Environmental Policy Act

The National Environmental Policy Act of 1969 requires preparation of appropriate documentation to analyze potential environmental impacts associated with proposed federal actions. An environmental impact statement is required to analyze the impacts associated with major federal actions that have the potential to significantly affect the quality of the human environment.

The following sections address environmental impact statements related to Hanford Site activities. Other National Environmental Policy Act documents include an environmental assessment, which is prepared when it is uncertain if a proposed action has the potential to impact the environment significantly and, therefore, would require the preparation of an environmental impact statement. A summary and status of environmental assessments that apply to specific activities and facilities on the Hanford Site may be found in HNF-SP-0903, Rev. 5, *National Environmental Policy Act Source Guide for the Hanford Site*. This report is updated annually.

Additionally, certain types of actions may fall into categories that have already been analyzed by DOE and have been determined not to result in a significant environmental impact. These actions, which are called categorical exclusions, are exempt from further National Environmental Policy Act review. Typically, over 20 specific categorical exclusions are documented by DOE Richland Operations Office annually, involving a wide variety of actions by multiple contractors. In addition, sitewide categorical exclusions are applied to hundreds of routine, typical actions conducted daily on the Hanford Site. In 1998, there were 20 sitewide categorical exclusions.

The Council on Environmental Quality, which reports directly to the President, was established to oversee the National Environmental Policy Act process. National Environmental Policy Act documents are prepared and approved in accordance with Council on Environmental Quality National Environmental Policy Act regulations (40 CFR 1500-1508),

DOE National Environmental Policy Act implementation procedures (10 CFR 1021), and DOE Order 451.1A. In accordance with the Order, DOE documents prepared for CERCLA projects incorporate National Environmental Policy Act values such as analysis of cumulative, offsite, ecological, and socioeconomic impacts to the extent practicable in lieu of preparing separate National Environmental Policy Act documentation.

2.2.13.1 Recent Environmental Impact Statements

Potential environmental impacts associated with ongoing, major activities at the Hanford Site have been analyzed in environmental impact statements issued in the past several years, followed by records of decision. Additional National Environmental Policy Act reviews, as appropriate, are being conducted during the course of the actions, moving forward as described in the records of decision. Environmental impact statements issued in 1998, and/or those that had significant related documentation issued, or other activities in 1998 are described below.

A final environmental impact statement for the Hanford Reach of the Columbia River was issued in June 1994 (National Park Service 1994). The proposed action is to designate the Hanford Reach of the Columbia River a recreational river under the National Wild and Scenic Rivers System, and designate the Wahluke Slope and Columbia River corridor areas of the DOE's Hanford Site a wildlife refuge under the U.S. Fish and Wildlife Service. The record of decision was issued in July 1996 (Babbitt 1996). No final decision regarding the Hanford Reach has been attained to date; discussions in Congress are ongoing. The Secretary of Energy announced a proposal in April 1998, that is consistent with the environmental impact statement proposed action, to manage the Wahluke Slope area as a National Wildlife Refuge.

An environmental assessment for the treatment of low-level, mixes waste by Allied Technology Group, Inc. was prepared (DOE/EA-1135) under the Washington State Environmental Policy Act (WAC 197-11) by the city of Richland as the lead agency. Allied Technology Group, Inc. proposes to construct and operate a low-level mixed waste facility in Richland, Washington. The proposed facility would be located adjacent to Allied Technology Group's existing low-level radioactive waste treatment facility and would be designed to treat low-level mixed waste from DOE's Hanford Site and other governmental and commercial generators of low-level mixed waste. Additional documentation pertaining to the final environmental impact statement is listed below.

- A final environmental assessment for the transport of contact-handled, low-level, mixed waste from the Hanford Site to Allied Technology Group's mixed waste facility for nonthermal treatment and to return the treated waste to the Hanford Site for eventual land disposal was issued (DOE/EA-1189). A finding of no significant impact was issued on September 29, 1998.
- An environmental assessment for the thermal treatment of DOE's contact-handled, low-level, mixed waste at the Allied Technology Group's gasification and vitrification building was issued (DOE-1135). A finding of no significant impact was issued on May 6, 1999.

A final environmental impact statement for the management of spent nuclear fuel from the K-East and K-West Fuel Storage Basins (K Basins) was issued (DOE/EIS-0245F). The proposed action is drying/passivation of spent nuclear fuel, with subsequent dry storage. The record of decision was issued in March 1996 (61 FR 10736). A supplement analysis provided a basis for a determination of whether a supplemental environmental impact statement is required as a result of deleting a process step from the preferred alternative selected in the record of decision. It was determined that no additional National Environmental Policy Act analysis was required.

A final environmental impact statement, coprepared by the Washington State Department of Ecology and DOE, for the Hanford Site's tank waste remediation system was issued (DOE/EIS-0189). The proposed actions are the retrieval of radioactive wastes from double- and single-shell waste tanks and the subsequent stabilization of the wastes in forms suitable for disposal. The record of decision was issued in February 1997 (62 FR 8693). A supplement analysis (DOE/EIS-0189-SA2) was issued that addressed the potential effect that new data and information, developed since the preparation of the tank waste remediation system environmental impact statement, may have on the impacts presented in the statement. DOE determined that the information developed since the preparation of the environmental impact statement has a small effect on the impacts calculated in the statement and that the changes in environmental impacts are bounded by the impacts presented. Therefore, no additional National Environmental Policy Act analysis was required.

2.2.13.2 Programmatic Environmental Impact Statements

A final programmatic environmental impact statement was issued in May 1997 (DOE/EIS-0200F) to evaluate management and national siting alternatives for the treatment, storage, and disposal of five types of radioactive and hazardous waste. Hanford was considered in all alternatives. A record of decision was issued in January 1998 (63 FR 3623) on treatment and storage of transuranic waste. A subsequent record of decision on hazardous waste treatment was issued in August 1998 (63 FR 41810). Other records of decision are expected on this environmental impact statement.

2.2.13.3 Site-Specific Environmental Impact Statements in Progress

A Hanford Site remedial action environmental impact statement is being prepared for the development of a comprehensive land-use plan for the Hanford Site. A second draft environmental impact statement, prepared with cooperating agencies, was issued for public comment in April 1999 (DOE/EIS-0222D). The final environmental impact statement is expected to be issued in late 1999.

An environmental impact statement is being prepared for the Hanford Site Solid Waste (radioactive and hazardous) Program to address management of Hanford Site solid wastes. A draft environmental impact statement is being prepared in cooperation with the Yakama Indian Nation; it is expected to be issued for public comment in late 1999.

2.2.14 Hanford Site Permitting Summary

The Hanford Site has obtained, or is in the process of obtaining, numerous environmental permits. The permits and their status are summarized in DOE/RL-96-63 (Rev. 2), *Annual Hanford Site Environmental Permitting Status Report*. For RCRA permitting, the Hanford Site is considered a single facility and has been issued one EPA identification number. The identification number encompasses over 60 treatment, storage, and/or disposal units. (Three additional identification numbers were effective in November 1996. However, these do not apply to treatment, storage, and disposal units.) The initial RCRA permit was issued for less than the entire facility because all units cannot be permitted simultaneously. The permit, through the permit modification process, will eventually incorporate all treatment, storage, and disposal units.

Implementation of the Clean Air Act is facilitated by several permits. Title V of the Act requires an air operating permit for major stationary sources, including the Hanford Site. The proposed Hanford

Site air operating permit was issued in February 1999 for EPA review. The Washington State Department of Ecology has since withdrawn the proposed permit and is scheduled to reissue a revised draft permit for public review later in 1999. Regulatory approvals must be obtained prior to constructing or modifying facilities that emit regulated air pollutants. To date, 65 approvals have been obtained from the Washington State Department of Ecology, 314 from the Washington State Department of Health, and 161 from the EPA. These numbers change as a result of continuing activities that require permits.

The sitewide and the 300 Area Treated Effluent Disposal Facility pollutant discharge elimination system permits govern liquid process effluent discharges to the Columbia River. Stormwater discharges to the Columbia River are permitted by the National Pollutant Discharge Elimination System (40 CFR 122). Waste discharge permits are required by WAC 173-216 and are summarized in Section 2.2.7.1, "Liquid Effluent Consent Order."

Other Hanford Site permitting addressed in the permitting status report (DOE/RL-96-63, Rev. 2) includes research, development, and demonstration; solid waste handling; onsite sewage systems; and permitting of underground petroleum storage tanks. Also refer to Appendix C, Table C.6.

2.3 Activities, Accomplishments, and Issues

D. G. Black

This section further describes DOE's progress in meeting its mission at the Hanford Site. Section 2.2, "Compliance Status," described activities relating to compliance with regulations. This section describes other, major, ongoing activities. Ongoing compliance selfassessments, knowledge gained in implementing Tri-Party Agreement (Ecology et al. 1989) milestones, and communications with stakeholders continue to identify environmental compliance issues. Relevant issues are discussed openly with the regulators and with the public to ensure that environmental compliance issues are resolved.

2.3.1 Hanford Federal Facility Agreement and Consent Order

Highlights of accomplishments (not documents or publications), with the associated Tri-Party Agreement milestone numbers, include the following:

- completed N Reactor/100-N Area deactivation (M-16-01E)
- initiated excavation associated with Environmental Restoration and Disposal Facility cells 3 and 4 construction near the 200-West Area (M-16-92A)
- installed 11 RCRA groundwater monitoring wells at various Hanford Site locations (M-24-00J)
- completed project W-030 tank farm ventilation upgrades (M-43-01)
- completed project W-058 replacement of cross-site transfer system between the 200 Areas (M-43-07)
- completed melter tests (for mixing waste with molten glass) and selected reference melter for treating waste stored in the underground tanks (M-51-02)
- completed Plutonium-Uranium Extraction Plant and Uranium-TriOxide Plant facility transition phase in the 200-East and 200-West Areas, respectively (M-80-00)
- completed B Plant deactivation in the 200-East Area (M-82 series)
- initiated processing of contact-handled (versus remote-handled [high radioactivity levels]) transuranic and transuranic mixed waste at the Waste Receiving and Processing Facility in the 200-West Area (M-91-02)
- completed transfer of the 14 300 Area legacy cesium capsules to the Waste Encapsulation and Storage Facility in the 200-East Area (M-92-04). All of the legacy strontium had been removed from the 300 Area previously
- completed C Reactor interim safe storage large-scale demonstration in the 100-B,C Area (M-93-03).

Since the last issue of this report, negotiated changes to the Tri-Party Agreement established 20 new enforceable milestones. A summary of the significant approved changes is given in the following sections.

2.3.1.1 Waste Management

There was one approved change request related to waste management during 1998.

After consulting with DOE in the context of Tri-Party Agreement milestone M-34 negotiations, EPA and the Washington State Department of Ecology decided to employ CERCLA provisions as the regulatory process for the cleanup of the K Basins. This change of lead regulatory agency will maintain

consistency with the approach to regulatory authority and lead regulatory agency designation as agreed to under the Sixth Amendment of the Tri-Party Agreement Action Plan (Attachment 2 to Ecology et al. 1989). Under paragraph 88 of the action plan, EPA and the Washington State Department of Ecology will have joint authority to determine the choice of lead regulatory process in consultation with DOE.

2.3.1.2 Environmental Restoration

There were nine approved change requests related to environmental restoration during 1998.

Milestone M-13-00 contains schedules for the submittal of work plans for accomplishing all 200 Areas soil investigations by December 31, 2008 (M-15-00C). The three parties jointly developed an improved approach to investigation and subsequent remediation of 200 Areas contaminated soil sites within the responsibility of the Environmental Restoration Program based on lessons learned from Hanford's 100 and 300 Areas. To date, the investigation approach for the 200 Areas has been based on a geographic boundary (operable unit), consisting of different waste site types. Remedial investigations will now focus on representative sites from groups with similar histories and waste site types (ponds, ditches, cribs), and the results will be applied generally to the entire waste site group.

The 300-FF-2 Operable Unit limited field investigation assumed that waste sites that were near or under active facilities would be deferred until such time as characterization activities could be coordinated with decontamination and decommissioning as well as RCRA activities. This would result in additional limited field investigations and subsequent records of decision. Based on this assumption, the scope of the focused feasibility study and proposed plan was limited to approximately 40 waste sites that have been addressed in the limited field investigation, out of a total of 415 waste sites that comprise the entire 300-FF-2 Operable Unit. Discussions held in the spring of 1998 with the EPA concluded that all known 300-FF-2 waste sites should be included in the focused feasibility study and proposed plan, so that only one record of decision will be necessary. With the inclusion of the additional waste sites, an extension of 4 mo was approved for the associated milestone for completion of the necessary documents.

During the fall of 1998, an effort was initiated to evaluate the waste sites identified in the 300-FF-2 Operable Unit following the waste site reclassification process. At the conclusion of 1998, a number of joint meetings were held that resulted in a significant number of waste sites requiring no further action. This effort, which is scheduled to be completed in the spring of 1999, will result in a substantial reduction in the number of waste sites that need to be addressed in the 300-FF-2 focused feasibility study and proposed plan.

Once enough hardware/waste had been removed from the N Reactor fuel storage basin, a decontamination method, using (176 kg/cm^2 [2,500 lb/in.^{2}]) water, was tested but was unsuccessful in achieving low-enough dose rates (radiation levels in the air) to be at compliant levels along the nearby Columbia River shoreline. Follow-on efforts also failed to achieve sufficient dose reduction and proved not to be viable. The option that was determined to be the most expedient and cost effective was placement of concrete panels (30.48 cm [1 ft]) over the entire basin for shielding and airborne contamination control, as well as placement of steel covers (0.64 cm [0.25 in.]). N Reactor environmental restoration milestones were met.

In 1996, interim milestones were established for remediation and backfill of 37 liquid waste sites in the 100-BC-1, 100-DR-1, and 100-HR-1 Operable Units. The volumes of contaminated material at 100-BC-1 and 100-DR-1 have increased substantially over what was originally predicted. In 1998, milestones were modified to include additional liquid

waste sites in operable units 100-BC-1, 100-DR-1, and 100-HR-1, plus sites in operable units 100-BC-2, 100-DR-2, 100-FR-1, 100-FR-2, and 100-KR-1.

In 1998, milestones were established for initiation of excavation associated with Environmental Restoration and Disposal Facility cells 3 and 4 construction and completion of construction and readiness to accept waste in these cells, located near the 200-West Area.

Milestone M-20-00 contains schedules for the submittal of closure plans for the cleanup of RCRA treatment, storage, and disposal units. Similar to milestone M-13-00, the three parties jointly developed an improved approach to investigation and subsequent remediation of waste sites closely associated with past-practice units within the Environmental Restoration Program based on lessons learned from Hanford's 100 and 300 Areas. The coordination of the treatment, storage and disposal unit's closure with the past-practice investigation and remediation activity is necessary to prevent overlap and duplication of work, thereby economically and efficiently addressing the contamination. These treatment, storage, and disposal groups/units assigned to an operable unit are prioritized in conjunction with past-practice units and are to be investigated and managed together. Remedial investigations will now focus on representative sites from groups with similar histories and waste site types (ponds, ditches, cribs), and the results will be applied generally to the entire waste site group.

New interim milestones were established for RCRA groundwater monitoring well locations in support of milestone M-24-00. This milestone requires the installation of groundwater monitoring wells at the rate of up to 50/yr. These agreed-on locations were based on RCRA permitting as well as detection and monitoring requirements.

2.3.1.3 Tank Waste Remediation System

The completion date of the cross-site transfer system between the 200 Areas was extended by 1 mo. There was no planned use for the system during the period the construction was extended. This system is used to transfer waste between underground tanks in the 200-East and 200-West Areas.

2.3.1.4 Facilities Transition

A change request extended the milestone date of the report documenting the hazardous substances/dangerous wastes remaining within B Plant in the 200-East Area. The extension of the milestone due date was made to coincide with submittal of the preclosure work plan. This timing will ensure submittal of all remaining information prior to completion of the M-82-00 major milestone.

Additional project technical baseline information was developed as part of the 324 Radiochemical Engineering Cell/High-Level Vault (300 Area) closure plan (DOE/RL-96-73, Rev. 1) after Tri-Party Agreement milestone M-89-00 was originally established.

2.3.2 Pollution Prevention Program

Pollution prevention is DOE's preferred approach to environmental management. The Hanford Site Pollution Prevention Program is an organized and continuing effort to reduce the quantity and toxicity of hazardous, radioactive, mixed, and sanitary wastes. The program fosters the conservation of resources and energy, the reduction of hazardous substance use, and the prevention or minimization of pollutant releases to all environmental media from all operations and site cleanup activities.

The program is designed to satisfy DOE requirements, executive orders, and federal and state regulations and requirements. In accordance with

sound environmental management, preventing pollution through source reduction is the first priority in this program; the second priority is environmentally safe recycling. Waste treatment to reduce quantity, toxicity, or mobility (or a combination of these) will be considered only when source reduction and recycling are not possible or practical. Disposal to the environment is the last option.

Overall responsibility for the Hanford Site Pollution Prevention Program resides with the DOE Richland Operations Office. The office defines overall program requirements that each prime contractor is responsible for meeting.

Hanford Site pollution prevention efforts in 1998 helped to prevent the generation of an estimated 10,200 m^3 (13,400 yd^3) of radioactive mixed waste, 270 metric tons (300 tons) of RCRA hazardous/dangerous waste, 57.8 million L (15.3 million gal) of process wastewater, and 7,100 metric tons (7,800 tons) of sanitary waste. Estimated waste disposal cost savings in 1998 exceeded $35 million for these activities.

During 1998, the Hanford Site recycled 525 metric tons (579 tons) of office paper, 57 metric tons (63 tons) of cardboard, 66 metric tons (72.7 tons) of newspapers/magazines, 5 metric tons (5.5 tons) of telephone books, 1,433 metric tons (1,580 tons) of ferrous metal, 78 metric tons (86 tons) of nonferrous metal, 123 metric tons (135 tons) of lead, 6 metric tons (6.6 tons) of solid chemicals, 17 metric tons (19 tons) of fluorescent light tubes, 37 metric tons (40.8 tons) of lead acid/gel cell batteries, and 795 metric tons (876 tons) of miscellaneous materials. Estimated disposal cost savings in 1998 exceeded $1.6 million.

Numerous generator-specific initiatives were put into place that enabled these waste reductions and cost savings. To celebrate these pollution prevention activities, the *Hanford Site Pollution Prevention Accomplishments* (HNF-2350) was published in October 1998. The book outlines many of the initiatives that were implemented and now in use at locations throughout the Hanford Site.

2.3.3 Environmental Molecular Sciences Laboratory

The William R. Wiley Environmental Molecular Sciences Laboratory, an 18,600 m^2 (200,200 ft^2) facility in the Richland North Area, was completed and DOE Headquarters authorized full operation in October 1997. Over 180 permanent staff members have moved into the laboratory from other facilities.

The city of Richland issued an industrial wastewater permit (CR-IU005) to DOE that allows for process wastewater from this laboratory to be discharged to the city of Richland's publicly owned treatment works. The permit was issued in accordance with the provisions of city ordinances in October 1996 and expires in October 2001. The discharge permit requires monthly effluent monitoring and reporting of the analytical data to the city. Routine discharges under this permit have begun. Additionally, as required by the permit, an accidental spill prevention plan (PNNL-11311) was developed and submitted to the city. That plan describes measures taken to prevent, control, and mitigate the effects of accidental releases of hazardous materials from the laboratory to the city.

2.3.4 Spent Nuclear Fuel Project

In February 1994, the Spent Nuclear Fuel Project was established to provide safe, economic, and environmentally sound management of Hanford Site spent nuclear fuel in a manner that readies it for final disposition.

The 40-year-old K Basins are being used to store 2,100 metric tons (2,300 tons) of N Reactor irradiated fuel and a small quantity of slightly irradiated single-pass reactor fuel. Approximately 20% of the fuel has corroded and is undergoing degradation as a result of extended underwater storage. In 1995, a Spent Nuclear Fuel Project strategy was approved. The strategy stipulated that the N Reactor fuel be removed from wet storage in the K Basins and placed into dry interim storage in the 200-East Area. Prior to interim storage, the fuel will be cleaned to remove corrosion products and particulates, packaged into fuel storage containers called multicanister overpacks, and vacuum processed to remove as much water as possible from the packaged fuel. Following the drying process, the fuel will be transported to the Canister Storage Building in the 200-East Area (see Figure 1.0.2). The multicanister overpacks will be seal welded, and the fuel will be maintained in storage pending a decision by the Secretary of Energy on its final disposition. This strategy supports completion of fuel removal from the K Basins by the agreed-to target date of December 2003.

If necessary, the fuel could remain in dry storage for up to 40 yr. The Canister Storage Building has been designed and constructed with a functional storage capacity of up to 75 yr. DOE strategic planning recommends that the fuel stored in K Basins and other spent nuclear fuel on the site and throughout the complex be placed in a geologic repository for final disposition. The construction of a national repository is awaiting congressional approval.

Fuel corrosion and fuel handling operations have led to the accumulation of sludge and corrosion products in fuel storage canisters and on the floors of the K Basins. The majority of the sludge is in the K-East Basin. Following the removal of the spent nuclear fuel from the K Basins, activities will be undertaken to retrieve the sludge from the basins and treat it as necessary to accommodate final disposal.

Debris, empty fuel canisters, and water remaining in the K Basins will also be removed or undergo treatment. The debris will be removed and disposed of on the Hanford Site at RCRA-permitted disposal facilities in compliance with existing waste acceptance criteria. The K Basins then will be prepared for interim stabilization, pending final remediation.

Other spent nuclear fuel stored on the Hanford Site (Fast Flux Test Facility fuel in the 400 Area; Training, Research, and Isotope Production General Atomics fuel in the 400 Area; fuel from the Shippingport, Pennsylvania reactor at T Plant in the 200-West Area; and miscellaneous special case and research reactor fuels in the 324, 325, and 327 Buildings in the 300 Area) will be relocated to suitable storage locations to await final disposition.

Through early 1999, the project continued to make progress on its accelerated strategy for moving the wet-stored K Basin fuel away from the Columbia River and into the Canister Storage Building. Construction of the building is complete, including installation of operating and support equipment and components. These components are now undergoing preoperational testing and validation. Operational procedures are being written in preparation for the operational readiness review and the start of fuel movement in November 2000. A concrete storage pad was constructed contiguous to the Canister Storage Building. This pad will be used to consolidate and store other spent nuclear fuel located at various places on the Hanford Site.

Construction of a cold vacuum drying facility is in progress at the 100-K Area. This facility will remove all free water from the fuel following removal from wet storage to stabilize it for dry storage at the Canister Storage Building. The first of three cold vacuum drying process units (skids) was procured and received. A test on the cold vacuum drying skid was completed, verifying the efficacy of the process using surrogate material.

Several critical pieces of equipment were obtained, constructed, or modified in 1998.

- Five transport vehicles and shipping casks were procured and delivered. These are to be used for transfer of the multicanister overpacks from the K Basins to the cold vacuum drying facility and from the cold vacuum drying facility to the Canister Storage Building.
- Thirty stainless steel fuel baskets to be used in loading the N Reactor fuel into the multicanister overpack containers were constructed onsite.
- Remote-controlled robotic fuel manipulators to be used in loading fuel into fuel baskets, commonly referred to as "Conan arms," were received.
- Existing operating systems at the K-West Basin were modified or upgraded to ensure safe lifting and manipulation of the fuel baskets, the multicanister overpacks, and the transport casks. The project is also completing design activities, safety analysis reports, and fabrication of process-related equipment.

2.3.5 Facility Stabilization Project

This project's mission is to transition those Hanford Site facilities for which it has responsibility from an operating mode to a long-term surveillance and maintenance mode. This includes maintaining facilities in a safe and compliant status, providing for the safe storage of nuclear materials, and reducing risks from hazardous materials and contamination. Under the project, the deactivation of primary systems to effectively reduce risks to human health and the environment will also be conducted. These activities will allow the lowest surveillance and maintenance costs to be attained while awaiting determination of a facility's final disposition and possible turnover to the Environmental Restoration Program.

The Facility Stabilization Project is engaged in five major deactivation efforts at the Hanford Site: B Plant, Facility Stabilization and Environmental Restoration Team, 300 Area Stabilization Project, Waste Encapsulation and Storage Facility, and Plutonium Finishing Plant. In addition, surveillance and maintenance of the Plutonium-Uranium Extraction Plant continued, following the completion of deactivation activities. The mission of each project and related accomplishments during 1998 are summarized below.

2.3.5.1 B Plant

B Plant, located in the 200-East Area, went into service in 1944 to recover plutonium by a chemical separation process. Following the advent of the more-efficient Plutonium-Uranium Extraction Plant process, B Plant's mission was modified to recover the high-heat isotopes (primarily cesium-137 and strontium-90) from highly radioactive waste. In October 1995, DOE directed that B Plant be deactivated.

The B Plant deactivation schedule was accelerated and completed 4 yr ahead of the baseline schedule and $100 million under budget. The facility, which had required $20 million annually to maintain in a standby mode, has been placed in a stable, static condition in a surveillance and maintenance phase and requires approximately $750,000 annually to maintain. The surveillance and maintenance will continue until a final disposition for the facility has been determined.

A significant effort during the B Plant deactivation was to decouple the facility from the Waste Encapsulation and Storage Facility, which continues

to provide safe storage of the high-heat isotopes recovered during B Plant's operational phase.

Significant accomplishments achieved during the accelerated B Plant deactivation effort include the following:

- All Tri-Party Agreement milestones associated with facility deactivation were completed on or ahead of schedule.
- The final 15,000 L (4,000 gal) of highly radioactive organic solvent waste from past processing operations were removed from the facility and shipped to an offsite RCRA-permitted mixed waste treatment, storage, and disposal facility for final disposition. One of the tanks constructed for interim storage of the organic solvent was never used and was redeployed to another project.
- Effluent systems were deactivated, eliminating all liquid discharges to the soil and to the 200 Areas Treated Effluent Disposal Facility. In addition, all the gaseous effluent stacks and vents were shut down, isolated, and replaced with a new ventilation system. The new system incorporated the latest ventilation design and sampling system.

2.3.5.2 Facility Stabilization and Environmental Restoration Team

The Facility Stabilization and Environmental Restoration Team (always referred to by its acronym FASTER) is a group with comprehensive cleanup experience. They were organized to share their experiences and lessons learned from the Uranium-TriOxide Plant and Plutonium-Uranium Extraction Plant deactivation projects with similar projects at Hanford and other DOE sites nationwide.

The FASTER Team has been assigned several facilities on the Hanford Site, primarily isolated facilities without associated staff, to prepare for deactivation as resources allow. The FASTER Team is also involved with deactivation planning for facilities at the Rocky Flats Plant in Colorado, the Savannah River Site in South Carolina, and the Oak Ridge Site in Tennessee.

2.3.5.3 300 Area Stabilization Project

This project has two subprojects: 1) 300 Area fuel supply shutdown subproject and 2) 324/327 Building transition subproject.

The fuel supply subproject includes buildings dating back to 1943 that housed manufacturing equipment for production of fuel for Hanford Site reactors. These processing operations were discontinued in 1987 when N Reactor was shut down and placed in a standby mode.

The other subproject includes the 324 and 327 Buildings, which were constructed in 1966 and 1953, respectively. These buildings house hot cells that were used for radiological research and development work. Both facilities were transferred to the Facility Stabilization Project in 1996.

The mission of this project is to complete deactivation and closure activities while maintaining the facilities in a safe and compliant status until turnover to the Environmental Restoration Program.

During 1998, the following significant accomplishments were achieved by this project:

- removed five billet furnaces from the 333 Reactor Fuel Manufacturing Facility as part of deactivation
- performed RCRA closure activities at the 303-K Material Storage Facility consistent with the closure plan
- completed 324 Building B cell equipment 1B rack (storage rack) size reduction activities, including grouting and shipping operations for the resulting remote-handled, low-level, radioactive waste containers
- completed the collection of dispersible materials in the 324 Building B cell under hot cell 1A rack and 1B rack
- submitted the final 324 Radiochemical Engineering Cell Closure Plan (DOE/RL-96-73, Rev. 1) and received Washington State Department of Ecology approval (Milestone M-20-55)

- completed the project planning and fabrication activities for the 324 Building cesium powder and pellet inventory and the Nordian capsules (encapsulated radioactive cesium chloride salt, used in the past for its radioactive characteristics) and completed shipment to the Waste Encapsulation and Storage Facility (Milestone M-92-04)
- packaged and shipped 236 legacy transuranic and low-level waste "buckets" from the 327 Building hot cells to safe storage in the 200-West Area
- developed and issued the management plan for 324/327 Building stabilization and deactivation (HNF-IP-1289, Rev. 1), which provides the facility's deactivation schedule
- received approval for Phase II of decontamination and inspection planning for the 300 Area Waste Acid Treatment System from the Washington State Department of Ecology
- prepared an initial draft of the Phase III decontamination and inspection plan for the 300 Area Waste Acid Treatment System which would complete closure activities for review by the Washington State Department of Ecology.

2.3.5.4 Waste Encapsulation and Storage Facility

The Waste Encapsulation and Storage Facility project's mission is to provide safe interim storage of encapsulated radioactive material (cesium and strontium). The facility was initially constructed as a portion of the B Plant complex and went into service in 1974. A primary task over the last 3 yr has been to "decouple" the Waste Encapsulation and Storage Facility from B Plant systems, such that the facility could continue its mission of providing safe storage of the encapsulated radioactive material following deactivation of B Plant. The major accomplishments during 1998 included the following:

- All activities related to decoupling the Waste Encapsulation and Storage Facility from B Plant were completed, such that B Plant could be placed in a surveillance and maintenance program and the Waste Encapsulation and Storage Facility could continue to provide safe storage for the inventory of encapsulated radioactive material.
- A low-level radioactive waste tank (Tank 100) that had become contaminated with dangerous waste was removed, and the surrounding concrete vault was decontaminated and approved as "clean-closed" by the Washington State Department of Ecology. A new tank was then installed. This project significantly reduced the amount of waste from this facility that required transfer to the double-shell tank system and allowed this waste to be treated onsite.
- Fourteen legacy cesium-137 capsules were transferred from the 324 Building and placed in safe storage at the facility.
- An emergency response system was installed to capture radioactive material in the event of a capsule failure.
- Dangerous waste management practices were modified to reduce the generation of waste and minimize the amount of waste requiring storage.
- The facility's emission monitoring system was evaluated and demonstrated to be in compliance with all current standards.

2.3.5.5 Plutonium Finishing Plant

The Plutonium Finishing Plant went into service in 1949 to process plutonium nitrate solutions into metallic forms for the production of nuclear weapons. Operation of this plant continued into the late 1980s. In 1996, DOE issued a shutdown order for the plant, authorizing deactivation and transition of the plutonium processing portions of the facility in preparation for decommissioning. The mission is to stabilize, repackage, immobilize, and/or properly dispose of plutonium-bearing materials in the plant; to deactivate the processing facilities; and to provide for the safe and secure storage of nuclear materials until final disposition.

Significant accomplishments achieved at the Plutonium Finishing Plant during 1998 include the following:

- Operational readiness reviews for restart of material stabilization activities were completed. The successful completion of these detailed reviews established that the plant was ready to safely resume stabilization of plutonium-bearing materials.
- A RCRA Part A, Form 3 permit application for proposed treatment of mixed waste at the Plutonium Finishing Plant in support of transition activities was approved by the DOE Richland Operations Office and submitted to the Washington State Department of Ecology.
- The plant's emergency preparedness and response program was significantly upgraded.
- The plant's strategic vision, which defines the detailed path forward for the facility stabilization and deactivation activities, was completed ahead of schedule (HNF-3617).

Two underground diesel fuel storage tanks were successfully removed and replaced with a single underground storage tank.

2.3.5.6 Plutonium-Uranium Extraction Plant

Plant deactivation was completed in May 1997, 14 mo ahead of schedule and >$75 million under budget. The facility remained in a surveillance and maintenance phase through 1998. Prior to deactivation, the Plutonium-Uranium Extraction Plant required approximately $35 million annually to maintain in a standby condition. The plant now requires <$1 million/yr to maintain in a surveillance and maintenance phase that will continue until disposition is determined. Final arrangements are being concluded to turn the facility over to Bechtel Hanford, Inc. for continuation of the facility surveillance and maintenance program.

2.3.6 Fast Flux Test Facility

2.3.6.1 History

The Fast Flux Test Facility, a 400-MW thermal reactor cooled by liquid sodium, located in the 400 Area, was built in 1978 to test plant equipment and fuel for the Liquid Metal Reactor Development Program. Although the facility is not a breeder reactor, this program demonstrated the technology of commercial breeder reactors. Breeder reactors are so termed because they can produce both power and nuclear fuel to supply other reactors. During the Fast Flux Test Facility's years of operation, it successfully tested advanced nuclear fuels, materials, and safety designs, and also produced a variety of different isotopes for medical research.

The reactor was shut down in December 1995 after a panel commissioned by the Secretary of Energy concluded that there was no combination of missions that had financial viability over the next 10 yr. In January 1997, the Secretary of Energy directed that the facility be maintained in "standby" condition until DOE could evaluate and decide whether it should be part of the nation's tritium production strategy. Studies and analyses completed in November 1997 addressed safety issues, environmental impacts, and the economic viability of producing tritium and medical isotopes at the facility. On December 22, 1998, the Secretary of Energy announced that the Fast Flux Test Facility would not be used for the production of tritium, but would be evaluated for other civilian missions such as the production of medical isotopes and plutonium-238 for use in future space mission power systems. The Secretary stated that the evaluation would be completed and a decision made in the spring of 1999.

Meanwhile, deactivation activities that do not preclude a restart are continuing. Fuel was removed from the reactor vessel, and fuel assemblies (sealed metal tubes that hold fuel pellets) are contained in

two fuel storage vessels and in aboveground, dry storage casks. Of the facility's 100 plant systems, 23 are deactivated. The facility continues to be maintained in a standby mode in accordance with state and federal requirements.

2.3.6.2 Possible Future Missions

Medical Isotope Production. Medical isotopes are produced in accelerators or reactors or by extracting them from byproduct materials created by the weapons program. Dozens of different isotopes can be created, each with unique characteristics and potential uses. These isotopes are used for diagnosis or therapy. Diagnostic isotopes are used for imaging internal organs, similar to the result of an x-ray. Therapeutic isotopes are injected directly into a tumor or attached to an antibody that seeks out and locates the tumor. In this manner, cancer cells are destroyed, with little or no damage to the surrounding healthy cells.

New therapeutic applications for radioisotopes are showing great promise in clinical trials, but only small quantities of radioisotopes are available for research. If clinical trials are successful and there is subsequent U.S. Food and Drug Administration approval, the number and size of operating reactors in the United States would not be able to meet the expected medical need. The Fast Flux Test Facility is capable of producing a wide variety of isotopes. Over the reactor's life, approximately 40 different medical and industrial isotopes were produced for researchers and medical practitioners.

Plutonium-238 Production. For more than 30 years, DOE developed radioisotope power systems, radioisotope heater units, and radioisotope thermoelectric generators and supplied them to the National Aeronautics and Space Administration for various space missions. The radioisotope used in these systems is plutonium-238. DOE has projected that, over the next 20 to 25 yr, the National Aeronautics and Space Administration will continue to conduct missions that will require power sources fueled with plutonium-238. Historically, the reactors and chemical processing facilities at DOE's Savannah River Site were used to produce plutonium-238. As a result of downsizing the DOE nuclear weapons complex, the reactors at Savannah River were shut down in 1988. Since then, the United States has purchased plutonium-238 from Russia.

DOE proposes to reestablish a reliable domestic capability for producing plutonium-238 for future space travel requirements. A production rate of 2 to 5 kg/yr (0.9 to 2.3 lb/yr) would be sufficient to meet the projected long-term requirements. The Fast Flux Test Facility was previously evaluated for the production of plutonium-238, and it was determined that the facility could safely produce 30 kg/yr (13.6 lb/yr). DOE is preparing an environmental impact statement on the proposed production of plutonium-238. If DOE decides in 1999 to consider the facility for a multimission role, including plutonium-238 production, input would be factored into this environmental impact statement to evaluate the facility as a reactor alternative for the irradiation of neptunium targets. The Fuels and Materials Examination Facility, located adjacent to the Fast Flux Test Facility, would also be included for storage of neptunium-237, fabrication of targets, and processing of the irradiated targets to extract the plutonium-238 product and recycle the neptunium.

The Decision Process. DOE is conducting an independent review to determine if there are sufficient facilities to meet the future programmatic needs of the Department. The results of this effort will help DOE decide whether to initiate the Fast Flux Test Facility restart environmental impact statement, continue to maintain the facility in a standby mode, or to resume shut-down activities. DOE is expected to make this decision in 1999. A decision to proceed with further consideration of restart of the Fast Flux Test Facility would trigger a full National Environmental Policy Act review.

2.3.7 Advanced Reactors Transition Project

The mission of this project is to maintain the Fast Flux Test Facility and its associated support facilities in a safe and stable condition. This project includes the Fast Flux Test Facility reactor complex, the Fuels and Materials Examination Facility, nuclear energy legacy facilities, and the 309 Plutonium Recycle Test Reactor facility.

Fast Flux Test Facility standby activities conducted in 1998 included completion of reactor vessel equipment testing to verify the condition of this equipment that was last used in 1995; completion of the design, fabrication, and full-scale mockup testing of the irradiation hardware; and completion of the conceptual design of the solid waste cast hoist and grapple upgrade. The replacement of the Freon 12 refrigerant in eight chiller units with non-ozone depleting R-134a refrigerant was also completed.

Activities completed in the 309 facility, located in the 300 Area, included the acceptance of the rupture loop annex (Room 20) and the fuel examination cell for stabilization by Bechtel Hanford, Inc. Characterization was completed on the Plutonium Recycle Test Reactor core structure and cavity, fuel storage basin, and fuel transfer pit.

A RCRA clean-closure certification for the 3718-F Alkali Metal Treatment and Storage Facility in the 300 Area was accepted by the Washington State Department of Ecology in 1998.

In the Nuclear Energy Legacy Facility Deactivation Program, a retired sodium test system in the 200-West Area was dismantled and sent to an offsite treatment center (for sodium-wetted components) for waste disposal. The storage tanks, containing sodium from the system, were transported to the 300 Area and drained into U.S. Department of Transportation-rated 208-L (55-gal) drums, which are awaiting offsite shipment. The total weight of the sodium transferred was approximately 550 kg (250 lb). Approximately 430 kg (195 lb) of sodium-potassium were drained from the 337 Building's cold trap cooling loop into U.S. Department of Transportation-rated receiving vessels. The vessels were shipped offsite to a disposal center. Residual sodium was removed from both a small (308-L [81-gal]) and a large (19,000-L [5,000-gal]) tank such that the tanks are now ready for redeployment.

2.3.8 Tank Waste Remediation System Activities

2.3.8.1 Waste Tank Status

The status of the 177 waste tanks as of December 1998 was reported in HNF-EP-0182-129. This report is published monthly; the December report provided the following information:

- number of waste tanks
  - 149 single-shell tanks
  - 28 double-shell tanks
- number of "assumed leaker" tanks[a]
  - 67 single-shell tanks
  - 0 double-shell tanks
- chronology of single-shell tank leaks
  - 1956: first tank reported as suspected of leaking (Tank 241-U-104)
  - 1973: largest estimated leak reported (Tank 241-T-106; 435,000 L [115,000 gal])

(a) "Assumed leaker" refers to tanks that have leaked or are assumed to have leaked. No tanks are known to be leaking at this time.

- 1988: Tanks 241-AX-102, -C-201, -C-202, -C-204, and -SX-104 reported as confirmed leakers
- 1992: latest tank (241-T-101) added to assumed leaker list, bringing total to 67 single-shell tanks
- 1994: Tank 241-T-111 declared an assumed re-leaker

- number of ferrocyanide tanks on the watch list
  - 0 (all 18 single-shell tanks were removed from the watch list in 1996)
- number of flammable gas tanks on the watch list
  - 19 single-shell tanks
  - 6 double-shell tanks
- number of organic tanks on the watch list
  - 2 single-shell tanks (18 tanks were removed from the watch list in December 1998).
- number of high-heat tanks
  - 1 single-shell tank.

So far, 119 single-shell tanks have been stabilized, with the tank stabilization program to be completed in 2000. At the end of 1998, 108 single-shell tanks had intrusion prevention devices completed, and 51 single-shell tanks were disconnected and capped to avoid inadvertent liquid additions to the tanks.

The total estimated volume to date of radioactive waste leakage from single-shell tanks is 2,300,000 to 3,400,000 L (600,000 to 900,000 gal).

During 1998, waste was pumped from four single-shell tanks to two double-shell tanks. Portions of Tanks 241-SX-104, SX-106, T-104, and T-110 (all in the 200-West Area) were pumped.

2.3.8.2 Waste Tank Safety Issues

The Safety Issue Resolution Projects (formerly known as the Waste Tank Safety Program) was established in 1990 to address the hazards associated with storage of radioactive mixed waste in the 177 underground storage tanks at the Hanford Site. The projects serve as the focal point for identification and resolution of selected high-priority waste tank safety issues. The tasks to resolve safety issues are planned and implemented in the following logic sequence: 1) evaluate and define the associated safety issue, 2) identify and close any associated unreviewed safety questions (DOE/EH-0173T), 3) mitigate any hazardous conditions to ensure safe storage of the waste, 4) monitor waste storage conditions, and 5) resolve the respective safety issues. Each of these steps has supporting functions of some combination of monitoring, mathematical analyses, laboratory studies, and in-tank sampling or testing. The path followed depends on whether the waste requires treatment or can be stored safely by implementing strict controls.

The Safety Issue Resolution Projects is focusing on resolution of flammable gas, organic, high-heat, and criticality safety issues as described below. The tanks of concern are placed on a watch list and categorized by safety issue. In 1996, all 24 ferrocyanide tanks had been removed from the watch list, and the issue was deemed resolved by DOE and the Defense Nuclear Facilities Safety Board. During 1998, 18 organic complexant tanks were removed from the watch list, leaving the 2 organic solvent tanks on the list. At the end of 1998, there were 28 tanks remaining on the watch list: 25 flammable gas tanks, 1 high-heat tank, and 2 organic tanks (some of the tanks are included under more than one category). These tanks were identified in accordance with the Defense Authorization Act, Section 3137, "Safety Measures for Waste Tanks at Hanford Nuclear Reservation" (1990).

2.3.8.3 Watch List Tanks

In early 1991, all Hanford Site high-level waste tanks were evaluated and organized into categories to ensure increased attention and monitoring. Other safety concerns, including the possibility of nuclear criticality in a waste tank, have been addressed.

Ferrocyanide. The ferrocyanide safety issue, which was an earlier concern, involved the potential for uncontrolled exothermic reactions of ferrocyanide and nitrate/nitrite mixtures (WHC-EP-0691). There were originally 24 ferrocyanide tanks on the watch list: 4 were removed in 1993, 2 in 1994, and 18 in 1996. The ferrocyanide levels have decreased by at least 90%, and in some cases by 99%, over what was originally in the tanks. Experimental studies and core samples from 10 of the ferrocyanide tanks show that hydrolysis and radiolysis of the ferrocyanide occurred and sufficient fuel to be of concern is no longer present (WHC-SD-WM-SARR-038, Rev. 1). DOE approved resolution of the ferrocyanide safety issue in December 1996.

Flammable Gas. The flammable gas safety issue involves the generation, retention, and potential release of flammable gases by the waste. Twenty-five tanks have been identified and placed on the watch list. In prior years, work controls were instituted to prevent introduction of spark sources into these tanks, and evaluations were completed to ensure that installed equipment was intrinsically safe.

The worst-case tank (241-SY-101) was successfully mitigated in 1994, with the installation of a mixing pump. The pump is operated up to three times a week to mix the waste and release gases that are generated and retained in the waste. This mitigation technique has been completely successful, and no episodic releases of gas have occurred since the pump was installed. Two spare mixer pumps are available in the event the original pump should fail.

In November 1995, more-stringent flammable gas controls were placed on all 177 high-level waste storage tanks after several events occurred where hydrogen gas was found during several waste intrusive activities. In early 1997, a complete set of operating controls with respect to flammable gases was submitted to DOE Richland Operations Office for the flammable gas unreviewed safety question. The controls specified were incorporated into the basis for interim operations (HNF-SD-WM-BIO-001, Rev. 1).

The unreviewed safety question for Tank 241-SY-101 was closed in June 1996, but in November 1996, the flammable gas unreviewed safety question was expanded to cover 176 underground storage tanks (excluding SY-101) and all auxiliary tanks in the tank farm. The DOE Richland Operations Office closed the unreviewed safety question for all single- and double-shell tanks in September 1998.

Conditions within Tank 241-SY-101 changed in 1997 and this led to a continuous rise in the waste level. In February 1998, the DOE Richland Operations Office declared an unreviewed safety question related to the waste surface level changes. The responsible contractor formed a project team to remediate the level rise and a project plan was recently issued (HNF-3824).

Hydrogen monitors have been installed on all 25 flammable gas watch list tanks; in addition, another 17 monitors were installed to gather more data on a variety of tanks and operations. These systems continuously monitor for hydrogen and have the capability to obtain grab samples for additional analyses.

Other instruments have been developed for characterizing the waste in the watch list tanks. These instruments include meters to measure the viscosity of the waste in the tanks, in-tank void fraction meters that determine the amount of gas in a given volume of waste, retained gas samplers that capture a waste sample in a gas-tight chamber and allows the gas composition and volume to be measured after the apparatus is brought into a hot cell, and gas characterization systems that allow a broad spectrum of dome-space gases (including hydrogen, ammonia, and nitrous oxide) to be monitored continuously in selected tanks. All of these devices became operational in 1996.

The Tri-Party Agreement milestone for resolution of the flammable gas safety issue is scheduled for September 2001.

High-Heat Tank. This safety issue concerns Tank 241-C-106, a single-shell tank in the 200-East Area, that requires water additions and forced ventilation for evaporative cooling. Without the water additions, which would have to be severely restricted in the event of a leak, the tank could exceed structural temperature limits and result in potential concrete degradation and possible tank collapse. This tank waste is scheduled for retrieval, starting in 1999, and transfer to a double-shell tank. Double-shell tanks were designed to better handle heat-bearing materials than single-shell tanks. As part of the waste removal project, a refrigerated chiller system was installed to remove radioactive decay heat and the heat generated by the waste transfer pumps. The chiller system was activated in late 1998.

Organic Tanks. This safety issue involves the potential for uncontrolled exothermic reactions of organic complexants and organic solvents present in some of the tanks. Criteria to screen tanks for possible organic compounds were established based on analyses and simulant testing. Tank waste was screened against these criteria (WHC-SD-WM-SARR-033, Rev. 1). DOE identified 20 single-shell tanks for the organic watch list between 1991 and 1994. The selection of the tanks was based on the evaluation of hazards such as spontaneous and continuous burning of material or the spontaneous combustion of the waste from selfheating. Of these tanks, 18 were identified as containing organic complexants and 2 were identified as containing organic solvents. Organic solvents do not mix with water and, therefore, float on the top of the liquid wastes, while the organic complexants are water soluble and are mixed with liquids in the tanks.

During 1990, work controls were implemented in these tanks to prevent the uncontrolled release of high-level waste. It was determined that concentrations and temperatures required to support propagating exothermic reactions are comparable to those necessary for ferrocyanide reactions (WHC-SD-WM-ER-496). During 1995, as part of the vapor-sampling program, it was shown that organic vapors in the organic tanks are too low in concentration to exceed even 25% of their lower flammability limits. In addition, moisture levels of 20 weight percent will prevent reactions from propagating regardless of the fuel concentration. Other work indicates that the aging processes have destroyed or significantly lowered the energy content of the organic tanks. (WHC-EP-0823, WHC-SD-WM-SARR-033, Rev. 1). In addition, WHC-EP-0899-1 shows that most organic complexants used during nuclear fuel reprocessing at the Hanford Site and the primary degradation products of tributyl phosphate are water soluble in nitrate/nitrite salt solutions.

During 1995 through 1997, waste samples from the organic tanks were taken to determine the quantities of organic constituents present in each tank. Most of the organics identified have been of low energy. None of the samples showed any tendency to react when tested in a special tube propagation calorimeter (FAI/96-45, FAI/96-48). In May 1994, vapor sampling and safety analyses were completed that provided the technical basis for closing the unreviewed safety question on the flammability of the floating organic layer in Tank 241-C-103 (WHC-SD-WM-SARR-001). During 1998, DOE closed the organic complexant safety issue and removed the 18 organic complexant tanks from the watch list. The evaluation concluded that hazards do not exist because the organic concentrations in the wastes are too low to support a propagating reaction and no credible means are available to increase tank temperature to runaway reaction levels.

The two remaining organic watch list tanks contain organic solvents. DOE is expected to analyze the technical data on these tanks and resolve the safety issue in 1999. The Tri-Party Agreement milestone for resolution of the organic tank safety issue is scheduled for September 2001.

Criticality. The unreviewed safety question on the potential for criticality in the high-level waste

tanks was closed in 1994 by completing additional analyses, strengthening tank criticality prevention controls, and improving administrative procedures and training (WHC-SD-WM-SARR-003). In 1996, an extensive effort was put forth to provide the technical basis for resolving the technical issues related to the criticality safety issue. Technical studies were completed that showed a criticality event within a high-level waste tank is not likely during storage (WHC-SD-WM-TI-725). All of the single- and double-shell tanks at the Hanford Site contain sufficient neutron absorbers to ensure safe storage; however, additional sampling and controls will be required for retrieval- and pretreatment-related activities. Successful completion of this review will enable DOE to close the criticality safety issue and satisfy the related Tri-Party Agreement milestone. The Tri-Party Agreement milestone for resolution of the criticality safety issue is scheduled for September 1999.

2.3.8.4 Vadose Zone Characterization Near Single-Shell Underground Waste Storage Tanks

Since 1995, the DOE Grand Junction Office has been performing a baseline spectral gamma borehole logging characterization of the vadose zone around the single-shell underground waste storage tanks at Hanford. This characterization work is being done in part to comply with RCRA requirements to identify contamination sources and to determine the nature and extent of the contamination from the single-shell tanks. The work will also assist with RCRA closure of the tanks.

The characterization program involves establishing a baseline of the contamination distribution of gamma-emitting radionuclides in the vadose zone by logging the existing boreholes surrounding the tanks with spectral gamma-ray logging systems. Once the activities of the subsurface radionuclides are determined around a single tank, an interpretation of the contaminant distribution correlation is made and presented in a tank summary data report for the particular tank. When all of the tank summary data reports for tanks in a particular tank farm have been completed, the results of characterization around the single-shell tanks are assembled into a comprehensive tank farm report. In the tank farm report, inter-borehole correlations of contamination intervals are presented as three-dimensional representations of contamination plumes in the vadose zone. The log data along with the visual representations can provide a basic understanding of the contamination distribution and can be of importance as a guide for directing future characterization work. In addition, the data acquired in this initial characterization serve as a baseline against which future comparisons can be made for evaluating the stability of intervals of contamination.

This project, as planned, has inherent limitations. These limitations were understood in the original planning; however, as designed, the project serves as the initial investigation needed prior to beginning a thorough vadose zone characterization. First, the gamma-emitting radionuclides are assayed because they are easy to detect and quantify, whereas many of the radionuclides and hazardous constituents that pose potential health and safety risks are not detected. The project is also limited to providing log assays of the contamination in existing boreholes. No new boreholes are being drilled for logging alone, though the equipment has been used to log three new characterization boreholes put in the SX single-shell tank farm in the 200-West Area. This includes the extension of borehole 41-09-39 to groundwater, results of which are reported in Section 6.2, "Vadose Zone Characterization and Monitoring." Another limitation relates to questions about the representativeness of the three-dimensional contamination plume visualizations. The accurate determination of the distributions and quantification of contaminants is just beginning. Statistically rigorous cross-borehole correlations are not yet developed, thereby making the representativeness of portions of some visualizations questionable.

The baseline characterization program has been successful in its original objective by identifying the nature of the vadose zone contamination problem and locating areas needing further and more-comprehensive characterization. The utility of the baseline characterization has been shown by the discovery of cesium-137 deeper in the vadose zone than previously predicted, thereby questioning the understanding of the mobility of cesium-137 in soils at the Hanford Site.

The logging operations for the baseline characterization began in 1995 and should be completed in early 1999. During 1998, 79 additional boreholes surrounding tanks in the T and B tank farms, in the 200-West and 200-East Areas, respectively, were logged. Also, 15 boreholes in the SX tank farm (200-West Area) were relogged to evaluate the stability of intervals of contamination that were identified in the initial 1995 logging. The details of this work are discussed in Section 6.2, "Vadose Zone Characterization and Monitoring."

Preparation of tank summary data reports began in 1995. During 1998, 25 additional tank summary data reports for tanks in the A, B, BX (all 200-East Area), and T tank farms (200-West Area) were prepared using data acquired from boreholes logged between 1996 and 1998 (e.g., GJ-HAN-106).

During 1998, tank farm reports were prepared for the BX and C tank farms in the 200-East Area and for the S tank farm in the 200-West Area. The preparation of the A tank farm report was well under way at the end of 1998, with scheduled publication in the first quarter of 1999.

During 1998, additional experiments were performed to enhance spectral shape factor analysis, which was developed in 1996 as an analytical method to distinguish distributions of radionuclides detected in the tank monitoring boreholes. This method basically allows a qualitative assessment of the gamma-ray spectra to help differentiate between regions where contamination may be distributed adjacent to the casing versus regions where the contamination may be distributed uniformly in the formation materials surrounding the borehole as a source remote from the borehole. Spectral shape factor analysis has been used routinely in the processing of log data since the latter part of 1997.

The SX tank farm expert panel reviewed the improvements made to shape factor analysis through June 1998 and recommended several considerations for refinement. In response to these recommendations, additional experiments were conducted in 1998 that were directed at evaluating source/detector distributions involving point sources of contamination on the exterior of the borehole casing and at a distance from the borehole.

Additionally, spectral shape factor analysis was evaluated in response to uniformly distributed contamination in thick and thin horizontal tabular zones. Details of the results are documented in GJO-99-80-TAR, GJO-HAN-24.

When used in conjunction with other analysis and information, and with experience gleaned from reviewing many logs, spectral shape factor analysis can help in the identification of contaminant distribution. Incorporation of spectral shape factor results and other interpretations has made significant improvements to the quality and accuracy of three-dimensional representations of the contaminant plumes.

The AX, BY, SX, TX, and U tank farm reports (GJ-HAN-12; GJ-HAN-6; DOE/ID/12584-268, GJPO-HAN-4; GJ-HAN-11; GJ-HAN-8; respectively) were completed before spectral shape factor analysis was implemented in 1997. Reevaluation of the SX tank farm log data was initiated in 1998 and is scheduled for completion in 1999. The data will be evaluated on the basis of knowledge gained since the SX tank farm report was completed in 1996, and the visualization will be recreated to reflect

interpretations. The remaining four tank farms will be reevaluated in 1999, and addenda will be prepared for each of these five tank farm reports.

The baseline characterization work completed in 1998 identified several areas where additional work is required to broaden knowledge of contamination conditions in the tank farm vadose zone. See Section 6.2, "Vadose Zone Characterization and Monitoring," for additional details regarding specific tank farms. Section 6.2 gives a more-comprehensive description of the single-shell tank vadose zone characterization program and for references to detailed reports.

2.3.8.5 Waste Immobilization

Approximately 204 million L (54 million gal) of radioactive and hazardous wastes, accumulated from >40 yr of plutonium production operations, are stored in 149 underground single-shell tanks and 28 underground double-shell tanks. It is planned to pretreat the waste and then solidify it into a glass matrix. Pretreatment will separate the wastes into a low-radioactivity fraction and a high-radioactivity and transuranic fraction. In separate facilities, both fractions will be vitrified in a process that will destroy or extract organic constituents, neutralize or deactivate dangerous wastes and immobilize toxic metals. The immobilized low-radioactivity fraction will be disposed of in a near-surface facility on the Hanford Site in a retrievable form. The immobilized high-radioactivity fraction will be stored onsite until a geologic repository is available offsite for permanent disposal. Tri-Party Agreement milestones specify December 2028 for completion of pretreatment and immobilization of the tank wastes.

During 1996, a change request to Tri-Party Agreement milestones was approved, allowing DOE to proceed with the planned privatization of the initial pretreatment and immobilization function of the Tank Waste Remediation Program. The approach to privatization will be conducted in two phases.

Phase I is proof of concept/commercial demonstration. This phase involves pretreatment and vitrification of the low-level and high-level wastes. The objectives of this phase are to 1) demonstrate technologies and processes in a production-level environment; 2) treat and immobilize sufficient waste to demonstrate early progress in remediating the tank situation to the stakeholders; 3) better understand the costs, risks, and benefits of the fixed-price privatization framework; 4) ascertain the financial viability of the private marketplace to accomplish the mission; 5) establish conditions for DOE to be a "smart buyer" and for private companies to be "smart providers" of treated waste products for Phase II; and 6) balance the private companies' objectives with DOE's objectives.

A contract with British Nuclear Fuels Limited, Inc. reflects an evolution of the original tank waste remediation system privatization approach. Part A lasted 20 mo and ended in mid-1998. The purpose of Part A was to evaluate the technical, operational, regulatory, business, and financial elements required by privatized facilities that would provide treatment and immobilization services on a fixed-unit-price basis. Part B has been restructured and one contractor, British Nuclear Fuels Limited, Inc., has been authorized to proceed to the design phase of Phase I. The revised approach allows DOE to move forward on design without delay, but defers a final decision until the project is further refined with respect to its design and technical approach, regulatory requirements, and financial and incentive structure. Part B begins with: a design phase, leading to all major process and facility systems (approximately 30% design) being completed in 24 mo. If British Nuclear Fuels Limited, Inc. is authorized to proceed beyond the design phase, it will move forward to the completion of the design, construction, startup, testing, and operation of the facility to provide waste treatment services at the fixed-unit prices established at the end of the design phase. Under the contract negotiated with British Nuclear Fuels Limited, Inc., DOE forecasts that waste treatment will begin in 2005 to 2006

and will continue for at least 10 yr. During that period, DOE expects the contractor to immobilize approximately 10% of Hanford's waste by mass. That waste processing will include both high-level and low-activity waste treatment and immobilization. The waste processed will be retrieved from 11 tanks and will free up valuable double-shell tank space to enable transfer of waste from the high-risk single-shell tanks. The waste to be processed constitutes between 20% and 25% of the total radioactivity in the Hanford tanks and includes waste from some of the highest safety-risk tanks at the site. The facility design provides for the ability to expand the capacity of the plant at a later date. This could allow a significant amount of the waste planned for the tank waste remediation system Phase II to be processed in the expanded facility.

Phase II will be the full-scale production phase. Facilities will be sized so all of the remaining waste can be processed and immobilized on a schedule that will accommodate removing the waste in single-shell tanks by 2018, or a subsequent date if the Tri-Party Agreement is renegotiated. Objectives of the full-scale production phase are to 1) implement the lessons learned from Phase I; 2) process all tank waste into forms suitable for final disposal while meeting environmental, health, and safety requirements; 3) meet or exceed the Tri-Party Agreement benchmark performance milestones; and 4) as in Phase I, balance the private vendor's objectives with DOE's objectives. At the end of any contract, the contractor will deactivate all contractor-provided facilities.

2.3.9 Solid Waste Management Activities

2.3.9.1 Central Waste Complex

Solid waste is received at the Central Waste Complex in the 200-West Area (see Figure 1.0.2) from all radioactive waste generators at the Hanford Site and any offsite generators authorized by DOE to ship waste to the Hanford Site for treatment, storage, and disposal. The waste received at the Central Waste Complex is generated by ongoing site and research and development activities. Offsite waste has been primarily from DOE research facilities and other DOE sites. The characteristics of the waste received vary greatly, from nondangerous, solid waste to solid, transuranic, mixed waste.

The planned capacity of the Central Waste Complex to store low-level mixed waste and transuranic waste is 15,540 m^3 (20,330 yd^3). This capacity is adequate to store the projected volumes of low-level, transuranic, and mixed waste to be generated, assuming on-schedule treatment of the stored waste. Plans call for treatment of the mixed waste to begin in 1999, which will reduce the amount of waste in storage and make room available for newly generated mixed waste. The majority of waste shipped to the Central Waste Complex is generated in small quantities by routine plant operation and maintenance activities. The dangerous waste designation of each container of waste is determined at its point of generation based on process knowledge of the waste placed in the container or on sample analysis if sufficient process knowledge is unavailable.

2.3.9.2 Waste Receiving and Processing Facility

During 1994, construction was started on the first major solid waste processing facility associated with cleanup of the Hanford Site. Having started operation in March 1997, the Waste Receiving and Processing Facility is staffed to analyze, characterize, and prepare drums for disposal of waste resulting from plutonium operations at Hanford. The 4,800-m^2 (52,000-ft^2) facility is near the Central Waste Complex in the 200-West Area (see Figure 1.0.2). The

facility is designed to process approximately 6,800 drums and 70 boxes of waste annually for 30 yr.

Wastes destined for the Waste Receiving and Processing Facility include Hanford's inventory of >37,000 drums of stored suspect-transuranic waste as well as materials generated by future site cleanup activities. Consisting primarily of clothing, gloves, face masks, small tools, and particulates suspected of being contaminated with plutonium, waste containers may also contain other radioactive materials and hazardous components. Processed waste that qualifies as low-level waste and meets disposal requirements will be buried directly at the Hanford Site. Low-level waste not meeting burial requirements will be treated in the facility until it meets the requirements or will be prepared for future treatment at other onsite or offsite treatment, storage, and disposal facilities. Waste determined in the facility to be transuranic will be certified and packaged for shipment to the Waste Isolation Pilot Plant in Carlsbad, New Mexico for permanent storage. Materials requiring further processing to meet disposal criteria will be retained at Hanford, pending treatment.

2.3.9.3 Radioactive Mixed Waste Disposal Facilities

The radioactive mixed waste disposal facilities at the Hanford Site are the first in DOE's complex for disposal of radioactive mixed wastes. These facilities are located in the low-level burial grounds in the 200-West Area and are designated Trenches 218-W-5, -31, and -34. Trench 34 is operating in a storage mode containing long-length contaminated equipment, macroencapsulated tubes, and a DOE laboratory reactor core basket. This storage mode will continue until sufficient volumes of mixed waste meeting RCRA land disposal requirements are available to economically operate the facility in a disposal mode. The trenches are rectangular landfills, with approximate base dimensions of 76 by 30 m (250 by 100 ft). The bottoms of the excavations slope slightly, giving a variable depth of 9 to 12 m (30 to 40 ft).

These trenches are designed to comply with RCRA requirements for double liners and leachate collection and removal systems. The bottom and sides of the facilities are covered with a deep layer of soil (1 m [3 ft]) to protect the liner system during fill operations. There is a recessed section at one end of the excavations that houses the sumps for leachate collection. Access to the bottom is provided by ramps along the perimeters.

2.3.9.4 T Plant Complex

The function of the T Plant complex in the 200-West Area (see Figure 1.0.2) is to provide waste processing and decontamination services for the Hanford Site. Two facilities are used to provide these services: the T Plant canyon and the 2706-T complex. Other areas around these facilities are also used to support these services. The T Plant complex is a RCRA-permitted facility, which can store waste for >90 d and perform treatment in tanks and other containers. T Plant's waste handling activities in 1998 included the following:

- performing content verification of wastes being shipped to solid waste facilities for storage or disposal
- repackaging and/or sampling waste to meet solid waste acceptance criteria or to determine acceptability of waste for treatment
- treating dangerous and mixed wastes to meet RCRA requirements for land disposal
- decontaminating equipment to allow for reuse or disposal as waste
- storing 27 metric tons (30 tons) of spent reactor fuel (from Shippingport, Pennsylvania) in a water basin.

Upgrades to the 2706-T complex liquid waste storage tank system were started in January 1997 and completed in December 1998. These upgrades have made the 2706-T tank system fully compliant with RCRA regulations and will allow for improved liquid waste handling capabilities. Since December 1998, the 2706-T complex has been undergoing readiness

activities. After about June 1999, all decontamination, packaging, and verification work will be performed exclusively in the 2706-T complex.

2.3.9.5 Radioactive Mixed Waste Treatment and Disposal

After a banner year in 1997, budget constraints severely reduced the amount of mixed waste treated and/or disposed of in 1998; 13 m^3 (17 yd^3) of mixed waste were treated and/or disposed of. The waste materials were obtained from a number of projects and included the following:

- 11,000 L (3,000 gal) of organic liquid (tributyl phosphate) from the B Plant facility were incinerated at Diversified Scientific Services, Inc. in Tennessee.
- 1 m^3 (1.3 yd^3) of elemental lead was decontaminated and released for reuse during 1998. The lead was sorted and removed from approximately 290 containers. This was a waste minimization "return-on-investment" project.
- A total volume of 1 m^3 (1.3 yd^3) of ash from the Waste Experimental Reduction Facility in Idaho was stabilized at the T Plant facility in the 200-West Area. This waste came to Hanford under a federal facility consent agreement between Bettis Atomic Power Laboratory and the Hanford Site. After the waste was successfully treated, it was shipped back to Bettis.
- 96 drums of combustible hazardous debris were shipped to the Waste Experimental Reduction Facility in Idaho and are awaiting treatment. Treatment is planned in 1999, with return of the treatment residues to Hanford by September 1999. This activity is considered an inter-site demonstration between the Idaho National Engineering and Environmental Laboratory and Hanford. If deemed successful, additional treatment campaigns will be arranged.

2.3.9.6 Radioactive Mixed Waste Treatment Contracts

In November 1995, a contract was awarded to Allied Technology Group, Inc., Richland, Washington for thermal treatment of Hanford's mixed waste in accordance with RCRA and the Toxic Substances Control Act of 1976. The contract provides for treating up to 5,135 m^3 (6,715 yd^3) of mixed waste over 5 yr with five 1-yr renewal options. Waste processing is scheduled to begin in fiscal year 2001.

During 1997, a competitive procurement was conducted for the processing of mixed waste requiring nonthermal treatment in accordance with RCRA. The resulting contract provides for treatment of up to 1,860 m^3 (2,432 yd^3) of waste. The contract, which was also awarded to Allied Technology Group, Inc., has a 1-yr base period (fiscal year 1999) with two 1-yr renewal options (fiscal years 2000 and 2001).

During September 1998, a National Environmental Policy Act environmental assessment (DOE/EA-1189) was completed for this activity, with a finding of no significant impact. Completion of this assessment met Tri-Party Agreement compliance agreement M-19-01-T03.

These contracts, together with follow-on procurements, will provide cost-effective alternatives for continued mixed waste treatment.

2.3.9.7 Navy Reactor Compartments

Six defueled United States Navy reactor compartment disposal packages were received and placed in Trench 94 in the 200-East Area during 1998. This brings the total number received to 77. The compartments originate from decommissioned nuclear-powered submarines.

The reactor compartment disposal packages are being regulated by Washington State as dangerous waste because of the presence of lead used as shielding and by EPA because of the presence of small amounts of polychlorinated biphenyls tightly bound within the composition of solid materials such as

thermal insulation, cable coverings, and rubber. Also, the compartments are regulated as mixed waste because of radioactivity in addition to dangerous waste.

2.3.9.8 325 Building Hazardous Waste Treatment Units

The 325 Building hazardous waste treatment units in the 300 Area receive, store, and treat mixed and hazardous waste generated by Pacific Northwest National Laboratory programs. The units consist of the Shielded Analytical Laboratory and the Hazardous Waste Treatment Unit. These units are operating under RCRA final permit status granted in February 1998.

The Shielded Analytical Laboratory is a facility that has a dual role as an analytical laboratory and a treatment facility. The laboratory performs tank treatment and bench-scale treatment of high-dose-rate laboratory waste (2,000 rem/h capability).

The Hazardous Waste Treatment Unit is a facility that contains fume hoods and gloveboxes for bench-scale treatment of mixed and dangerous waste from various Pacific Northwest National Laboratory programs and for treating transuranic and transuranic mixed waste by neutralization and stabilization.

2.3.9.9 Underground Fuel Storage Tanks

There are 13 underground fuel storage tanks on the Hanford Site registered with the Washington State Department of Ecology (WAC 173-360). Four of the tanks contain gasoline or diesel fuel (two each) for vehicles and nine are diesel storage tanks for supplying emergency diesel generators. Two of the fuel tanks, located within the former 1100 Area, will be transferred to the Port of Benton in the near future. Of the 13 registered tanks, 3 were upgraded and 10 were replaced to meet the new compliance standards for leak detection and inventory control that went into effect on December 22, 1998.

2.3.10 Liquid Effluent Activities

2.3.10.1 242-A Evaporator

Available storage space to support remediation of tank waste and cleanup of the Hanford Site is limited in the double-shell tanks. The 242-A Evaporator in the 200-East Area (see Figure 1.0.2) processes double-shell tank waste into a concentrate (that is returned to the tanks) and a process condensate stream. Only a cold (nonradioactive) run was conducted at the 242-A Evaporator in 1998 because of delays in preparing for waste processing. The purpose of the cold run was to demonstrate operational readiness of the evaporator using the newly installed package boiler. The run produced 280,000 L (74,000 gal) of aqueous waste that were sent to the Liquid Effluent Retention Facility (discussed in Section 2.3.10.2). One 242-A Evaporator campaign is planned for 1999, two are scheduled for 2000.

Effluent treatment and disposal capabilities are available to support the continued operation of the 242-A Evaporator. The 200 Areas Effluent Treatment Facility near the 200-East Area was constructed to treat the process condensate. Process condensate is temporarily stored in the Liquid Effluent Retention Facility while awaiting treatment in the 200 Areas Effluent Treatment Facility. Cooling water and nonradioactive steam condensate from the evaporator are discharged to the 200 Areas Treated Effluent Disposal Facility.

2.3.10.2 Liquid Effluent Retention Facility

This facility consists of three RCRA-compliant surface impoundments for storing and treating process condensate from the 242-A Evaporator and other

aqueous wastes. The facility provides treatment through equalization of the flow and adjustment of pH of the feed to the 200 Areas Effluent Treatment Facility. The maximum capacity of the Liquid Effluent Retention Facility is 89 million L (23.4 million gal). The basins are constructed of two, flexible, high-density, polyethylene membrane liners. A system is provided to detect, collect, and remove leachate from between the primary and secondary liners. Beneath the secondary liner is a soil/bentonite barrier should the primary and secondary liners fail. Each basin has a mechanically tensioned floating membrane cover constructed of very low-density polyethylene to keep out unwanted material and to minimize evaporation of the basin contents. The facility began operation in April 1994. Aqueous waste is being received from both RCRA- and CERCLA-regulated cleanup activities. Approximately 28 million L (7.4 million gal) of aqueous waste were stored in the basins at the end of 1998.

2.3.10.3 200 Areas Effluent Treatment Facility

This facility provides treatment and storage for hazardous and radioactive aqueous waste. The treated effluent is stored in verification tanks, sampled and analyzed, and discharged to the 616-A Crib (also called the State-Approved Land Disposal Site) (north of the 200-West Area). The treatment process constitutes best available technology, and includes pH adjustment, filtration, ultraviolet light/peroxide destruction of organic compounds, reverse osmosis to remove dissolved solids, and ion exchange to remove the last traces of contaminants. The facility began operation in December 1995. Treatment capacity of the facility is 570 L/min (150 gal/min). Approximately 108 million L (28.4 million gal) of aqueous waste were treated in 1998.

The treated effluent is sampled to verify that the radioactive and hazardous waste constituents have been reduced to regulatory levels; then discharged via a dedicated pipeline to the State-Approved Land Disposal Site. The disposal site is located north of the 200-West Area and is an underground drain field. The percolation rates for the field have been established by site testing and evaluation of soil characteristics. Tritium in the liquid effluent cannot be practically removed, and the location of the disposal site maximizes the time for migration to the Columbia River to allow for radioactive decay. The final delisting (40 CFR 261, Appendix IX, Table 2) excludes the treated effluent from the requirements of dangerous waste regulations and RCRA; however, certain effluent quality restrictions are imposed. An application was submitted in 1998 to remove the restrictions on the type of multisource leachate (dangerous waste number F039 under RCRA) that can be treated at the 200 Areas Effluent Treatment Facility; the final delisting applies to multisource leachate that is derived from RCRA waste coded F001 through F005 solvent wastes. Application was also made to change the final delisting to increase the allowable discharge volume. The disposal site is permitted under WAC 173-216. The discharge permit requires monitoring of the groundwater and the treated effluent to ensure that levels for certain constituents are not exceeded.

Secondary waste from treating aqueous waste is concentrated, dried, and packaged in 208-L (55-gal) drums. The secondary waste from treating regulated aqueous waste is transferred to the Central Waste Complex for subsequent treatment (if needed to meet land disposal restriction treatment standards) and disposal in the radioactive mixed waste disposal facility, Trench 31 or 34, in the 200-West Area. The secondary waste from treating CERCLA-regulated aqueous waste is disposed of in the Environmental Restoration Disposal Facility near the 200-West Area.

2.3.10.4 200 Areas Treated Effluent Disposal Facility

This disposal facility is a collection and disposal system for non-RCRA-permitted waste streams that have implemented "best available technology/all

known and reasonable treatment." Implementation of regulatory "best available technology/all known and reasonable treatment" is the responsibility of the generating facilities. There are 14 waste generating facilities in the 200 Areas that send waste to the 200 Areas Treated Effluent Disposal Facility (see Figure 1.0.2).

This facility began operation in April 1995 and has a capacity of 12,900 L/min (3,400 gal/min). Approximately 742 million L (196 million gal) of effluent were discharged in 1998. The effluent is discharged to two 2-ha (5-acre) disposal ponds located east of the 200-East Area. The discharge permit requires monitoring of the effluent and the groundwater to ensure that concentrations for certain constituents are not exceeded.

2.3.10.5 300 Area Treated Effluent Disposal Facility

Industrial wastewater generated throughout the Hanford site is accepted and treated in the 300 Area Treated Effluent Disposal Facility. Laboratories, research facilities, office buildings, and former fuel fabrication facilities in the 300 Area constitute the primary sources of wastewater. The wastewater consists of once-through cooling water, steam condensate, and other industrial wastewaters. Laboratory services are particularly critical to Hanford Site cleanup activities, including tank waste remediation efforts.

This facility is designed for continuous receipt of wastewaters, with a storage capacity of up to 5 d at the design flow rate of 1,100 L/min (300 gal/min). The treatment process includes iron coprecipitation to remove heavy metals, ion exchange to remove mercury, and ultraviolet light/hydrogen peroxide oxidation to destroy organics and cyanide. Sludge from the iron coprecipitation process is dewatered and used for backfill in the low-level burial grounds. The treated liquid effluent is monitored and discharged through an outfall to the Columbia River under a National Pollutant Discharge Elimination System permit (40 CFR 122). The National Pollutant Discharge Elimination System permit is being revised to allow for the treatment of dangerous waste in accordance with WAC-173-303-802. Capability exists to divert the treated effluent to holding tanks before discharge, if needed, until a determination can be made for final disposal based on sampling. This facility began operation in December 1994. In 1998, approximately 297 million L (78 million gal) of wastewater were treated. The National Pollutant Discharge Elimination System permit is being revised (public comment ended February 11, 1999) to allow for the treatment of dangerous waste in accordance with state dangerous waste regulations.

2.3.10.6 340 Waste Handling Facility

This facility ceased receiving waste in September 1998 and is planned to be deactivated. A new waste handling facility, with storage and truck loadout capability, is being provided in the 325 Building to serve Pacific Northwest National Laboratory programs. For other wastes, waste handling systems are being developed at the 324 and 327 Buildings in the 300 Area. Mixed, low-level, liquid waste will be transported to either the 200 Areas Effluent Treatment Facility for treatment or to double-shell tanks for storage.

The 340 Waste Handling Facility provided receipt, storage, and loadout capability for low-level, mixed, liquid waste generated during laboratory operations in the 300 Area. The waste was accumulated and stored in two 57,000-L (15,000-gal) tanks located in a covered, below-grade vault in the 340 Building. Six additional 30,000-L (8,000-gal) tanks in the adjacent 340-A Building provided backup storage capability. The accumulated waste was pumped into railcars and transported to the 204-AR Unloading Facility in the 200-East Area for neutralization and transfer to double-shell tanks for

storage. The 340 Waste Handling Facility does not have a RCRA permit for storage; therefore, wastes could not be stored for >90 d.

2.3.10.7 Miscellaneous Streams

Miscellaneous streams are lower priority wastewater streams that discharge to the soil column throughout the Hanford Site and are subject to requirements in Consent Order DE 91NM-177. The *Plan and Schedule for Disposition and Regulatory Compliance for Miscellaneous Streams* (DOE/RL-93-94, Rev. 1) was approved by the Washington State Department of Ecology in February 1995. That plan and schedule ensure that miscellaneous streams will be in compliance with the applicable state regulations (e.g., WAC 173-216, 173-218). The commitments established in the plan and schedule include annually updating the miscellaneous streams inventory (through 1998), registering injection wells, submitting categorical permit applications, and implementing best management practices.

The inventory includes more than 640 miscellaneous streams. Not included in the inventory are streams that already have discharge permits in place or streams for which permit applications have been submitted. All injection wells were registered under WAC 173-218 in August 1995, including injection wells that were previously registered. This ensured that the registrations were current, complete, and in the same format.

Use of categorical permits provides a vehicle to easily permit miscellaneous streams with similar characteristics. Categorical permit applications have been submitted or permits have been issued for the following:

- hydrotesting, maintenance, and construction discharges; permit #ST-4508 was issued in May 1997
- cooling water discharges and uncontaminated steam condensate; permit #ST-4509 was issued in May 1998
- stormwater discharges; permit application was submitted in 1998.

Another categorical permit was planned for vehicle washing, coal ramp washdowns, and safety shower discharges. These streams have either been eliminated or were included in another existing permit. A best management practices report (DOE/RL-96-40) was submitted to the Washington State Department of Ecology in August 1997, identifying preferred options and an implementation plan to remediate those streams that have a potential to affect the groundwater.

2.3.10.8 Vadose Zone Characterization Summary

Vadose zone monitoring of past-practice liquid waste disposal facilities is part of the Hanford Site Groundwater Monitoring Project's responsibilities for monitoring and tracking groundwater contamination in fulfillment of the requirements of RCRA and DOE Orders. Vadose zone monitoring can serve as an early warning for potential impacts on groundwater quality. Vadose zone monitoring of liquid waste disposal facilities is conducted at those sites deemed most threatening to groundwater. Vadose zone monitoring at those sites is scheduled to be conducted periodically until the threat to groundwater is remediated through the efforts of the Environmental Restoration Program.

In 1998, the Hanford Groundwater Monitoring Project produced proposed guidance for vadose zone monitoring of liquid waste disposal facilities (PNNL-11958). Prior to this, the most recent published vadose zone monitoring plan was written in 1984 (RHO-RE-PL-23) before the Hanford Site mission changed from production to cleanup and before the availability of the high-quality, field-deployable, spectral gamma-ray tools at Hanford. The 1998 proposal incorporated both the mission and strategies of the Hanford Site and the use of spectral gamma-ray (as opposed to gross gamma-ray) monitoring technologies. The proposal provided a framework and general criteria directing site-specific vadose zone monitoring plans and a path to achieve site-specific

vadose zone monitoring. The proposal was submitted for review and comment by all interested parties and will be finalized in 1999.

The vadose zone at three inactive liquid waste disposal facilities associated with the Plutonium Finishing Plant in the 200-West Area was monitored in 1998. Those facilities were the 216-Z-1A Tile Field, the 216-Z-9 Trench, and the 216-Z-12 Crib. Monitoring consisted of spectral gamma-ray logging of 21 boreholes. The three facilities were chosen for monitoring because they were identified as containing some of the most significant sources of radioactive contamination in the Hanford Site vadose zone. Transuranic contamination is known to exist beneath the facilities, and most boreholes had not been monitored for several years. The basic question addressed by the monitoring was "Has the configuration of subsurface contamination changed since it was last measured?" The conclusion of the monitoring effort was that there has been very little change in the distribution of gamma-emitting contamination beneath the facilities. The monitoring is discussed in detail in Section 6.2.2, "Vadose Zone Monitoring at Waste Disposal Facilities."

2.3.11 Revegetation and Mitigation Planning

The DOE Richland Operations Office and Bechtel Hanford, Inc. work cooperatively with the Natural Resource Trustees on the mitigation action plans for the various remedial action projects. The plans describe the planning and implementation of appropriate mitigation measures for areas disturbed during remediation. Mitigation measures include avoidance, minimization, rectification, or compensation of impacted resources. Revegetation/mitigation plans will include the use of native plant species (seeds and shrubs) as appropriate to restore the areas disturbed by remediation activities.

The *Hanford Site Biological Resources Management Plan* (DOE/RL-96-32) was developed to provide DOE and its contractors with a consistent approach to protect biological resources and monitor, assess, and mitigate impacts to them from site development and environmental cleanup and restoration activities. This comprehensive plan provides a framework to enable Hanford Site resource professionals to effectively fulfill their responsibilities and address tribal, resource agency, and other stakeholder concerns about the site's biological resources. The policies and guidelines described in the plan were developed based on legal requirements and policy initiatives that direct an ecosystem management approach toward resources management. DOE is in the process of revising the biological resources management plan.

The *Hanford Site Biological Resources Mitigation Strategy Plan* (DOE/RL-96-88) contains strategy that is part of the broader biological resource policy contained in the biological resources management plan (DOE/RL-96-32). The strategy is designed to aid DOE in balancing its primary missions of waste cleanup, technology development, and economic diversification with its stewardship responsibilities for the biological resources it administers. This biological resources mitigation strategy will help ensure consistent and effective implementation of mitigation recommendations and requirements, ensure mitigation measures for biological resources meet the responsibilities of DOE under the law, enable Hanford Site development and cleanup projects to anticipate and plan for mitigation needs via early identification of mitigation requirements, and provide guidance to site personnel in implementing mitigation in a cost-effective and timely manner. DOE is in the process of revising the mitigation strategy plan.

Planning was initiated for habitat mitigation for Project W-519 (a project to provide utilities to various 200-East facilities). This effort will involve the planting of approximately 130,000 sagebrush plants

on the Fitzner-Eberhardt Arid Lands Ecology Reserve (see Figure 1.0.1), replanting native grass and sagebrush seed east of the 200-East Area, and research on the introduction of additional species into restoration/mitigation sites.

Bechtel Hanford, Inc. conducted three habitat mitigation and restoration projects in 1998. Seventy-seven hectares (190 acres) of sagebrush were planted in several small plots on the Fitzner-Eberhardt Arid Lands Ecology Reserve as compensatory mitigation for the construction of Cells 3 and 4 of the Environmental Restoration Disposal Facility; 1.2 ha (3 acres) were replanted with sagebrush, Sandberg's bluegrass, snow buckwheat, and yarrow on the remediated 116-C-1 Liquid Waste Disposal Trench in the 100-B,C Area. At the 105-DR Reactor Interim Safe Stabilization Project in the 100-D Area, a noncontaminated processwater tunnel was preserved to provide habitat for a Washington State-protected bat species that had been living in the reactor building (Washington State Department of Fish and Wildlife 1996). A new access to the tunnel was constructed for the bats that would prevent human intrusion but allow the bats to enter the tunnel. This mitigation project used an existing structure to preserve an important maternity roost that the bats had been using for many years.

Previous mitigation plantings continued to be monitored during 1998, including the sagebrush planting performed as mitigation for the replacement cross-site transfer system, and the planting performed as mitigation for the Solid Waste Complex (Project W-112). Monitoring of these plantings indicate relatively high survival of the planted sagebrush (70% to 85% overall).

2.3.12 Environmental Restoration Project

2.3.12.1 Environmental Restoration Disposal Facility

This facility opened in July 1996. The 918,000-m^3 (1,200,000-yd^3) earthen facility is located near the 200-West Area (see Figure 1.0.2). Constructed with double liners and a leachate collection system, the facility was designed to serve as the central disposal site for contaminated waste removed during cleanup operations conducted under CERCLA on the Hanford Site. Cleanup materials may include soil, rubble, or other materials (excluding liquids) contaminated with hazardous, low-level radioactive or mixed (combined hazardous chemical radioactive) wastes.

In 1998, the facility received 620,908 metric tons (684,574 tons) of contaminated soil. This was also the year that the facility received the one-millionth ton of contaminated material from Hanford Site cleanup operations. From the startup of the facility, 1,248,070 metric tons (1,376,042 tons) of contaminated materials have been received.

Ongoing and upcoming remediation projects will require additional space for contaminated materials. In 1998, a contract was awarded for expansion of facility disposal cells three and four. The project design calls for excavation and removal of approximately 1,120,000 m^3 (1,460,000 yd^3) of material. By the end of 1998, the project had removed approximately 990,000 m^3 (1,300,000 yd^3), with the completion date scheduled for November 1999.

2.3.12.2 Waste Site Remediation Activities

Full-scale remediation of waste sites began in the 100 Areas in 1996. Remediation continued through 1998 at several liquid waste disposal sites in the 100-B,C and 100-D Areas.

In the 100-B,C Area, 122,315 metric tons (134,857 tons) of soil were removed in 1998. Through December 1998, 463,347 metric tons (510,857 tons)

of contaminated soil have been removed and shipped to the Environmental Restoration Disposal Facility.

Remediation operations continued in 1998 at the 100-D Area. Cleanup operations for the 116-D-7 Retention Basin and associated sludge pits began in March 1997 and continued through 1998 and into 1999. Over 450,000 metric tons (500,000 tons) of contaminated soils have been removed and transported to the Environmental Restoration Disposal Facility. Cleanup operations that began in March 1997 were completed in December 1998 for the 116-DR-9 Retention Basin and two associated sludge pits. The 1607-D2 Septic Tile Field was remediated in January and February 1998.

Remediation activities for the 300-FF-1 Operable Unit began in the 300 Area in 1997. Historically, both chemical and radiological materials were disposed of at the 300-FF-1 waste sites. In 1998, remediation operations removed nearly 138,000 metric tons (152,000 tons) of contaminated soils and debris that were shipped to the Environmental Restoration Disposal Facility. Over 175,000 metric tons (192,000 tons) have been removed to date.

Remediation was completed in the 300 Area at the 316-5, 300-10, 300-44, and 300-45 waste sites. The two parallel ditches of the 316-5 Process Trenches were fully remediated to "clean closure" standards: one was backfilled and revegetated, the other was partially backfilled and will be completed and revegetated at a later date. Remediation operations will continue into 1999 for the 628-4 Landfill and the 316-2 Process Pond. Remediation work at the 618-4 Burial Ground was temporarily halted in 1998 when drums of uranium mill shavings and uranium oxide powders were discovered. Work is expected to resume in 1999, following a scope of work change for the disposal of the drums.

2.3.12.3 100-N Area Project

Decontamination and decommissioning of N Reactor were completed in 1998, completing the Tri-Party Agreement Interim Milestone M-16-01E. This was the last production reactor to be deactivated on the Hanford Site. Bechtel Hanford, Inc., jointly with the Washington State Department of Ecology, created an effective working relationship necessary to meet cleanup challenges. A significant challenge during the 3-yr cleanup operation was presented with the cleanup and stabilization of 105-N Basin. The N Basin facility contained two deep pools (7.3 m [24 ft]), with a capacity of >3.8 million L (1 million gal) of water, which were used to store highly radioactive spent fuel. Even though the fuel was previously removed, large amounts of contamination and contaminated equipment remained. Innovative techniques and special tools were developed to remove contaminated water, hardware, and debris. During the 3-yr 100-N Area deactivation effort, 86 facilities were deactivated and stabilized.

2.3.12.4 Decommissioning Project

Decontamination and decommissioning continued in 1998 in the 100-B,C Area. During the year, the interim safe storage project for C Reactor was completed, satisfying Tri-Party Agreement milestone M-93-03. The footprint of the reactor was reduced by 81%, with the removal of 23 of the 24 associated facilities. High-strength, corrosion-resistant steel was placed on the roof. The enclosure is designed to protect people and the environment for the next 75 yr. Interim safe storage for C Reactor will reduce maintenance costs for the reactor by an estimated $185,000/yr. With the completion of this project, C Reactor became the first full-scale reactor to be placed in safe storage. Eight of the nine Hanford reactors are slated for interim safe storage.

Interim safe storage projects were also started for F and DR Reactors and are approximately 2 yr ahead of Tri-Party Agreement milestones.

Decommissioning and demolition began in 1998 for the 233-S Plutonium Concentration Facility in the 200-West Area. Because of high levels of radiation, this facility poses special challenges. During the year, decommissioning activities took place in the nonprocess pipe gallery and control room. Equipment, asbestos, and electrical equipment were also removed from three other process rooms.

2.3.12.5 Surveillance/Maintenance and Transition Project

This project performs surveillance and maintenance of inactive facilities until final disposition activities commence. The project also provides for the transition of facilities and waste sites into the Environmental Restoration Program after deactivation is complete. The project includes the Radiation Area Remedial Action Program, which is responsible for the surveillance, maintenance, and decontamination or stabilization of approximately 800 inactive waste sites. These include cribs, ponds, ditches, trenches, unplanned release sites, and burial grounds. These sites are maintained by performing periodic surveillances, radiation surveys, and herbicide applications and by initiating timely responses to identified problems. The overall objective of this project is to maintain these sites in a safe and stable configuration until final remediation strategies are identified and implemented. The main focus of this objective is to prevent the contaminants contained in these sites from spreading in the environment.

This project is also analyzing the end state (final status/condition) of the canyon facilities (i.e., large concrete structures formerly used in Hanford Site production missions) that exist in the project and those that are coming to the project through facility transition activities. The canyon disposition initiative is evaluating the potential to use the canyon facilities as waste disposal units, compared to standard decontamination and decommissioning of the facilities. The canyon disposition initiative has a potential to achieve a savings of $1 billion compared to removal of the facilities.

2.3.13 Groundwater/Vadose Zone Integration Project

2.3.13.1 Integration

In late 1997, the DOE Richland Operations Office established the Hanford Site Groundwater/Vadose Zone Integration Project and directed Bechtel Hanford, Inc. to lead. The Groundwater/Vadose Zone Project Team includes Fluor-Daniel Hanford, Inc. and Pacific Northwest National Laboratory. The project team members bring significant technical expertise and resources to the effort and help to ensure close coordination with site programs, projects, and contractors.

The project's vision centers on establishing trust and collaboration among participants and stakeholders in Hanford Site cleanup work to develop credible, defensible decisions that protect water resources. The project coordinates and integrates Hanford Site work that could impact water resources, with the goal of protecting those resources, including the Columbia River.

In 1998, the project issued *Management and Integration of Hanford Site Groundwater and Vadose Zone Activities* (DOE/RL-98-03) for review. Also during 1998, the public involvement process for the

project was implemented, an expert panel selected, and panel meetings initiated.

2.3.13.2 Groundwater Restoration Activities

Chromium. Chromium-contaminated groundwater that underlies portions of the 100-D, 100-H, and 100-K Areas (the 100-HR-3 and 100-KR-4 Operable Units) is of potential ecological concern (i.e., impact on Columbia River ecosystem). High levels of chromium are toxic to aquatic organisms, particularly those that use the riverbed sediment as habitat (DOE/RL-94-102, DOE/RL-94-113). In 1994, a groundwater extraction system was installed in the 100-D Area to test chromium removal from groundwater using ion exchange technology. Following the approval of the record of decision (1996), full-scale pump and treat systems were constructed in the 100-D, 100-H, and 100-K Areas and completed in 1997. Treated water is reinjected into the ground.

In 1998, the combined total of water treated for the 100-D and 100-H pump-and-treat systems totaled 254 million L (67.2 million gal), with the removal of 38.7 kg (85 lb) of chromium. To date, 458.3 million L (102.6 million gal) of groundwater have been treated, with 50.6 kg (111.6 lb) of chromium removed. The objective of chromium removal is to prevent the chromium from getting into the Columbia River.

The 100-KR-4 pump-and-treat system began operation in late September 1997. Since inception, approximately 242 million L (64 million gal) of groundwater have been processed, with 34.3 kg (73 lb) of chromium removed. Because of sedimentation problems and inadequate screen size, extraction well 199-K-118A was replaced with well 199-K-125A to continue treating groundwater for chromium.

To further evaluate chromium and other constituent contamination in groundwater near the Columbia River shoreline, 178 aquifer sample tubes were installed in 1997. Sample tubes were installed approximately every 610 m (2,000 ft), except in known chromium-contaminated plumes, where the tubes were installed approximately every 305 m (1,000 ft) parallel to the shoreline. Installation of the tubes began near the 100-B,C Area and continued downstream approximately 40 km (25 mi) to near the Old Hanford Townsite.

In 1998, samples were taken from approximately 50 sample tube locations. Samples are being analyzed for chromium, nitrates, tritium, strontium-90, and technetium-99. Collected data will provide information to support remediation operations, monitoring objectives, and environmental efforts now and into the future. Sample tube data will provide highly detailed information on the distribution of chromium in groundwater entering the river at locations very close to sensitive ecological receptors such as aquatic organisms.

Strontium-90. The 100-NR-2 (N Springs) pump-and-treat system began operations in 1995 north of the N Reactor complex and was designed to reduce the flux of strontium-90 to the Columbia River. The pump-and-treat system operates extraction wells to maintain hydraulic capture. The water is pumped through a treatment system to remove strontium-90 from contaminated groundwater. The system was upgraded in 1996 and continued to operate through 1998, with treated water reinjected into the ground. Approximately 109 million L (27 million gal) were processed in 1998. During that period, 0.096 Ci of strontium was removed from the groundwater. Over 329 million L (87 million gal) have been processed since the system began operation.

Carbon Tetrachloride. The carbon tetrachloride plume in the 200-West Area (underlying the 200-ZP-1 Operable Unit) covers approximately 9 km^2 (3.5 mi^2). Phase I of a pump-and-treat system initiated in 1994 was designed to test the removal of carbon tetrachloride and other organics from the groundwater using liquid-phase activated carbon, with the treated groundwater reinjected into

the aquifer. The pilot-scale system was expanded to include Phases II and III that were completed in 1996 and 1997, respectively. The 200-ZP-1 pump-and-treat system reached full operation in 1997, following a three-phase operational approach that included the use of air stripping and vapor-phase granulated activated carbon adsorption technology to remove volatile organic compounds. The system contains six extraction wells and five injection wells. The system was designed to extract, contain, and reduce the contaminated portion of the plume. In 1998, approximately 335 million L (88.4 million gal) of water were treated, with 1,270 kg (2,800 lb) of carbon tetrachloride removed. Over 695 million L (184 million gal) have been processed since the system began operation.

Uranium, Technetium-99, Carbon Tetrachloride, and Nitrates. Treatment of the groundwater plume underlying the 200-UP-1 Operable Unit in the 200-West Area continued in 1998. The plume contains uranium, technetium-99, carbon tetrachloride, and nitrates. Since 1994, a pump-and-treat system has been operated to remove contaminants from groundwater using ion exchange. Contaminated groundwater is extracted from a well in the 200-West Area and treated at the 200 Areas Effluent Treatment Facility near the 200-East Area. Treated groundwater is discharged north of the 200-West Area at the State-Approved Land Disposal Site. The objective is to prevent the contaminants from getting into the Columbia River.

In 1998, the system was shut down from mid-January to mid-February so the 200 Areas Effluent Treatment Facility could support other Hanford Site treatment operations. For the remainder of the year, the pump-and-treat system pumped 87 million L (23 million gal) and removed 7.2 g (0.017 lb) of technetium-99, 17.3 kg (39.9 lb) of uranium, 16.6 kg (38 lb) of carbon tetrachloride, and 4,120 kg (9,084 lb) of nitrates. The pump-and-treat operation made measurable progress toward reducing uranium and technetium-99 to below required cleanup concentration levels (DOE/RL-99-02).

2.3.13.3 Vadose Zone Activities

Soil vapor extraction systems designed to remove carbon tetrachloride vapor from the vadose zone beneath the 200-West Area began operating in 1992 and continued through 1998. Soil vapor is passed through aboveground granular activated carbon, which absorbs carbon tetrachloride. The granular activated carbon is then shipped offsite for treatment. Beginning in 1993, contaminant concentrations have been monitored using infrared photoacoustic spectrometers at the soil vapor extraction system inlets, vent stacks, individual wells, and soil vapor probes.

In 1996, the system was shut down for 8 mo to study and evaluate the magnitude and rate of carbon tetrachloride rebound. During the shutdown, data indicated the carbon tetrachloride concentrations increased at the three sites. Following the study, the system was restarted in 1997, and the mass-removal rates gradually declined to preshutdown rates. Following the 1997 rebound study that noted a declining rate of carbon tetrachloride removal during continuous extraction operations, the 1998 operating strategy was modified. The modification resulted in the operation of only the 14.2-m^3/min (500 ft^3/min) system for the removal of carbon tetrachloride. The 28.3- and 42.5-m^3/min (1,000- and 1,500-ft^3/min) vapor extraction systems were placed on standby. The modification allowed the 14.2-m^3/min (500-ft^3/min) system to be moved between the well fields that encompass the 216-Z-1A Tile Field, 216-Z-9 Trench, 216-Z-12 Crib, and 216-Z-18 Crib. In 1998, a planned 6-mo system shutdown was initiated to let carbon tetrachloride concentrations rebound. The shutdown allowed a more-efficient, per-hour operation for mass removal of carbon tetrachloride.

2.3.14 Noxious Weed Control Program

The noxious weed control program on the Hanford Site has been developed in response to federal, state, and local laws requiring eradication or control of noxious weeds. Developed in an effort to satisfy agreements made in the federal interagency memorandum of understanding (1994) signed by the DOE, the noxious weed control program at the Hanford Site has been designated as a model for noxious weed control at other DOE sites around the country.

Nine species of noxious weeds are on the high-priority list for control at Hanford: yellow starthistle, rush skeletonweed, babysbreath, Dalmatian toadflax, spotted knapweed, diffuse knapweed, Russian knapweed, saltcedar, and purple loosestrife. A detailed discussion of 1998 noxious weed control can be found in Section 7.5, "Noxious Weed Control Program."

2.3.15 Research and Technology Development Activities

Research and technology development activities are conducted in the 200, 300, 400, and Richland North Areas. Many of these activities are intended to improve the techniques and reduce the costs of waste management, cleanup, environmental protection, and site restoration. Specific 1998 accomplishments for technology deployment are given in DOE/RL-98-79.

Surface barrier monitoring and testing continue at the Hanford Site. A 4-yr treatability test, which began in 1994, was successfully completed in 1998 for the Hanford barrier prototype project. The project was designed to document surface barrier constructability, construction costs, and physical and hydrologic performance over the 216-B-57 Crib in the 200-East Area. Treatability tests were undertaken in two phases: Phase I included the design and construction of the prototype and was completed in 1994 and Phase II included the 4-yr testing and monitoring program.

The primary function of the surface barrier was to ensure buried wastes were contained and protected from the infiltration of water. The barrier consisted of a layer of fine soil overlaid by coarser materials such as sand, gravels, and basalt rip-rap. Silt loam provided a medium to store moisture until the evaporation and transpiration cycles could recycle moisture back into the atmosphere. The silt loam also provided a suitable area for plant growth. Coarser materials located below the silt loam created a capillary break that inhibits the downward percolation of water through the silt. Coarser soils also helped deter root penetration, animal burrowing, and inadvertent human intrusion.

Testing was completed for water balance within the barrier under conditions of ambient and extreme precipitation, surface wind and water erosion, stability of the barrier foundation, surface and rip-rap side slope, surface vegetation dynamics, and animal intrusion. During the testing period, results demonstrated the ease of construction with standard construction equipment, all design performance criteria were met or exceeded, and the design components were highly effective (DOE/RL-99-11, Decisional Draft).

In situ redox manipulation is a groundwater remediation technique that is based on changing the oxidation-reduction conditions of an aquifer so that hazardous constituents are either destroyed or immobilized in place. When ferrous iron is present within the aquifer, certain hazardous metallic ions, such as

hexavalent chromium or uranium, precipitate out of solution and become immobilized. A fixed, permeable, treatment zone is created because the ferrous iron is located within the aquifer sediments.

During 1991 to 1996, laboratory research was performed that indicated hexavalent chromium is reduced in concentration by a chemically reduced (oxygen-depleted) aquifer environment. During 1995 to 1996, in situ redox manipulation was successfully field tested at a single well site in the 100-H Area. The field test, which was located in a previously uncontaminated area, showed complete reduction of the aquifer sediments, with no dissolved oxygen present. Previously detected background levels of hexavalent chromium were no longer present in the reduced environment. During 1997 and 1998, in situ redox manipulation was deployed as a treatability test in the 100-D Area in an area of hexavalent chromium contamination. Test results to date indicate the permeable treatment zone is completely reduced and that hexavalent chromium concentrations have been reduced to below detection limits.

DOE's Tanks Focus Area, in partnership with the Tank Waste Remediation System, continued efforts within the Hanford Tanks Initiative Project to 1) develop retrieval performance criteria supporting readiness to close single-shell tanks, 2) demonstrate and deploy improved sampling and characterization technologies, and 3) demonstrate tank waste retrieval technologies to establish risk/performance data for future waste retrieval operations. In 1998, significant progress was made in several of these areas.

- Four samples from the floor of a high-level waste tank were retrieved using a new auger-sampling tool. The successful sampling campaign demonstrated for the first time that waste can be recovered from the deepest tanks at Hanford with simple auger tools. After retrieval from the tank, the auger samples were transferred to an onsite laboratory for analysis. Analyses of the retrieved waste samples will be used to validate or revise inventory estimates of the key risk-based radionuclides and hazardous chemicals left in the tank. The successful deployment resulted in auger sampling using the new tool being reintroduced as the baseline sampling technology.
- A light-duty utility arm was prepared for routine underground waste tank applications. Initially, it will be used to gather key in-tank waste characterization information (e.g., chemical and radionuclide inventory) from a representative sluiced and near-empty single-shell tank (241-AX-104 in the 200-East Area) that is assumed to have leaked. This information is needed to support a decision basis for future National Environmental Policy Act, safety, and regulatory actions affecting both waste retrieval and operable unit closure of the tank farms. A tank waste sampler and end effector (i.e., tool for sampling and other activities attached to the end of the arm) were developed and tested, system engineering drawings were updated, and staff were trained in preparation for deployment.
- In an effort to provide additional input for the decision basis for tank waste retrieval and tank farm closure decisions, the Hanford 32-metric-ton (35-ton) cone penetrometer platform was readied and probes were designed and tested for application in the upper vadose zone at the 241-AX-104 tank site in the 200-East Area. A multisensor integrated probe that includes a gamma spectrometer, moisture sensor, x-ray fluorescence sensor, and standard sleeve and tip rheology sensors was designed, fabricated, and tested. Semiquantitative information from this probe is intended to support the selection of positions at depth for retrieval of soil samples for confirmatory laboratory analysis. A unique sampler probe was also designed and successfully tested that can obtain soil samples at preselected depths without withdrawal of the pipe string. This demonstration is expected to introduce to Hanford an alternative technology to augment current gamma-logging and drilled well techniques to characterize the extent and magnitude of contaminant leakage into the upper vadose zone that is fast, less expensive, produces less secondary waste, results in less radiological risk to workers, and can be used to guide the location for expensive drilled wells.

In addition to the Hanford Tanks Initiative Project, the Tanks Focus Area also supported the

Tank Waste Remediation System by providing technical data and assistance to address one of the most critical Hanford safety issues, Tank 241-SY-101 in the 200-West Area. As a result of advancements in the understanding of saltcake dissolution chemistry, the Tanks Focus Area was able to provide technical assistance to Hanford Tank Farm Operations. The crust in the tank has been growing, and the growth raises safety questions. Researchers used dilution and pumping models to determine the consequences of adding water containing corrosion inhibitors to the tank's crust. The extensive thermodynamic calculations done as part of the modeling showed that solids volume could be reduced by 30%. These modeling calculations are being used to further evaluate waste transfers and water additions.

Interim safe storage activities at the C Reactor provided a stage for showcasing innovative decontamination and decommissioning technologies. At least 20 technologies and approaches were field tested to demonstrate safer, less-expensive, and more-efficient ways of decommissioning aging nuclear facilities. Through 1998, 13 innovative or improved technologies were demonstrated. Eight have since been adopted, replacing baseline technologies. Four of these technologies have been deployed at other Hanford projects and at other DOE facilities. One has been selected for use at the Chornobyl Reactor in Ukraine.

A gamma camera, which was designed to provide real-time images and source strengths of contamination sites, has been used to record the radiation fields in the 221-B Plant canyon building in the 200-East Area. The camera produces a two-dimensional map of radiation fields that is overlaid on an image of equipment and piping. The map includes topographic contours of different colors that depict the intensity of exposure. This new technology cost-effectively reduces the collective radiation exposure of personnel and provides documentation of facility conditions that are necessary for future decontamination and decommissioning work in the B Plant facility. The camera is operated remotely from an overhead crane, and eliminates the need to use manual sampling techniques while providing a higher quality assessment.

2.4 Environmental Occurrences

G. W. Patton

Onsite and offsite environmental releases of radioactive and regulated materials are reported to DOE and other federal and state agencies as required by law. The specific agencies notified depend on the type, amount, and location of the individual occurrences. In some cases, an occurrence may be under continuing observation and evaluation. All emergency, unusual, and off-normal occurrences at the Hanford Site are reported to the Hanford Site Occurrence Notification Center. This center is responsible for maintaining both a computer database and a hard-copy file of event descriptions and corrective actions. Copies of occurrence reports are made available for public review in the DOE's Hanford Reading Room located in the Consolidated Information Center on the campus of Washington State University at Tri-Cities, Richland, Washington.

As defined in DOE Order 232.1, emergency occurrences "are the most serious occurrences and require an increased alert status for onsite personnel and, in specified cases, for offsite authorities." There was one emergency occurrence report filed in 1998.

An unusual occurrence is defined in the DOE Order as "a nonemergency occurrence that exceeds the Off-Normal Occurrence threshold criteria, is related to safety, environment, health, security, or operations, and requires immediate notification to DOE." There was one environmentally significant unusual occurrence report filed during 1998.

Off-normal environmental occurrences are classified in the DOE Order as "abnormal or unplanned events or conditions that adversely affect, potentially affect, or are indicative of degradation in the safety, safeguards and security, environmental or health protection, performance or operation of a facility." Several of these occurrences are discussed in Section 2.2.5.4, "RCRA Inspections;" Section 2.2.6.1, "Clean Air Act Enforcement Inspections;" and Section 2.2.7, "Clean Water Act." The following summarizes some of the emergency and off-normal environmental occurrences not previously discussed or that were not discussed in detail. For each occurrence summarized below, the title and report number from the Hanford Site Occurrence Notification Center is given in the heading.

2.4.1 Emergency Occurrences

- Small Bottle of Suspect Material Discovered – Alert-Level Emergency Declared (RL-PHMC-327FAC-1998-0002)

On January 28, 1998, a small bottle, labeled "picric acid," and containing an unknown dry solid was discovered in a crawlspace off the basement of the 327 Building in the 300 Area. Building personnel had entered the crawlspace to perform an inspection for future steam line work. The bottle was found in a plastic pail next to the crawlspace wall. Because of the location of the bottle and because the dry solid form of picric acid could potentially explode if exposed to flame or friction, an alert-level emergency (defined as the potential degradation of the level of safety of the facility) was declared. The facility was evacuated, appropriate notifications were made, an incident command post was established, and protective actions were initiated. An entry plan was developed and, following approval, an entry was made into the crawlspace to videotape the bucket, container, and surrounding area. The alert-level emergency was terminated on January 28, 1998 on discovery that the quantity of picric acid involved (approximately 35 to 50 g [0.077 to 0.11 lb]) could

not result in a large-enough explosion to compromise the facility. The bottle and its contents were stabilized and removed from the facility on January 30, 1998. Subsequent analysis confirmed that the material was picric acid. No personal injury, personal contamination, or environmental releases occurred as a result of this event.

2.4.2 Unusual Occurrences

- Contamination Control Issue at the 200-East Area, Hanford Site and Associated Contamination Detection at Offsite Locations (RL-PHMC-FSS-1998-0021)

On September 28, 1998, Radiation Control Technicians were conducting radioactivity surveys at Mobile Office MO-967 in the 200-East Area and detected contamination in some unusual locations. Because this general area has a long history of contaminated biota (e.g., tumbleweeds, ants, beetles, mice), known pathways for these vectors were investigated. Searches into locations where biological vectors would be expected to have spread contamination yielded negative results, as did collections of animals known to be vectors from these areas.

Expanded surveys detected contamination on refuse in a dumpster located outside of MO-967. The dumpster was isolated so that contamination would not be transported off the site. On September 30, 1998, a Radiation Control Technician was monitoring radioactivity on a pipe in MO-967 and observed the contamination to "fly away." The technician and her partner then repeated the exercise with the same results. Closer inspection revealed the contamination to be located on very small flying insects, later identified as fruit or vinegar flies (*Drosophila* spp.).

On September 30, 1998, it was recognized that a large contamination event was under way. Through continued investigation, it was learned that the dumpster located near MO-967 had been emptied on September 28, 1 d ahead of schedule, and that the contents had been hauled to the Richland City Landfill. The landfill manager was notified, all refuse-hauling trucks were isolated, a Radiation Control Technician was dispatched to the landfill, and flying insect traps were placed in suspect environs. Subsequent radioactivity surveys of the refuse trucks and the landfill confirmed that contamination had gone off the site. Fruit flies appeared to be the primary vector, however, the source of the contamination was still unknown.

Beginning on October 1, 1998, and for several days thereafter, contaminated fruit flies were found in traps near MO-967 and the nearby 241-ER-152 Diversion Pit. Because of its past history of biotic contamination incidents, the diversion pit was investigated as the potential source of the contaminated fruit flies. Initial isotopic analysis of the fruit flies and other refuse contamination indicated nearly pure strontium-90 with some cesium-137. Visual inspections revealed openings into the diversion pit and that fruit flies were present. No other sources were identified that would account for the contaminated fruit flies. Additionally, in 3 mo of trapping, only one contaminated fruit fly was found at any other location. The lone contaminated fruit fly found away from the diversion pit was in a trap near US Ecology on a day following strong northeasterly winds blowing from the direction of the pit.

It was discovered that, prior to a scheduled maintenance campaign to be conducted on September 15, the diversion pit had been sprayed on September 10 with a mono-saccharin-based fixative to prevent aerial dispersion of contamination when the pit was to be opened. The fixative acted as a food source attractant to the fruit flies, which had open access on September 15 to enter and lay eggs in the moist (now contaminated) media. The natural life cycle of the fruit fly (10 to 14 d) provided a population of contaminated flies by September 28, 1998.

Radioisotopic analysis of both the spot contamination and of the contaminated fruit flies identified nearly identical ratios of strontium-90 to cesium-137, the primary contaminants. The maximum contamination in the fruit flies was found on a sample of nine fruit flies that had 260,000 pCi of strontium-90 per sample. Ingestion of all nine fruit flies would result in a 50-yr committed effective-dose equivalent of approximately 34 mrem.

Control measures included trapping, pesticide application (both in and around the diversion pit, to all local dumpsters, to the affected landfill and burial ground, and to refuse hauling trucks), removing the contaminated material from the Richland City Landfill to a Hanford Site low-level burial ground, ceasing transport of Hanford refuse to offsite locations, and establishing a refuse receiving and monitoring transfer station before offsite transfers of Hanford refuse were reinitiated. The diversion pit was resealed and fogged with insecticide prior to a final campaign in the spring of 1999. Monitoring of flying insects has been added to the routine monitoring schedule for near-facility monitoring. A new program, the Integrated Biological Control Program, has been established to identify and correct known and suspected biological intrusion problems on the Hanford Site. This program will coordinate with Near-Facility Monitoring to control the biological spread of radioactive contamination.

2.4.3 Off-Normal Occurrences

- Waste Drums Discovered at 618-4 Burial Ground (RL-BHI-REMACT-1998-0002)

On April 2, 1998, approximately 350 waste drums with unknown contents were discovered at the 618-4 Burial Ground during an ongoing remediation activity in the 300 Area. It was suspected that the drums contained depleted uranium filings and mineral oil. Several of the drums had leaked, and the suspect leakers were placed into overpack drums and additional mineral oil was added to cover the metal filings. Exposed drums were then reburied to isolate them from the atmosphere. Work was suspended at this burial ground until a more-detailed plan could be developed for future excavation, treatment, and disposal of the drums. No additional impact on the environment or human health resulted from this discovery.

- Notice of Violation for Operation of 324 Building Plasma Arc Furnace (RL-PHMC-324FAC-1998-0003)

On May 13, 1998, the Washington State Department of Health issued a Notice of Violation for operation of the plasma arc furnace from April 13 to 17, 1998 at the 324 Building in the 300 Area during a classified technology demonstration project, involving the treatment and destruction of dismantled weapons components. Tritium was released to the environment during this test; however, the tritium monitoring system was not operated during this demonstration because it was determined that sampling results would be classified and it was believed that this action was allowable under the notice of construction permit for the plasma arc furnace. A notice of construction permit is issued by the Washington State Department of Health for activities that involve the potential release of radionuclides. The notice of construction permit had been modified and approved by the Washington State Department of Health in August 1997 to allow for the release of 20 Ci of tritium during this demonstration. The notice of construction permit did not require air sampling. Alleged violations include failure to provide tritium sampling in accordance with regulatory requirements and failure (prior to the event) to disclose the nature and general description of the material processed. After the event, classified tritium source term information was presented to the Washington State Department of Health to verify that the facility had not exceeded the tritium release limits approved in

the notice of construction. Although review of the applicable regulatory and notice of construction requirements supported the position that tritium sampling was not required, consultation with the Washington State Department of Health would have clarified the matter and prevented the notice of violation.

- Tritium Released Through the Stack from High-Level Radiochemistry Hot Cell (RL-PNNL-PNNLNUCL-1998-0008)

On August 26, 1998, a continuous air monitor that measures stack emissions from the radiochemical-processing laboratory in the 325 Building in the 300 Area alarmed because of elevated tritium activities. The source of tritium was determined to be a hot cell, where a cold vapor trap was being purged with helium as part of a sample collection process (the liquid nitrogen coolant had been removed from the trap as part of the collection procedure). Once the source was identified, the helium purge gas was turned off, the cold vapor trap was isolated, and the tritium activities in the stack quickly decreased. Effluent monitoring data indicated that 118 Ci of tritium were released. No release levels or exposure limits were exceeded during this event. The potential dose to hypothetical onsite and offsite personnel was estimated to be a maximum of 0.4 mrem on the site and 0.05 mrem off the site. Hot cell procedures were reviewed and modified to prevent this type of release in the future.

- Halon® Based Fire Suppression System Activated and Released Halon® into a Room During Preventive Maintenance (RL-PHMC-PFP-1998-0040)

On September 11, 1998, the Halon® fire suppression system in building 2701-Za in the 200-West Area inadvertently discharged during a preventive maintenance activity. Approximately 145 kg (319 lb) of Halon® were discharged during this event. Halon® is a fairly nontoxic chemical but is hazardous in high concentrations because it displaces oxygen. In addition, Halon® is an ozone-depleting compound, and accidental releases should be minimized. All personnel immediately evacuated the building, and the Hanford Fire Department responded by exhausting the Halon® from the building. Five personnel in the room during the discharge were evaluated by fire department personnel and were determined to have no adverse health effects. One individual, who was near a discharge nozzle, was sent to a local hospital for further evaluation and was released. Procedures were reviewed and will be modified, as needed, to prevent such accidental releases in the future.

- Unplanned Tritium Emission from the 325 Radiochemical Processing Laboratory (RL-PNNL-PNNLNUCL-1998-0011)

On December 8, 1998, a continuous air monitor on the exhaust stack of the 325 Building in the 300 Area activated an alarm (12-min duration). The release was caused by an operator error that resulted in an incorrect opening of a fume hood valve. Effluent monitoring staff calculated that the alarm resulted from the release of 68 Ci of tritium, with estimated potential doses to the offsite public of 0.003 mrem at the closest accessible point and 0.0004 mrem to the nearest residential area. On December 10, 1998, the Washington State Department of Health issued an order temporarily suspending tritium operations associated with the air permit for the Tritium Target Qualification Project in the 325 Building, pending corrective actions.

2.5 Waste Management and Chemical Inventories

L. P. Diediker

2.5.1 Waste Management

Waste produced from Hanford Site cleanup operations is classified as either radioactive, nonradioactive, mixed, or toxic. Radioactive waste is categorized as transuranic, high level, and low level. Mixed waste contains both radioactive and hazardous nonradioactive substances. Hazardous waste contains either dangerous waste or extremely hazardous waste or both, as defined in WAC 173-303. Hanford's hazardous wastes are managed in accordance with WAC 173-303.

Radioactive and mixed wastes are handled in several ways. High-level waste is stored in single- and double-shell tanks. Low-level waste is stored in double-shell tanks, on storage pads, or is buried. The method used to manage low-level waste depends on the source, composition, and concentration of the waste. Transuranic waste is stored in vaults or on underground and aboveground storage pads from which it can be retrieved.

Approximately 200 Hanford Site facilities have the capacity to generate dangerous and toxic waste. An annual report lists the dangerous wastes and extremely hazardous wastes generated, treated, stored, and disposed of on and off the site (DOE/RL-99-10). Dangerous wastes are treated, stored, and prepared for disposal at several Hanford Site facilities. Dangerous wastes generated at the site are also shipped off the site for disposal, destruction, or recycling.

Nondangerous wastes generated at the Hanford Site have historically been buried in the Solid Waste Landfill near the 200 Areas. Beginning in December 1995, nondangerous wastes have been disposed of at the Richland City Landfill, a municipal landfill located at the southern edge of the Hanford Site boundary. Since 1996, medical wastes have been shipped to Waste Management of Kennewick. Asbestos has been shipped to Basin Disposal, Inc. in Pasco and the onsite Environmental Restoration Disposal Facility. Since 1996, nonregulated drummed waste has been shipped to Waste Management of Kennewick.

These nondangerous wastes originate at a number of areas across the site. Examples of these wastes are construction debris, office trash, cafeteria waste, and packaging materials. Other materials and items classified as nondangerous waste include solidified filter backwash and sludge from the treatment of river water, failed and broken equipment and tools, air filters, uncontaminated used gloves and other clothing, and certain chemical precipitates such as oxalates. Demolition wastes from decommissioning projects in the 100 Areas are buried in situ or in designated sites in the 100 Areas.

Annual reports document the quantities and types of solid wastes generated on the site, received, shipped off the site, and disposed of at the Hanford Site (HNF-EP-0125-11). Solid waste program activities are regulated by RCRA and the Toxic Substances Control Act and are discussed in Section 2.2, "Compliance Status." Solid waste quantities generated on the site, received from off the site, shipped off the site, and disposed of at the site from 1993 through 1998 are shown in Tables 2.5.1 through 2.5.3. Table 2.5.4 provides a detailed summary of the radioactive solid wastes stored or disposed of in 1998.

Table 2.5.1. Quantities of Solid Wastes[a] Generated on the Hanford Site, kg (lb)

Waste Category	1993	1994	1995	1996	1997	1998
Mixed	150,000 (331,000)	568,000 (1,250,000)	132,000 (291,000)	199,000 (439,000)	442,000 (975,000)	509,000 (1,120,000)
Radioactive	1,120,000 (2,470,000)	1,390,000 (3,070,000)	1,890,000 (4,170,000)	3,870,000 (8,530,000)	6,590,000 (14,500,000)	1,470,000 (3,240,000)

(a) Solid waste includes containerized liquid waste.

Table 2.5.2. Quantities of Solid Wastes[a] Received from Offsite, kg (lb)

Waste Category	1993	1994	1995	1996	1997	1998
Mixed	208,000 (459,000)	96,000 (212,000)	52,800 (116,000)	2,070 (4,560)	3,560 (7,850)	267 (589)
Radioactive	1,590,000 (3,510,000)	1,360,000 (2,990,000)	1,310,000 (2,890,000)	1,670,000 (3,680,000)	1,430,000 (3,150,000)	2,870,000 (6,330,000)

(a) Solid waste includes containerized liquid waste. Solid waste quantities do not include United States Navy submarine reactor compartments.

Table 2.5.3. Quantities of Hazardous Wastes[a] Shipped Offsite, kg (lb)

Waste Category	1993	1994	1995	1996	1997	1998
Containerized	124,000 (273,000)	267,000 (589,000)	224,000 (494,000)	590,000 (1,300,000)	110,000 (243,000)	65,700 (145,000)
Bulk Solids	250,000 (551,000)	2,870,000 (6,330,000)	478,000 (1,050,000)	0	335,000 (739,000)	47,500 (105,000)
Bulk Liquids	94,000 (207,000)	249,000 (549,000)	130,000 (287,000)	98,800 (218,000)	5,025,000 (11,100,000)	41,800 (92,200)
Total	468,000[b] (1,032,000)	3,386,000[c] (7,470,000)	832,000 (1,840,000)	689,000 (1,520,000)	5,470,000 (12,100,000)	155,000 (342,000)

(a) Does not include Toxic Substances Control Act wastes.
(b) Includes 250,000 kg (551,250 lb) from demolition of 190-B Building, 100-B Area.
(c) Includes 2,660,000 kg (5,865,300 lb) from Wahluke Slope cleanup and 161,000 kg (355,005 lb) from carbon tetrachloride soil extraction near the Plutonium Finishing Plant, 200-West Area.

Table 2.5.4. Radioactive Solid Wastes Stored or Disposed of on the Hanford Site, 1998

Constituent	Quantity, Ci	
	Low Level[a]	Transuranic[b]
Tritium	240	(c)
Carbon-14	9.1	0.000002
Iron-55	35,000	(c)
Cobalt-58	2,600	(c)
Cobalt-60	6,900	40
Nickel-63	82,000	(c)
Strontium-90	3,200	2,600
Yttrium-90	3,200	2,600
Technetium-99	0.17	0.035
Cesium-137	1,600	4,300
Barium-137m	1,500	4,100
Europium-154	29	(c)
Uranium-233	98,000	(c)
Uranium-234	0.29	0.0000016
Uranium-235	0.023	0.000000052
Uranium-236	0.0079	0.00000012
Uranium-238	1.7	0.00000094
Plutonium-238	0.98	8.0
Plutonium-239	4.0	22
Plutonium-240	1.6	7.3
Plutonium-241	68	380
Plutonium-242	0.00057	0.004
Americium-241	2.3	11
Curium-244	1.9	0.37

(a) The quantities of low-level wastes include both radioactive and mixed waste totals.
(b) Transuranic waste quantities (>100 nCi/g) also include both radioactive and mixed transuranic waste.
(c) Not reported or trace quantity.

The quantities of liquid wastes generated in 1998 and stored in underground storage tanks are included in the annual dangerous waste report (DOE/RL-99-10). Table 2.5.5 is a summary of the liquid wastes generated from 1993 through 1998, which are stored in underground storage tanks.

2.5.2 Chemical Inventories

Types, quantities, and locations of hazardous chemicals are tracked through compliance activities associated with the Emergency Planning and Community Right-To-Know Act (see community right-to-know activities discussed in Section 2.2.4). The 1998 tier two emergency and hazardous chemical inventory (DOE/RL-99-16) was issued in February 1999 in compliance with Section 312 of the Act. Table 2.5.6 summarizes the information reported, listing the 10 chemicals stored in greatest quantity on the Hanford Site in 1998.

Table 2.5.5. Quantities of Bulk Liquid Wastes[a] Generated and Stored on the Hanford Site in 1998 and in Each of the Previous 5 Years, L (gal)

1993	1994	1995	1996	1997	1998
22,200,000 (5,870,000)	10,700,000 (2,830,000)	18,200,000 (4,810,000)	2,420,000 (639,000)	865,000[b] (229,000)	1,780,000 (470,000)

(a) Bulk liquid waste is defined as liquid waste sent to double-shell underground storage tanks. This does not include containerized waste (e.g., barreled) included in the solid waste category.
(b) Revised number. The number reported in PNNL-11795 was incorrect.

Table 2.5.6. Average Balance of 10 Hazardous Chemicals Stored in Greatest Quantity on the Hanford Site, 1998

Hazardous Chemical	Average Quantity, kg (lb)
Coal	5,300,000 (11,700,000)
Mineral oil	1,700,000 (3,750,000)
Sodium	1,000,000 (2,210,000)
Diesel fuel (Grades 1 and 2)	580,000 (1,280,000)
No. 6 fuel oil	540,000 (1,190,000)
Crystalline silica (quartz, cristobalite, tridymite)	480,000 (1,060,000)
Bentonite	270,000 (595,000)
Ethylene glycol	250,000 (551,000)
Nitrogen	86,000 (190,000)
Carbon	77,000 (170,000)

2.6 References

10 CFR 1021. U.S. Department of Energy. "Compliance with the National Environmental Policy Act." *Code of Federal Regulations.*

29 CFR 1910. U.S. Department of Labor. "Occupational Safety and Health Administration." *Code of Federal Regulations.*

40 CFR 61, Subpart H. U.S. Environmental Protection Agency. "National Emissions Standards for Emissions of Radionuclides Other Than Radon From Department of Energy Facilities." *Code of Federal Regulations.*

40 CFR 61, Subpart M. U.S. Environmental Protection Agency. "National Emission Standard for Asbestos." *Code of Federal Regulations.*

40 CFR 70. U.S. Environmental Protection Agency. "State Operating Permit Programs." *Code of Federal Regulations.*

40 CFR 82. U.S. Environmental Protection Agency. "Protection of Stratospheric Ozone." *Code of Federal Regulations.*

40 CFR 122. U.S. Environmental Protection Agency. "EPA Administered Permit Programs: The National Pollutant Discharge Elimination System." *Code of Federal Regulations.*

40 CFR 141. U.S. Environmental Protection Agency. "National Primary Drinking Water Regulations; Radionuclides; Proposed Rule." *Code of Federal Regulations.*

40 CFR 261. U.S. Environmental Protection Agency. "Identification and Listing of Hazardous Waste." *Code of Federal Regulations.*

40 CFR 264. U.S. Environmental Protection Agency. "Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities." *Code of Federal Regulations.*

40 CFR 265. U.S. Environmental Protection Agency. "Interim Status Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities." *Code of Federal Regulations.*

40 CFR 300. U.S. Environmental Protection Agency. "National Oil and Hazardous Substances Pollution Contingency Plan." *Code of Federal Regulations.*

40 CFR 300.605. U.S. Environmental Protection Agency. "State Trustees." *Code of Federal Regulations.*

40 CFR 355. U.S. Environmental Protection Agency. "Emergency Planning and Notification." *Code of Federal Regulations.*

40 CFR 761. U.S. Environmental Protection Agency. "Polychlorinated Biphenyls (PCBs) Manufacturing, Processing, Distribution in Commerce, and Use Prohibitions." *Code of Federal Regulations.*

40 CFR 1500-1508. Council on Environmental Quality. "Regulations for Implementing the Procedural Provisions of the National Environmental Policy Act." *Code of Federal Regulations.*

43 CFR 11. U.S. Department of the Interior. "Natural Resource Damage Assessments." *Code of Federal Regulations.*

61 FR 10736. U.S. Department of Energy. "Record of Decision: Management of Spent Nuclear Fuel from the K Basins at the Hanford Site, Richland, WA." *Federal Register.*

62 FR 8693. U.S. Department of Energy. "Record of Decision for the Tank Waste Remediation System, Hanford Site, Richland, WA." *Federal Register.*

63 FR 35383. U.S. Environmental Protection Agency. "Disposal of Polychlorinated Biphenyls (PCBs); Final Rule." *Federal Register.*

63 FR 3623. U.S. Department of Energy. "Record of Decision for the Department of Energy's Waste Isolation Pilot Plant Disposal Phase; Notice." *Federal Register*.

63 FR 41810. U.S. Department of Energy. "Record of Decision for the Department of Energy's Waste Management Program: Treatment of Non-Wastewater Hazardous Waste." *Federal Register*.

63 FR 52430. U.S. Environmental Protection Agency. "Final Modification of the National Pollutant Discharge Elimination System (NPDES) Storm Water Multi-Sector General Permit for Industrial Activities; Termination of the EPA NPDES Storm Water Baseline Industrial General Permit; Notice." *Federal Register*.

American Indian Religious Freedom Act. 1978. Public Law 95-341, as amended, 92 Stat. 469.

Archaeological Resources Protection Act. 1979. Public Law 96-95, as amended, 93 Stat. 721.

Babbitt, B. 1996. *United States Department of the Interior Record of Decision, Hanford Reach of the Columbia River, Final Environmental Impact Statement for Comprehensive River Conservation Study*. Washington, D.C.

Cascio, J. (ed.). 1996. *The ISO 14000 Handbook*. CEEM Information Services with ASQC Quality Press, Milwaukee, Wisconsin.

Clean Air Act. 1986. Public Law 88-206, as amended, 42 USC 7401 et seq.

Clean Air Act Amendments. 1990. Public Law 101-549, as amended.

Clean Water Act. 1997. Public Law 95-217, as amended, 91 Stat. 1566 and Public Law 96-148 as amended.

Comprehensive Environmental Response, Compensation, and Liability Act. 1980. Public Law 96-150, as amended, 94 Stat. 2767, 42 USC 9601 et seq.

DE-91-NM-177. 1992. *Consent Order No. DE-91-NM-177 for the Permitting of Liquid Effluent Discharges Under the Washington Administrative Code (WAC) 173-216*. C. O. Gregoire, Washington State Department of Ecology, Olympia, Washington, and J. D. Wagoner, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Defense Authorization Act. 1990. Public Law 101-510, as amended.

DOE/EA-1135. 1999. *Environmental Assessment: Offsite Thermal Treatment of Low-Level Mixed Waste*. U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/EA-1189. 1998. *Environmental Assessment for Non-Thermal Treatment of Hanford Site Low-Level Mixed Waste*. U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/EH-0173T. 1991. *Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance*. U.S. Department of Energy, Washington, D.C.

DOE/EIS-0189. 1996. *Tank Waste Remediation System, Hanford Site, Richland, Washington, Final Environmental Impact Statement*. U.S. Department of Energy and Washington State Department of Ecology, Richland, and Olympia, Washington, 3 vols.

DOE/EIS-0189-SA2. 1998. *Supplement Analysis for the Tank Waste Remediation System*. U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/EIS-0200F. 1997. *Final Waste Management Programmatic Environmental Impact Statement For Managing Treatment, Storage, and Disposal of Radioactive and Hazardous Waste*. U.S. Department of Energy, Office of Environmental Management, Washington, D.C., 5 vols.

DOE/EIS-0222D. 1999. *Revised Draft, Hanford Remedial Action Environmental Impact Statement and Comprehensive Land-Use Plan.* U.S. Department of Energy, Washington, D.C.

DOE/EIS-0245/SA1. 1998. *Supplement Analysis of Environmental Effects of Changes in DOE's Preferred Alternative for Management of Spent Nuclear Fuel from the K Basins at the Hanford Site, Richland, Washington.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/EIS-0245F. 1996. *Addendum (Final Environmental Impact Statement) Management of Spent Nuclear Fuel from the K Basins at the Hanford Site, Richland, Washington.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/ID/12584-268, GJPO-HAN-4. 1996. *Vadose Zone Characterization Project at the Hanford Tank Farms, SX Tank Farm Report.* U.S. Department of Energy, Albuquerque Operations Office and Grand Junction Office for Richland Operations Office, Richland, Washington.

DOE Order 232.1. "Occurrence Reporting and Processing of Operations Information."

DOE Order 451.1A. "National Environmental Policy Act Compliance Program."

DOE Order 1230.2. "American Indian Tribal Government Policy."

DOE P 450.4. 1996. *Safety Management System Policy.* U.S. Department of Energy, The Office of Environment, Safety and Health, Washington D.C.

DOE/RL-91-28, Rev. 3. 1997. *Hanford Facility Waste Permit Application, General Information Portion.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-93-94, Rev. 1. 1994. *Plan and Schedule for Disposition and Regulatory Compliance for Miscellaneous Streams.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-94-86. 1994. *Ozone-Depleting-Substance Control and Phase-Out Plan.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-94-102. 1995. *Proposed Plan for Interim Remedial Measure at the 100-HR-3 Operable Unit.* Prepared by CH2M Hill Hanford, Inc. for Bechtel Hanford, Inc. for U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-94-113. 1995. *Proposed Plan for Interim Remedial Measure at the 100-KR-4 Operable Unit.* Prepared by CH2M Hill Hanford, Inc. for Bechtel Hanford, Inc. for U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-94-150. 1994. *Bald Eagle Site Management Plan for the Hanford Site, South-Central Washington.* R. E. Fitzner and S. G. Weiss, Pacific Northwest Laboratory and CH2M Hill for U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-96-32. 1996. *DRAFT, Hanford Site Biological Resources Management Plan.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-96-40. 1996. *Miscellaneous Streams Best Management Practices (BMP) Report.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-96-63, Rev. 2. 1998. *Annual Hanford Site Environmental Permitting Status Report.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-96-73, Rev. 1. 1998. *324 Building Radiochemical Engineering Cells, High-Level Vault, Low-Level Vault, and Associated Areas Closure Plan.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-96-88. 1996. *Draft, Hanford Site Biological Resources Mitigation Strategy Plan.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-98-03. 1998. *Management and Integration of Hanford Site Groundwater and Vadose Zone Activities.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-98-39. 1998. *1997 Toxic Chemical Release Inventory, Emergency Planning and Community Right-to-Know Act, Section 313.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-98-79. 1998. *FY 1998 Hanford Technology Deployment Accomplishments.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-99-02. 1999. *Fiscal Year 1998 Annual Summary Report for the 200-UP-1, 200-ZP-1, and 100-NR-2 Pump-and-Treat Operations and Operable Units.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-99-10. 1999. *Hanford Site Annual Dangerous Waste Report, Calendar Year 1998.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-99-11, Decisional Draft. 1999. *200-BP-1 Prototype Barrier Treatability Test Report.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-99-16. 1999. *1998 Tier Two Emergency and Hazardous Chemical Inventory, Emergency Planning and Community Right-To-Know Act, Section 312.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Emergency Planning and Community Right-To-Know Act. 1986. Public Law 99-499, as amended, 100 Stat. 1728, 42 USC 11001 et seq.

Endangered Species Act. 1973. Public Laws 93-205 through 100-707, as amended, 87 Stat. 884, 16 USC 1531 et seq.

EPA 100-K-93-001. 1993. *Pollution Prevention and Right-to-Know in the Government, Executive Order 12856.* U.S. Environmental Protection Agency, Office of the Administrator, Washington, D.C.

EPA-570/9-76-003. 1976. *National Interim Primary Drinking Water Regulations.* U.S. Environmental Protection Agency, Office of Water Supply, Washington, D.C.

EPA 822-R-96-001. 1996. *Drinking Water Regulations and Health Advisories.* U.S. Environmental Protection Agency, Office of Water, Washington,. D.C.

FAI/96-45. 1996. *Propagation Scale-Up Tests with Organic-Nitrate/Nitrite Mixtures.* H. K. Fauske and Associates, Inc., Burr Ridge, Illinois.

FAI/96-48. 1996. *An Update of Requirements for Organic-Nitrate Propagating Reactions Including RSST and Tube Propagation Test Results With Waste Simulants.* H. K. Fauske and Associates, Inc., Burr Ridge, Illinois.

Federal Facility Compliance Agreement for Radionuclide NESHAP. 1994. J. D. Wagoner, U.S. Department of Energy, and G. A. Emison, U.S. Environmental Protection Agency, Seattle, Washington.

Federal Insecticide, Fungicide, and Rodenticide Act. 1975. Public Laws 94-51 through 94-140, as amended, 7 USC 136 et seq.

GJ-HAN-6. 1997. *Hanford Tank Farms Vadose Zone, BY Tank Farm Report.* Prepared by MACTEC-ERS for U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

GJ-HAN-8. 1997. *Hanford Tank Farms Vadose Zone, U Tank Farm Report.* Prepared by MACTEC-ERS for U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

GJ-HAN-11. 1997. *Hanford Tank Farms Vadose Zone, TX Tank Farm Report.* Prepared by MACTEC-ERS for U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

GJ-HAN-12. 1997. *Hanford Tank Farms Vadose Zone, AX Tank Farm Report.* Prepared by MACTEC-ERS for U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

GJ-HAN-106. 1998. *Hanford Tank Farms Vadose Zone, Tank Summary Data Report for Tank A-101.* Prepared by MACTEC-ERS for U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

GJO-99-80-TAR/GJO-HAN-24. 1999. *Hanford Tank Farms Vadose Zone, Effects of Differing Source Distributions on Spectral Shape Factors for Contaminant Logging at the Hanford Site.* B. J. Higgins and C. J. Koizumi, MACTEC-ERS for U.S. Department of Energy, Albuquerque Operations Office, Grand Junction Office, Grand Junction, Colorado.

HNF-2350. 1998. *Hanford Site FY 1998 Pollution Prevention Accomplishments.* M. M. Seay, Fluor Daniel Hanford, Inc., Richland, Washington.

HNF-3100. 1998. *Hanford Site Comprehensive Compliance Evaluation Report–July 1, 1997 through June 30, 1998.* Fluor Daniel Hanford, Inc., Richland, Washington.

HNF-3617. 1999. *Integrated Project Management Plan for the Plutonium Finishing Plant Stabilization and Deactivation Project.* Prepared by B&W Hanford Company for Fluor Daniel Hanford, Inc., Richland, Washington

HNF-3824. 1999. *Tank 241-SY-101 Surface-Level-Rise Remediation Project Plan.* R. E. Raymond, Lockheed Martin Hanford Corporation for Fluor Daniel Hanford, Inc., Richland, Washington.

HNF-EP-925. 1997. *Environmental Management System Implementation Plan.* Fluor Daniel Hanford, Inc., Richland, Washington.

HNF-EP-0125-11. 1999. *Summary of Radioactive Solid Waste Received in the 200 Areas During Calendar Year 1998.* D. L. Hagel, Waste Management Federal Services of Hanford, Inc., Richland, Washington.

HNF-EP-0182-129. 1999. *Waste Tank Summary Report for Month Ending December 31, 1998.* Fluor Daniel Hanford, Inc., Richland, Washington.

HNF-IP-1289, Rev. 1. 1998. *324/327 Buildings Stabilization/Deactivation Project, Project Management Plan.* B&W Hanford Company, Richland, Washington.

HNF-MP-003. 1997. *Integrated Environment, Safety and Health Management System Plan.* Fluor Daniel Hanford, Inc., Richland, Washington.

HNF-SD-WM-BIO-001, Rev. 1. 1998. *Tank Waste Remediation System Basis for Interim Operation.* Prepared by DE&S Hanford, Inc. for Lockheed Martin Hanford Corporation, Flour Daniel Hanford, Inc., Richland, Washington.

HNF-SP-0903, Rev. 5. 1998. *National Environmental Policy Act Source Guide for the Hanford Site.* Flour Daniel Hanford, Inc., Richland, Washington.

ISO 14001. 1996. *Environmental Management Systems—Specifications with Guidance for Use.* American Society for Testing and Materials, West Conshohocken, Pennsylvania.

Memorandum of Agreement. 1996. *Memorandum of Agreement Among the United States Department of Energy, United States Department of the Interior, Nez Perce Tribe, State of Oregon, Confederated Tribes of the Umatilla Indian Reservation, State of Washington (including the Departments of Ecology and fish and Wildlife), and the Confederated Tribes and Bands of the Yakama Indian Nation.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Memorandum of Understanding. 1994. "Memorandum of Understanding for the Establishment of a Federal Interagency Committee for the Management of Noxious and Exotic Weeds." G. Buntrock, S. W. Goodman, R. E. Slater, and T. O'Toole, U.S. Department of Agriculture, U.S. Department of Defense, U.S. Department of Transportation, and U.S. Department of Energy, Washington, D.C.

National Environmental Policy Act. 1969. Public Laws 91-190, as amended, 42 USC 4321 et seq.

National Historic Preservation Act. 1966. Public Law 89-665, as amended, 80 Stat. 915-919.

National Park Service. 1994. *Hanford Reach of the Columbia River: Comprehensive River Conservation Study and Final Environmental Impact Statement.* U.S. Department of the Interior, Washington, D.C.

Native American Graves Protection and Repatriation Act. 1990. Public Law 101-601, as amended, 25 USC 3001 et seq.

PNNL-6415, Rev. 10. 1998. *Hanford Site National Environmental Policy Act (NEPA) Characterization.* D. A. Neitzel (ed.), and C. J. Fosmire, R. A. Fowler, S. M. Goodwin, D. W. Harvey, P. L. Hendrickson, D. J. Hoitink, T. M. Poston, A. C. Rohay, P. D. Thorne, and M. K. Wright, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-11311. 1997. *Accidental Spill Prevention Plan for the Environmental Molecular Sciences Laboratory (EMSL).* B. P. Atencio, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-11795. 1998. *Hanford Site Environmental Report for Calendar Year 1997.* R. L. Dirkes and R. W. Hanf (eds.), Pacific Northwest National Laboratory, Richland, Washington.

PNNL-11809. 1998. *Results of Phase I Groundwater Quality Assessment for Single-Shell Tank Waste Management Areas T and TX-TY at the Hanford Site.* F. N. Hodges, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-11957. 1998. *Immobilized Low-Activity Waste Site Borehole 299-E17-21.* S. P. Reidel, K. D. Reynolds, and D. G. Horton, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-11958, Rev. 1. 1998. *Proposal for Fiscal Year 1999 Vadose Zone Monitoring and Guidance for Subsequent Years for Liquid Waste Disposal Facilities.* D. G. Horton, S. P. Reidel, and G. V. Last, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-12124. 1999. *Borehole Data Package for 1998 Wells Installed at Single-Shell Tank Waste Management Area TX-TY.* D. G. Horton and F. N. Hodges, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-12125. 1999. *Borehole Data Package for 1998 Wells Installed at Single-Shell Tank Waste Management Area T.* D. G. Horton and F. N. Hodges, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-12126. 1999. *Borehole Data Package for 1998 Wells Installed at Single-Shell Tank Waste Management Area U.* D. G. Horton and F. N. Hodges, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-12127. 1999. *Borehole Data Package for 216-U-12 Crib Well 299-W22-79.* D. G. Horton and B. A. Williams, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-12128. 1999. *Borehole Data Package for Well 299-E33-44 at Single-Shell Tank Waste Management Area B-BX-BY.* D. G. Horton and S. M. Narbutovskih, Pacific Northwest National Laboratory, Richland, Washington.

Pollution Prevention Act. 1990. Public Law 101-508, as amended, 104 Stat. 1388-321, 41 USC 13101 et seq.

Record of Decision. 1996. *Declaration of the Record of Decision, USDOE Hanford 100 Areas, 100-HR-3 and 100-KR-4 Operable Units, Hanford Site, Benton County, Washington, April 1996.* State of Washington Department of Ecology, U.S. Environmental Protection Agency, and U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Resource Conservation and Recovery Act. 1976. Public Law 94-580, as amended, 90 Stat. 2795, 42 USC 6901 et seq.

Revised Code of Washington (RCW) 15.58. *Washington Pesticide Control Act.*

Revised Code of Washington (RCW) 17.21. *Washington Pesticide Application Act.*

Revised Code of Washington (RCW) 70.94. *Washington Clean Air Act.*

RHO-RE-PL-23. 1984. *Scintillation Logging Plan for Monitoring Inactive Cribs.* G. V. Last, K. R. Fecht, and M. A. Chamness, Rockwell Hanford Operations, Richland, Washington.

Safe Drinking Water Act. 1974. Public Law 93-523, as amended, 88 Stat. 1660, 42 USC 300f et seq.

Safe Drinking Water Act Amendments of 1986. 1986. Public Law 99-339, as amended, Stat. 666, 42 USC 300f et seq.

Safe Drinking Water Act Amendments of 1996. 1996. Public Law 104-182, as amended, Stat. 1613, 42 USC 300f et seq.

Superfund Amendments and Reauthorization Act. 1986. Public Law 99-499, as amended, 100 Stat. 1613 42 USC 11001 et seq.

Toxic Substances Control Act. 1976. Public Law 94-469, as amended, 90 Stat. 2003, 15 USC 2601 et seq.

Washington Administrative Code (WAC) 16-228. "Pesticide Regulations." Olympia, Washington.

Washington Administrative Code (WAC) 173-216. "State Waste Discharge Program." Olympia, Washington.

Washington Administrative Code (WAC) 173-218. "Underground Injection Control Program." Olympia, Washington.

Washington Administrative Code (WAC) 173-303. "Dangerous Waste Regulations." Olympia, Washington.

Washington Administrative Code (WAC) 173-303-170. "Requirements for Generators of Dangerous Waste." Olympia, Washington.

Washington Administrative Code (WAC) 173-303-400. "Interim Status Facility Standards." Olympia, Washington.

Washington Administrative Code (WAC) 173-303-645. "Releases from Regulated Units." Olympia, Washington.

Washington Administrative Code (WAC) 173-303-802. "Permits by Rule." Olympia, Washington.

Washington Administrative Code (WAC) 173-360. "Underground Storage Tank Regulations." Olympia, Washington.

Washington Administrative Code (WAC) 173-400. "General Regulations for Air Pollution Sources." Olympia, Washington.

Washington Administrative Code (WAC) 173-401. "Operating Permit Regulation." Olympia, Washington.

Washington Administrative Code (WAC) 173-460. "Controls for New Sources of Toxic Air Pollutants." Olympia, Washington.

Washington Administrative Code (WAC) 197-11. "SEPA Rules." Olympia, Washington.

Washington Administrative Code (WAC) 246-247. "Radiation Protection–Air Emissions." Olympia, Washington.

Washington Administrative Code (WAC) 246-290. "Group A Public Water Supplies." Olympia, Washington.

Washington State Department of Ecology (Ecology), U.S. Environmental Protection Agency (EPA), and U.S. Department of Energy (DOE). 1989. *Hanford Federal Facility Agreement and Consent Order Between the U.S. Environmental Protection Agency, the U.S. Department of Energy, and the State of Washington Department of Ecology, May 15, 1989*, as amended. Olympia, Seattle, and Richland, Washington.

Washington State Department of Ecology (Ecology), U.S. Department of Energy (DOE), and U.S. Environmental Protection Agency (EPA). 1997. *Community Relations Plan for the Hanford Federal Facility Agreement and Consent Order*. Olympia, Richland, and Seattle, Washington.

Washington State Department of Fish and Wildlife. 1996. *Priority Habitats and Species List*. Olympia, Washington. Available URL: http://www.wa.gov/wdfw/hab/phspage.htm

WHC-EP-0691. 1994. *Ferrocyanide Safety Program: Safety Criteria for Ferrocyanide Watch List Tanks*. A. K. Postma, J. E. Meacham, G. S. Barney, G. L. Borsheim, R. J. Cash, M. D. Crippen, D. R. Dickinson, J. M. Grigsby, D. W. Jeppson, M. Kummerer, J. M. McLaren, C. S. Simmons, and B. C. Simpson, Westinghouse Hanford Company, Richland, Washington.

WHC-EP-0823. 1994. *Synthetic Waste Chemical Mechanisms Studies*. E. C. Ashby, A. Annis, E. K. Barefield, D. Boatright, F. Doctorovich, C. L. Liotta, H. M. Neuman, A. Konda, C. F. Yao, K. Zhang, and N. G. McDuffie, Westinghouse Hanford Company, Richland, Washington.

WHC-EP-0899-1. 1996. *Solubilities of Significant Organic Compounds in HLW Tank Supernate Solutions - FY 1996 Progress Report*. G. S. Barney, Westinghouse Hanford Company, Richland, Washington.

WHC-SD-WM-ER-496. 1995. *The Contact-Temperature Ignition (CTI) Criteria for Propagating Chemical Reactions Including the Effect of Moisture and Application to Hanford Waste*. H. K. Fauske, M. Epstein, D. R. Dickinson, R. J. Cash, D. A. Turner, and J. E. Meacham, Westinghouse Hanford Company, Richland, Washington.

WHC-SD-WM-SARR-001. 1994. *Safety Analysis of Exothermic Reaction Hazards Associated with the Organic Liquid Layer in Tank 241-C-103*. A. K. Postma, D. B. Bechtold, G. L. Borsheim, J. M. Grigsby, R. L. Guthrie, M. Kummerer, M. G. Plys, and D. A. Turner, Westinghouse Hanford Company, Richland, Washington.

WHC-SD-WM-SARR-003. 1994. *High-Level Waste Tank Subcriticality Safety Assessment*. D. J. Braun and S. A. Szendre, Westinghouse Hanford Company, Richland, Washington.

WHC-SD-WM-SARR-033, Rev. 1. 1996. *Safety Criteria for the Organic Watch List Tanks at the Hanford Site*. J. E. Meacham, A. B. Webb, M. G. Plys, S. J. Lee, J. M. Grigsby, P. G. Heasler, J. L. Bryant, J. J. Toth, and P. M. Daling, Westinghouse Hanford Company, Richland, Washington.

WHC-SD-WM-SARR-038, Rev. 1. 1996. *Assessment of the Potential for Ferrocyanide Propagating Reaction Accidents*. J. E. Meacham, R. J. Cash, D. R. Dickinson, F. R. Reich, J. M. Grigsby, A. K. Postma, and M. A. Lilga, Westinghouse Hanford Company, Richland, Washington.

WHC-SD-WM-TI-725. 1996. *Tank Farm Nuclear Criticality Review*. D. R. Bratzel, W. W. Schulz, R. Vornehm, A. E. Waltar, H. Babad, G. S. Barney, J. Greenborg, L. H. Rodgers, R. E. Felt, D. W. Jeppson, C. A. Rogers, K. N. Schwinkendorf, T. S. Vail, R. J. Serne, and G. A. Whyatt, Westinghouse Hanford Company, Richland, Washington.

3.0 Facility-Related Monitoring

The following sections include information about facility-related environmental monitoring programs at the Hanford Site, including effluent monitoring (Section 3.1) and environmental monitoring (Section 3.2).

The monitoring of effluents and contaminants at Hanford Site facilities is necessary to determine the effects these materials may have on the public, workers at the site, and the environment. Effluent monitoring is conducted by the various site contractors at their facilities pursuant to requirements in DOE Order 5400.1. At the Hanford Site, effluent monitoring includes 1) collection of samples for analyses, 2) measurements of liquid and airborne effluents for the purposes of characterizing and quantifying contaminants released to the environment, 3) providing source terms for assessing potential impacts to the public, 4) providing a means to control effluents at or near the point of discharge, and 5) determining compliance with applicable standards and permit requirements.

Near-facility environmental monitoring consists of the routine monitoring of environmental media near facilities that have the potential to discharge or have discharged, stored, or disposed of radioactive or hazardous contaminants. Monitoring locations are generally associated with major, nuclear-related installations, waste storage and disposal units, and remediation efforts.

Additional program sampling and effluent information is contained in *Hanford Site Near-Facility Environmental Monitoring Data Report for Calendar Year 1998* (PNNL-12088, APP. 2) and in *Environmental Releases for Calendar Year 1998* (HNF-EP-0527-8).

3.1 Facility Effluent Monitoring

L. P. Diediker

Liquid and airborne effluents that may contain radioactive or hazardous constituents are continually monitored when released to the environment at the Hanford Site. Facility operators perform the monitoring mainly through analyzing samples collected near points of release into the environment. Effluent monitoring data are evaluated to determine the degree of regulatory compliance for each facility or the entire site, as appropriate. The evaluations are also useful in assessing the effectiveness of effluent treatment and control systems and management practices. Major facilities have their own individual effluent monitoring plans, which are part of the comprehensive Hanford Site environmental monitoring plan (DOE/RL-91-50, Rev. 2).

Measuring devices quantify most facility effluent flows, but some flows are calculated using process information. Effluent sampling methods include continuous sampling or periodic confirmatory measurements for most radioactive air emission units and proportional or grab sampling for most liquid effluent streams. Liquid and airborne effluents with a potential to contain radioactive materials at prescribed threshold levels are measured for gross alpha and beta activity and, as warranted, specific radionuclides. Nonradioactive constituents are also either monitored or sampled, as applicable.

Small quantities of tritium, cobalt-60, strontium-90, technetium-99, antimony-125, iodine-129, cesium-137, plutonium-238, plutonium-239,240, plutonium-241, and americium-241 were released to the environment through state and federally permitted release points. However, most radionuclides in effluents at the site are approaching levels indistinguishable from background or naturally occurring activities. The site mission of environmental cleanup is largely responsible for the improved trend in radioactive emissions. This decreasing trend results in smaller offsite radiation doses to the maximally exposed individual attributable to site activities. Figures 3.1.1 and 3.1.2 depict quantities of several prominent dose-contributing radionuclides released from the site over recent years. In 1998, releases of radioactive and nonradioactive constituents in effluents were less than applicable standards.

Effluent release data are documented in several reports, in addition to this one, and all are available to the public. For instance, the U.S. Department of Energy (DOE) annually submits to the U.S. Environmental Protection Agency (EPA) and the Washington State Department of Health a report of radioactive airborne emissions from the site (DOE/RL-99-41) in compliance with Title 40, Code of Federal Regulations, Part 61 (40 CFR 61), "National Emission Standards for Hazardous Air Pollutants," and Washington Administrative Code (WAC) 246-247, "Radiation Protection–Air Emissions." Data quantifying the radioactive liquid and airborne effluents are reported to DOE annually in the environmental releases report (HNF-EP-0527-8). Monitoring results for liquid streams regulated by the National Pollutant Discharge Elimination System permit (40 CFR 122) are reported to EPA. Monitoring results from liquid effluent streams regulated by WAC 173-216 are reported to the Washington State Department of Ecology. Nonradioactive air emissions are reported annually to the Washington State Department of Ecology.

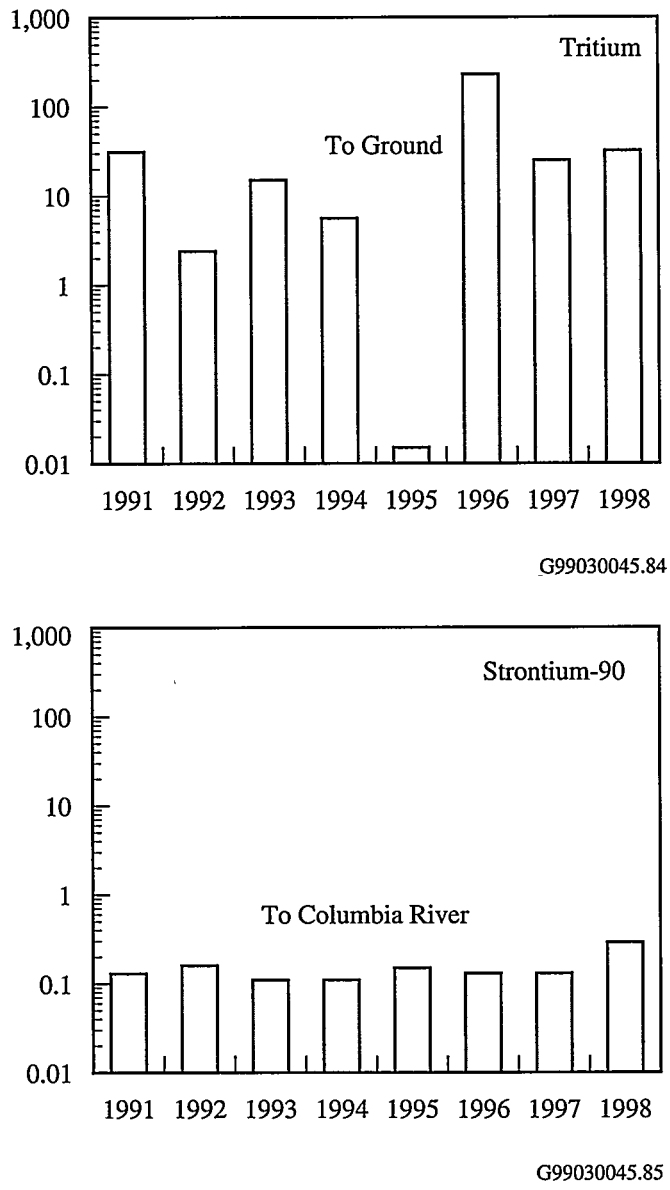


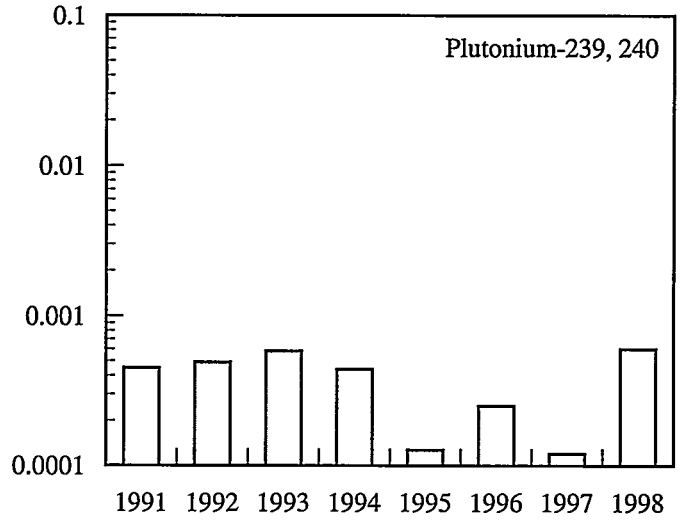
Figure 3.1.1. Liquid Releases of Selected Radionuclides from Hanford Site Facilities, 1991 Through 1998

3.1.1 Airborne Emissions

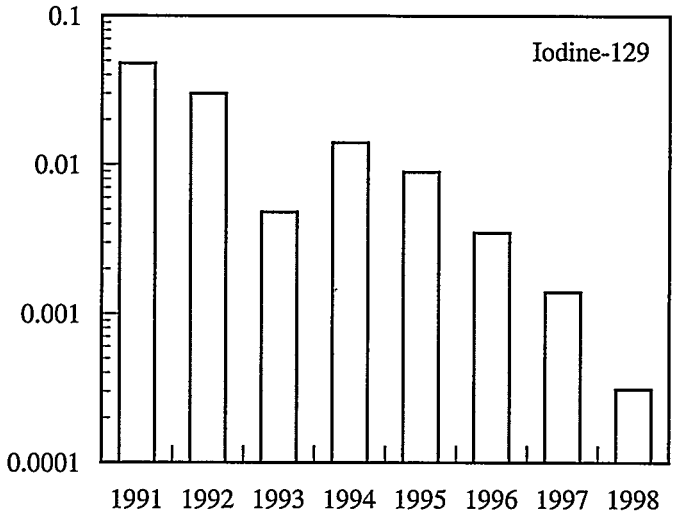
3.1.1.1 Radioactive Airborne Emissions

Radioactive airborne emissions from site activities contain at least one of these forms of radionuclides: particles, noble gases, or volatile compounds. Emissions having the potential to exceed 1% of the 10-mrem/yr standard for offsite doses are monitored continuously.

The continuous monitoring of radioactive emissions involves analyzing samples collected at points of discharge to the environment, usually from a stack or vent. Samples are analyzed for gross alpha and beta



G99030045.86



G99030045.87

Figure 3.1.2. Airborne Releases of Selected Radionuclides from Hanford Site Facilities, 1991 Through 1998

activity, as well as selected radionuclides. The selection of the specific radionuclides sampled, analyzed, and reported is based on 1) an evaluation of maximum potential unmitigated emissions expected from known radionuclide inventories in a facility or activity area, 2) the sampling criteria given in contractor environmental compliance manuals, and 3) the potential each radionuclide has to contribute to the offsite public dose. Continuous air monitoring systems with alarms are also used at selected discharge points, when a potential exists for radioactive emissions to exceed normal operating ranges by levels requiring immediate personnel alert.

Radioactive emission discharge points are located in the 100, 200, 300, and 400 Areas. The sources for these emissions are summarized below.

- In the 100 Areas, emissions resulted from the deactivation of N Reactor, the two water-filled storage basins (K-East and K-West Fuel Storage Basins [K Basins]) that contain irradiated fuel, a recirculation facility that filtered radioactive water from the N Reactor basin that was used for storage of irradiated fuel, and from sample preparation activities at the radiological counting facility. Five radioactive emission points were active in the 100 Areas during 1998; however, the last two stacks operating at N Reactor were permanently shut down following the completion of the N Basin project (see Section 2.3.12.3, "100-N Area Project").
- The 200 Areas contain inactive facilities for nuclear fuel chemical separations, reprocessing, and steam generation. The active facilities are for waste handling and disposal. Primary sources of radionuclide emissions are the Plutonium-Uranium Extraction Plant, Plutonium Finishing Plant, T Plant, 222-S Laboratory, underground tanks for storage of high-level radioactive waste, and waste evaporators. During 1998, 54 radioactive emission points were active in the 200 Areas.
- The 300 Area primarily contains laboratories and research facilities. Primary sources of airborne radionuclide emissions are the 324 Waste Technology Engineering Laboratory, 325 Applied Chemistry Laboratory, 327 Post-Irradiation Laboratory, and 340 Vault and Tanks. Radioactive emissions arise from research and development and waste handling activities. During 1998, 27 radioactive emission discharge points were active in the 300 Area.
- The 400 Area has the Fast Flux Test Facility, the Maintenance and Storage Facility, and the Fuels and Materials Examination Facility. Operations and support activities at the Fast Flux Test Facility and Maintenance and Storage Facility released small quantities of radioactive material to the environment, even though the reactor did not operate in 1998. The 400 Area had five radioactive emission discharge points active during 1998.

A summary of the Hanford Site's 1998 radioactive airborne emissions is provided in Table 3.1.1. Several constituents not detected or not measured are included in the table for historical comparisons.

3.1.1.2 Nonradioactive Airborne Emissions

Nonradioactive air pollutants emitted from power generating and chemical processing facilities are monitored when activities at a facility are known to generate potential pollutants of concern.

In past years, gaseous ammonia has been emitted from the Plutonium-Uranium Extraction Plant, 242-A Evaporator, 241-AP Tank Farm, and 241-AW Tank Farm all located in the 200-East Area. Ammonia emissions are monitored only when activities at these facilities are capable of generating them. The 200 Areas tank farms produced reportable ammonia emissions in 1998, which are summarized in Table 3.1.2.

Onsite, diesel-powered, electrical generating plants emitted particulate matter, sulfur oxides, nitrogen oxides, volatile organic compounds, carbon monoxide, and lead. The total annual releases of these constituents are reported in accordance with the air quality standards established in WAC 173-400. Power plant emissions are calculated from the quantities of fuel consumed, using EPA-approved formula (AP-42).

Should activities lead to chemical emissions in excess of quantities reportable under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), the release totals are reported immediately to the EPA. If the emissions remain stable at predicted levels, they may be reported annually with the EPA's permission. Table 3.1.2 summarized the 1998 emissions of nonradioactive constituents (it should be noted that the 100, 400, and 600 Areas have no nonradioactive emission sources of regulatory concern). Table 3.1.2 also included emissions estimates from the 200-West Area's carbon tetrachloride vapor extraction project, even though these emissions do not require reporting because they are below reportable quantities.

Table 3.1.1. Radionuclides Discharged to the Atmosphere, 1998

Radionuclide	Half-Life	Release, Ci[a]				
		100 Areas	200-East Area	200-West Area	300 Area	400 Area
Tritium (as HT)[b]	12.3 yr	NM[a]	NM	NM	1.1×10^{2}	NM
Tritium (as HTO)[b]	12.3 yr	NM	NM	NM	1.71×10^{2}	4.0×10^{0}
Cobalt-60	5.3 yr	ND[a]	ND	ND	ND	NM
Zinc-65	244.4 d	ND	ND	ND	ND	NM
Strontium-90	29.1 yr	1.7×10^{-5}	1.2×10^{-4}[c]	2.3×10^{-4}[c]	9.62×10^{-6}[c]	NM
Zirconium-95	64.02 d	ND	ND	ND	ND	NM
Ruthenium-106	368 d	ND	ND	NM	ND	NM
Tin-113	115.1 d	ND	ND	NM	ND	NM
Antimony-125	2.77 yr	ND	4.8×10^{-7}	NM	ND	NM
Iodine-129	1.6×10^{7} yr	NM	3.1×10^{-4}	NM	4.6×10^{-8}	NM
Cesium-134	2.1 yr	ND	ND	ND	ND	NM
Cesium-137	30 yr	3.0×10^{-5}	1.9×10^{-4}	3.2×10^{-9}	5.83×10^{-7}	5.5×10^{-6}[d]
Plutonium-238	87.7 yr	5.2×10^{-7}	7.9×10^{-10}	3.4×10^{-6}	1.7×10^{-9}	NM
Plutonium-239,240	2.4×10^{4} yr	3.4×10^{-6}	1.1×10^{-6}[e]	2.0×10^{-4}[e]	1.07×10^{-6}[e]	5.0×10^{-7}[e]
Plutonium-241	14.4 yr	3.8×10^{-5}	2.9×10^{-8}	4.4×10^{-5}	NM	NM
Americium-241	432 yr	2.0×10^{-6}	5.0×10^{-7}	3.0×10^{-5}	2.27×10^{-8}	NM
Uranium	4.5×10^{9} yr	NM	NM	NM	ND	NM

(a) 1 Ci = 3.7×10^{10} Bq; NM = not measured; ND = not detected (i.e., either the radionuclide was not detected in any sample during the year or the average of all the measurements for that given radionuclide or type of radioactivity made during the year was below background levels).
(b) HT = elemental tritium; HTO = tritiated water vapor.
(c) This value includes gross beta release data. Gross beta and unspecified beta results assumed to be strontium-90 for dose calculations.
(d) This value includes gross beta release data. Gross beta results assumed to be cesium-137 for dose calculations from Fast Flux Test Facility emissions
(e) This value includes gross alpha release data. Gross alpha and unspecified alpha results assumed to be plutonium-239,240 for dose calculations.

3.1.2 Liquid Effluents

3.1.2.1 Radioactive Liquid Effluents

Liquid effluents are discharged from facilities in all areas of the Hanford Site. Effluents that normally or potentially contain radionuclides include cooling water, steam condensates, process condensates, and wastewater from laboratories and chemical sewers. These wastewater streams are sampled and analyzed for gross alpha and beta activity, as well as selected radionuclides.

In 1998, only 200 Areas' facilities discharged radioactive liquid effluents to the 616-A-Crib (also known as the State-Approved Land Disposal Site. A summary of these radioactive liquid effluents is provided in Table 3.1.3. Table 3.1.4 summarizes data on radionuclides in liquid effluents released from the 100 Areas to the Columbia River. These measurements are used to determine potential radiation doses to the public. Several constituents not detected are included in the tables for historical comparisons.

Table 3.1.2. Nonradioactive Constituents Discharged to the Atmosphere, 1998[a]

Constituent	Release, kg 200 Areas	Release, kg 300 Area
Particulate matter	6.27×10^{2}	3.26×10^{3}
Nitrogen oxides	3.89×10^{4}	1.21×10^{4}
Sulfur oxides	2.43×10^{2}	4.43×10^{4}
Carbon monoxide	2.97×10^{3}	1.98×10^{3}
Lead	3.7×10^{-1}	6.3×10^{0}
Volatile organic compounds[b]	1.32×10^{3}	1.13×10^{2}
Ammonia[c]	6.72×10^{3}	NM[d]
Beryllium	NE[d]	1.36×10^{-1}
Cadmium	NE	6.85×10^{0}
Carbon tetrachloride	8	NE
Chromium	NE	4.15×10^{0}
Cobalt	NE	3.93×10^{0}
Copper	NE	9.02×10^{0}
Formaldehyde	NE	1.13×10^{1}
Selenium	NE	1.23×10^{0}

(a) The estimate of volatile organic compound emissions do not include emissions from certain laboratory operations.
(b) Produced from burning fossil fuel for steam and electrical generators.
(c) Ammonia releases are from the 200-East and 200-West Area tank farms and operation of the 242-A Evaporator.
(d) NE = no emissions; NM = not measured.

3.1.2.2 Nonradioactive Hazardous Materials in Liquid Effluents

Nonradioactive hazardous materials in liquid effluents are monitored in the 100, 200, 300, and 400 Areas. These effluents are discharged to the State-Approved Land Disposal Site and the Columbia River. Effluents entering the environment at designated discharge points are sampled and analyzed to determine compliance with the National Pollutant Discharge Elimination System permits and the state waste discharge permits for the site (40 CFR 122 and WAC 173-216). Should chemicals in liquid effluents exceed quantities reportable under CERCLA, the release totals are reported immediately to the EPA. If emissions remain stable at predicted levels, they may be reported annually with the EPA's permission. A synopsis of the National Pollutant Discharge Elimination System and state waste discharge permit violations in 1998 is given in Section 2.2.7, "Clean Water Act."

Liquid effluents containing both radioactive and hazardous constituents are stored in the 200 Areas in underground waste storage tanks or monitored interim-storage facilities. Activities in the 600 Area and former 1100 Area generated neither radioactive nor nonradioactive hazardous liquid effluents.

Table 3.1.3. Radionuclides in 200 Areas' Liquid Effluents Discharged to the State-Approved Land Disposal Site in 1998

Radionuclide	Half-Life	Release, Ci[a]
Tritium	12.3 yr	3.2×10^{1}
Strontium-90	29.1 yr	5.9×10^{-5}
Technetium-99	2.6×10^{6} yr	2.8×10^{-5}
Radium-226	1,600 yr	6.7×10^{-7}
Neptunium-237	2.14×10^{6} yr	1.0×10^{-5}
Plutonium-238	87.7 yr	1.3×10^{-5}
Plutonium-239,240	2.4×10^{4} yr	1.2×10^{-5}
Americium-241	432 yr	1.6×10^{-5}

(a) 1 Ci = 3.7×10^{10} Bq.
All other radionuclides are not detected.

Table 3.1.4. Radionuclides in 100 Areas' Liquid Effluents Discharged to the Columbia River, 1998

Radionuclide	Half-Life	Release, Ci[a]
Tritium	12.3 yr	0.29
Strontium-90	29.1 yr	0.29
Plutonium-239,240	2.4×10^{4} yr	1.3×10^{-6}
Americium-241	432 yr	1.7×10^{-5}

(a) 1 Ci = 3.7×10^{10} Bq.

3.1.3 CERCLA and Washington Administrative Code Chemical Releases

Reportable releases include spills or discharges of hazardous substances or dangerous wastes to the environment, other than releases permitted under federal or state law. These releases almost entirely consist of accidental spills. Releases of hazardous substances exceeding specified quantities that are continuous and stable in quantity and rate must be reported as required by Section 103(f)(2) of CERCLA.

Spills or nonpermitted discharges of dangerous wastes or hazardous substances to the environment are required to be reported (WAC 173-303-145). This requirement applies to spills or discharges onto the ground, into groundwater, into surface water, or into air such that human health or the environment is threatened, regardless of the quantity of dangerous waste or hazardous substance.

There were five releases reported under the Act's reportable quantity or WAC 173-303-145 requirements by Hanford Site contractors in 1998. Table 3.1.5 contains a synopsis of these reportable releases pursuant to these regulations.

Table 3.1.5. Reportable Spills, 1998

Material	Quantity	Location
Oil	0.10 kg (0.22 lb)	2721-Z Building, 200-West Area, old leak from Tank 2721-Z1
Radioactive air	Trace	AN Tank Farm, 200-East Area, overpressurized 208-L (55-gal) drum
Radioactive water	Trace	SX Tank Farm, 200-West Area, splashed out of pit during cleaning
Volatile organic compounds	>50 ppm	C Tank Farm, 200-East Area, volatile organic chemical vapor vented
Radioactive water	2,304 kg (5,080 lb)	327 Building, 300 Area, broken fire line

3.2 Near-Facility Environmental Monitoring

C. J. Perkins, A. R. Johnson, B. M. Markes, S. M. McKinney, R. M. Mitchell, and R. C. Roos

Near-facility (near-field) environmental monitoring is defined as routine monitoring near facilities that have potential to discharge, or have discharged, stored, or disposed of radioactive or hazardous contaminants. Monitoring locations are associated with nuclear facilities such as tank farms and the K Basins; inactive nuclear facilities such as N Reactor and Plutonium-Uranium Extraction Plant; and waste storage or disposal facilities such as burial grounds, cribs, ditches, ponds, tank farms, and trenches.

Much of the monitoring program consists of collecting and analyzing environmental samples and methodically surveying areas near facilities releasing effluents and waste streams. The program is also designed to evaluate acquired analytical data, determine the effectiveness of facility effluent monitoring and controls, measure the adequacy of containment at waste disposal units, and detect and monitor unusual conditions. The program implements applicable portions of DOE Orders 5400.1, 5400.5, 5484.1, and 5820.2A; 10 CFR 835 and 40 CFR 61; and WAC 246-247.

Several types of environmental media are sampled, and various radiological and nonradiological measurements are taken near Hanford Site facilities to monitor the effectiveness of effluent treatment and control practices, diffuse source emissions, and contamination control in waste management and restoration activities. These include air, surface and spring water, surface contamination, soil and vegetation, external radiation, and investigative samples (which can include wildlife). Samples are collected from known or expected effluent pathways. These pathways are generally downwind of potential or actual airborne releases and downgradient of liquid discharges.

Active and inactive waste disposal sites and the terrain surrounding them are surveyed to detect and characterize radioactive surface contamination. Routine survey locations include cribs, trenches, retention basin perimeters, pond perimeters, ditch banks, solid waste disposal sites (e.g., burial grounds), unplanned release sites, tank farm perimeters, stabilized waste disposal sites, roads, and firebreaks in and around the site operational areas.

Sampling and analysis information and analytical results for 1998 are summarized below. Additional data may be found in *Hanford Site Near-Facility Environmental Monitoring Data Report for Calendar Year 1998* (PNNL-12088, APP. 2). The routine activities of near-facility monitoring in 1998 are summarized in Table 3.2.1, which shows the type, quantity, and general location of samples collected.

3.2.1 Air Monitoring

Monitoring for radioactivity in air near Hanford Site facilities used a network of continuously operating samplers at 71 locations (Table 3.2.2) (sampling locations illustrated in PNNL-12088, APP. 2). Air samplers were located primarily at or within approximately 500 m [1,500 ft] of sites and/or facilities having the potential for, or history of, environmental releases, with an emphasis on the prevailing

Table 3.2.1. Near-Facility Routine Environmental Monitoring Samples and Locations, 1998

Sample Type	Number of Sample Locations	Operational Area								
		100-B,C	100-D,DR	100-K	100-F	100-N	ERDF[a]	200/ 600	300/ 400	TWRS[b]
Air	71	3	6	4	2	4	3	43[c]	6[d]	0
Water	12	0	0	0	0	10	0	2	0	0
External radiation	139	4	5	11	0	22	3	63	21	10
Soil	78	0	0	0	0	7	1	55	15	0
Vegetation	72	0	0	0	0	9	0	48	15	0

(a) Environmental Restoration Disposal Facility.
(b) Tank Waste Remediation System.
(c) Includes one station located at the Wye Barricade, 21 in the 200-East Area, and 21 in the 200-West Area.
(d) At the 300-FF-1 Operable Unit north of the 300 Area.

downwind direction. To avoid duplication of sampling, air data for the 300 and 400 Areas, some onsite remediation projects, and some offsite distant locations were obtained from existing Pacific Northwest National Laboratory air samplers.

Samples were collected according to a schedule established before the monitoring year. Airborne particles were sampled at each of these stations by drawing air through a glass-fiber filter. The filters were collected biweekly, field surveyed for gross radioactivity, held for at least 7 d, and then analyzed for gross alpha and beta activity. The 7-d holding period was necessary to allow for the decay of naturally occurring radionuclides that would otherwise obscure detection of longer-lived radionuclides associated with emissions from nuclear facilities. The gross radioactivity measurements were used to indicate changes in trends in the near-facility environment.

For most specific radionuclide analyses, the amount of radioactive material collected on a single filter during a 2-wk sampling period was too small to be measured accurately. The accuracy of the sample analysis was increased by compositing the samples into biannual samples for each location.

Figure 3.2.1 shows average values for 1998 and the preceding 5 yr for selected radionuclides in the 100 and 200 Areas compared to the DOE derived concentration guides and background air activity measured in distant communities. The DOE derived concentration guides (DOE Order 5400.5) are reference values that are used as indexes of performance. The data indicate a large degree of variability. Air samples collected from areas located at or directly adjacent to Hanford Site facilities had higher activities than did those samples collected farther away. In general, analytical results in all areas were at or near Hanford Site background activities for most radionuclides and much less than the DOE derived concentration guides. The data also show that activities of certain radionuclides were higher within different operational areas. For the radionuclides of interest, operational area and project-specific annual averages for 1998, with their corresponding maximum values, are shown in Table 3.2.3. The remedial action, interim safe storage, and surveillance and maintenance/transition projects listed below are described in more detail in Section 2.3.12, "Environmental Restoration Project."

The 1998 analytical results for the 100-B,C and D remedial action projects indicated that activities

Table 3.2.2. Near-Facility Air Sampling Locations and Analyses, 1998

Site	Number of Samplers	EDP Code[a]	Analyses: Biweekly	Analyses: Composite
100-B,C remedial action project	3	N464, N465, N466	Gross alpha, gross beta	GEA, Sr-90, Pu-iso, U-iso
100-D remedial action project	4	N467, N468, N469, N470	Gross alpha, gross beta	GEA, Sr-90, Pu-iso, U-iso
100-DR interim safe storage project	2	N492, N493	Gross alpha, gross beta	GEA, Sr-90, Pu-iso, U-iso
100-F interim safe storage project	2	N494, N495	Gross alpha, gross beta	GEA, Sr-90, Pu-iso, U-iso
100-K spent nuclear fuels	4	N401, N402, N403, N404	Gross alpha, gross beta	GEA, Sr-90, Pu-iso, U-iso, Pu-241, Am-241
100-N surveillance and maintenance/transition	4	N102, N103, N105, N106	Gross alpha, gross beta	GEA, Sr-90, Pu-iso, U-iso
200-East Area	19	N019, N158, N498, N499, N950, N957, N967, N968, N969, N970, N972, N973, N976, N977, N978, N984, N985, N998, N999	Gross alpha, gross beta	GEA,[b] Sr-90, Pu-iso,[c] U-iso[d]
Canister Storage Building, 200-East Area	2	N480, N481	Gross alpha, gross beta	GEA, Sr-90, Pu-iso, U-iso, Pu-241, Am-241
200-West Area	21	N155, N161, N165, N168, N200, N304, N433, N441, N442, N449, N456, N457, N956, N963, N964, N965, N966, N974, N975, N987, N994	Gross alpha, gross beta	GEA, Sr-90, Pu-iso, U-iso
300-FF-1 remedial action project	6	N130, N485, N486, N487, N488, N489	Gross alpha, gross beta	GEA, U-iso
600 Area	1	N981	Gross alpha, gross beta	GEA, Sr-90, Pu-iso, U-iso
Environmental Restoration Disposal Facility	3	N482, N483, N484	Gross alpha, gross beta	GEA, Sr-90, Pu-iso, U-iso

(a) EDP Code = sampler location code. See PNNL-12088, APP. 2.
(b) GEA = gamma energy analysis.
(c) Isotopic plutonium-238 and -239,240.
(d) Isotopic uranium-234, -235, and -238.

were only slightly greater than levels measured off the site. At the 100-B,C project, ambient air monitoring locations included one upwind Pacific Northwest National Laboratory sampler at the Yakima Barricade and three project-specific downwind samplers. At the 100-D project, ambient air monitoring locations included four project-specific samplers, one upwind and three downwind. Consistently detectable radionuclides were cesium-137 and uranium-234, -235, and -238. Occasionally detectable radionuclides were strontium-90 and plutonium-239,240.

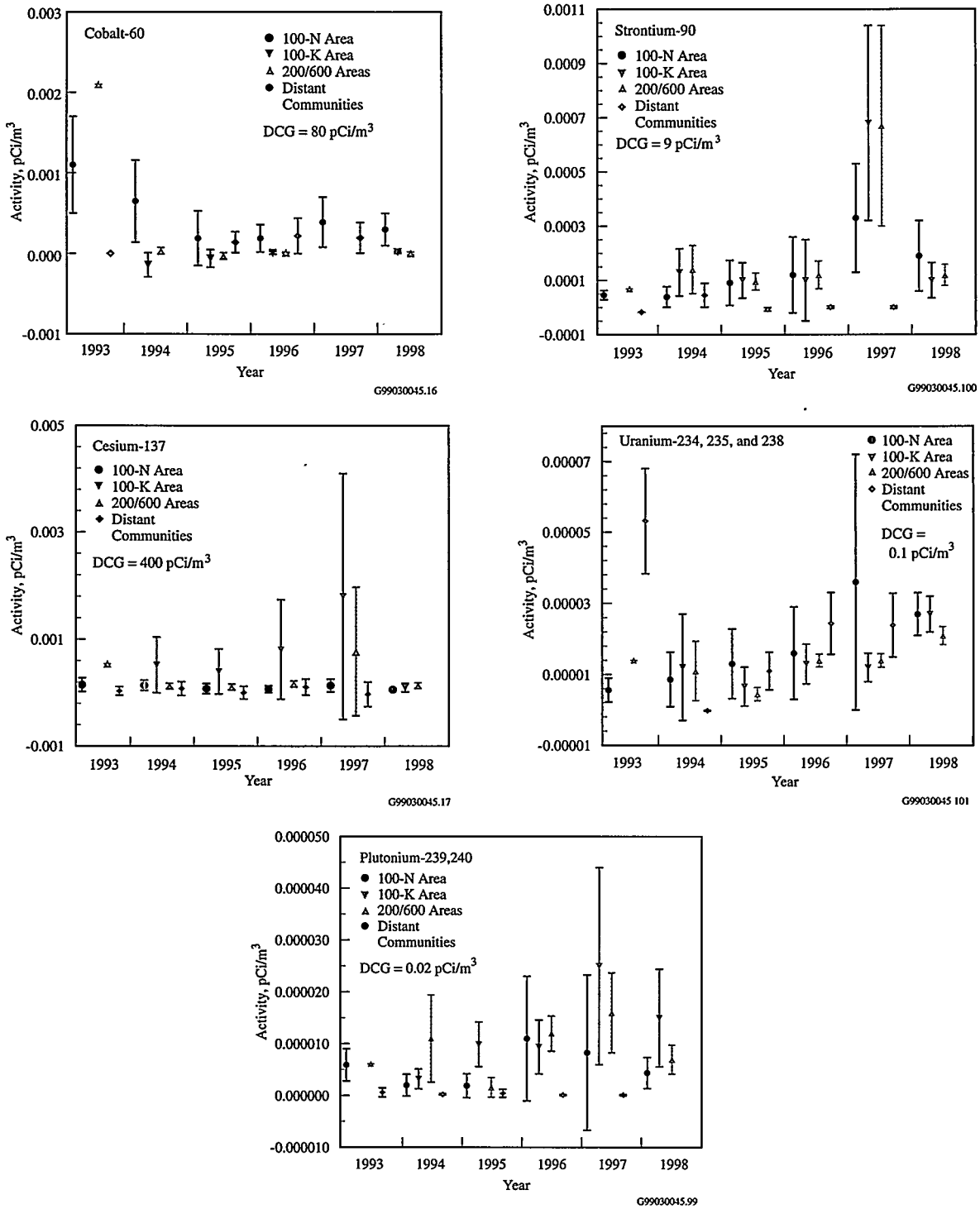


Figure 3.2.1. Average Activities (±2 standard error of the mean) of Selected Radionuclides in Near-Facility Air Samples Compared to Those in Distant Communities, 1993 Through 1998. As a result of figure scale, some uncertainties (error bars) are concealed by point symbol. Cobalt-60 was not detected in the 100-K Area in 1998. DCG = Derived concentration guide (DOE Order 5400.5).

Table 3.2.3. Annual Average and Maximum Activities (aCi/m^3) of Radionuclides in Near-Facility Air Samples, 1998

Cobalt-60

Site	Average[a]	Maximum[b]	EDP Code[c]
100-B,C	23 ± 32	79 ± 77	N464
100-D	24 ± 18	72 ± 55	N467
100-F/DR	-44 ± 110	160 ± 500	N495
100-K	1.7 ± 12	44 ± 62	N402
100-N	280 ± 230	1,000 ± 140	N105
200-East	-8.3 ± 31	270 ± 430	N499
200-West	11 ± 10	58 ± 81	N441
300-FF-1	9.9 ± 19	76 ± 550	N489
ERDF[d]	-4.9 ± 29	40 ± 56	N484
Distant community[e]	196 ± 190	640 ± 490	
DCG[f]		80,000,000	

Strontium-90

Site	Average[a]	Maximum[b]	EDP Code[c]
100-B,C	87 ± 140	370 ± 210	N466
100-D	92 ± 110	400 ± 120	N467
100-F/DR	290 ± 310	890 ± 590	N495
100-K	100 ± 66	220 ± 99	N403
100-N	190 ± 130	480 ± 110	N105
200-East	190 ± 67	960 ± 190	N984
200-West	62 ± 33	140 ± 140	N161
300-FF-1	130 ± 200	230 ± 160	N130
ERDF[d]	150 ± 94	350 ± 110	N484
Distant community[e]	-5.28 ± 4.3	-3.1 ± 16	
DCG[f]		9,000,000	

Cesium-137

Site	Average[a]	Maximum[b]	EDP Code[c]
100-B,C	160 ± 89	370 ± 110	N464
100-D	82 ± 37	160 ± 80	N467
100-F/DR	-38 ± 160	170 ± 290	N494
100-K	97 ± 81	360 ± 130	N401
100-N	61 ± 25	100 ± 85	N102
200-East	190 ± 93	1,500 ± 610	N499
200-West	110 ± 40	33 ± 63	N965
300-FF-1	58 ± 130	480 ± 120	N130
ERDF[d]	220 ± 320	1,000 ± 200	N483
Distant community[e]	-27 ± 230	370 ± 700	
DCG[f]		400,000,000	

Uranium-234

Site	Average[a]	Maximum[b]	EDP Code[c]
100-B,C	26 ± 4.6	31 ± 13	N465
100-D	21 ± 2.9	26 ± 8.8	N470
100-F/DR	41 ± 7.4	52 ± 33	N494
100-K	38 ± 12	70 ± 13	N401
100-N	35 ± 11	55 ± 13	N106
200-East	27 ± 4.5	86 ± 48	N498
200-West	30 ± 7.1	12 ± 6.2	N441
300-FF-1	90 ± 29	190 ± 63	N487
ERDF[d]	32 ± 8.0	47 ± 13	N482
Distant community[e]	21 ± 0.70	21 ± 5.6	
DCG[f]		90,000	

Uranium-235

Site	Average[a]	Maximum[b]	EDP Code[c]
100-B,C	9.1 ± 4.6	18 ± 6.8	N464
100-D	9.9 ± 4.7	22 ± 10	N467
100-F/DR	23 ± 9.8	36 ± 35	N495
100-K	24 ± 8.0	41 ± 11	N401
100-N	15 ± 8.3	35 ± 15	N103
200-East	14 ± 3.5	53 ± 28	N480
200-West	15 ± 3.7	1.6 ± 5.6	N987
300-FF-1	24 ± 6.4	39 ± 33	N488
ERDF[d]	8.0 ± 1.9	11 ± 8.3	N483
Distant community[e]	0.15 ± 0.34	0.32 ± 1.1	
DCG[f]		100,000	

Uranium-238

Site	Average[a]	Maximum[b]	EDP Code[c]
100-B,C	22 ± 7.5	36 ± 12	N465
100-D	17 ± 4.4	23 ± 8.3	N468
100-F/DR	59 ± 19	89 ± 50	N495
100-K	20 ± 4.5	31 ± 8.4	N403
100-N	30 ± 13	58 ± 14	N106
200-East	22 ± 5.0	100 ± 58	N498
200-West	22 ± 8.0	2.7 ± 3.2	N956
300-FF-1	78 ± 29	180 ± 59	N487
ERDF[d]	30 ± 10	46 ± 13	N482
Distant community[e]	17 ± 0.10	17 ± 51	
DCG[f]		100,000	

Two samplers for each of the 100-F and DR interim safe storage projects began operating in August and November 1998, respectively. The analytical results from both projects indicated that the activities were only slightly greater than levels measured off the site. The only consistently detectable radionuclides were uranium-234, -235, and -238. Plutonium-239,240 was occasionally detectable.

The airborne contaminant levels in the 100-K Area were greater than levels measured off the site.

Table 3.2.3. (contd)

Plutonium-238

Site	Average[a]	Maximum[b]	EDP Code[c]
100-B,C	-3.4 ± 11	6.4 ± 7.0	N466
100-D	1.8 ± 2.6	7.4 ± 5.6	N467
100-F/DR	11 ± 6.7	24 ± 24	N493
100-K	-0.18 ± 6.0	13 ± 27	N401
100-N	-0.039 ± 3.1	9.6 ± 8.9	N103
200-East	3.6 ± 3.5	38 ± 61	N498
200-West	0.3 ± 1.3	9.8 ± 11	N956
300-FF-1	1.6 ± 5.9	4.5 ± 6.7	N130
ERDF[d]	5.8 ± 6.2	20 ± 14	N484
Distant community[e]	0.005 ± 0.16	0.09 ± 0.64	
DCG[f]		30,000	

Plutonium-239,240

Site	Average[a]	Maximum[b]	EDP Code[c]
100-B,C	8.6 ± 8.3	29 ± 9.6	N466
100-D	4.5 ± 3.6	16 ± 8.8	N468
100-F/DR	22 ± 10	42 ± 31	N495
100-K	15 ± 9.4	38 ± 21	N401
100-N	4.4 ± 3.0	13 ± 6.5	N105
200-East	4.8 ± 2.2	32 ± 30	N480
200-West	9.6 ± 4.8	0.76 ± 1.5	N456
300-FF-1	-0.02 ± 1.5	0.71 ± 7.1	N130
ERDF[d]	11 ± 8.9	30 ± 10	N484
Distant community[e]	-0.22 ± 0.16	-0.15 ± 0.43	
DCG[f]		20,000	

Plutonium-241

Site	Average[a]	Maximum[b]	EDP Code[c]
100-K	-19 ± 790	1,200 ± 1,400	N404
200-East	-3,000 ± 1,400	-2,300 ± -2,000	N481
200-West	1,100 ± 220	900 ± 450	N165
Distant community[e]		Not reported[g]	
DCG[f]		1,000,000	

Americium-241

Site	Average[a]	Maximum[b]	EDP Code[c]
100-K	28 ± 5.2	41 ± 16	N401
200-East	97 ± 46	120 ± 67	N481
200-West	27 ± 3.7	23 ± 17	N964
Distant community[e]		Not reported[g]	
DCG[f]		20,000	

(a) ±2 standard error of the mean.
(b) ± overall analytical error.
(c) Sampler location code. See PNNL-12088, APP. 2.
(d) ERDF = Environmental Restoration Disposal Facility.
(e) PNNL-11795.
(f) DOE derived concentration guide.
(g) Reported value less than its overall error, or less than zero, or no peak detected.

Facility emissions in the 100-K Area decreased substantially in 1996, and subsequent radionuclide activities seen in the ambient air samples have been near detection limits. Consistently detectable radionuclides were uranium-234, -235, and -238. Occasionally detectable radionuclides were strontium-90 and cesium-137.

Analytical results from ambient air samples taken from the 100-N Area were slightly greater than levels measured off the site. Consistently detectable radionuclides were cobalt-60 and uranium-234, -235, and -238. Occasionally detectable radionuclides were strontium-90, cesium-137, and plutonium-239,240.

Radionuclide levels measured in the 200 Areas were greater than those measured off the site. Consistently detectable radionuclides were cesium-137 and uranium-234, -235, and -238. Occasionally detectable radionuclides were strontium-90 and plutonium-239,240.

Through November 1998, samplers at the 300-FF-1 Operable Unit remedial action project

included one near-facility monitoring upwind location at the nearby 300 Area Treated Effluent Disposal Facility; two Pacific Northwest National Laboratory upwind monitors in the 300 Area (stations #14 "300 Trench" and #15 "300 NE;" see Section 4.1, "Air Surveillance"); and three downwind, project-specific air monitors. Beginning in December 1998, two additional downwind, project-specific samplers were deployed to support expanded remediation activities. The analytical results indicated that radionuclide activities in air samples collected at this site were much less than the DOE derived concentration guides and only slightly greater than levels measured off the site. The only consistently detectable radionuclides were uranium-234, -235, and -238. Cesium-137 was occasionally detectable.

The air sampling network at the Environmental Restoration Disposal Facility used two existing Hanford Site monitors for upwind monitoring and three additional air monitors that provided downwind coverage. The 1998 analytical results indicated that the activities were only slightly greater than levels measured off the site. The only consistently detectable radionuclides were uranium-234, -235, and -238. Occasionally detectable radionuclides were strontium-90, cesium-137, and plutonium-239,240.

A complete listing of the 1998 near-facility ambient air monitoring results can be found in PNNL-12088, APP. 2. Results for selected Pacific Northwest National Laboratory air samples are also reported in PNNL-12088, APP. 2, as well as in Section 4.1, "Air Surveillance."

3.2.2 Surface-Water Disposal Units and 100-N Area Riverbank Springs Monitoring

Two surface-water disposal units in the 200-East Area that received potentially radiologically contaminated effluents were sampled during 1998: the 200-East Area Powerhouse Ditch and the 216-B-3C Expansion Pond. Both radiological samples and nonradiological measurements (pH, nitrates) were obtained. In June 1998, the 200-East Area Powerhouse was deactivated and sampling for liquids was discontinued. In 1997, the effluent stream to the 216-B-3C Expansion Pond was rerouted to the 200 Areas Treated Effluent Disposal Facility and only aquatic vegetation and sediment samples were collected in 1998.

Other water samples were taken at riverbank springs in the 100-N Area. The sampling methods are discussed in detail in WMNW-CM-004. Samples were also collected from a small discharge pond in the 400 Area by Pacific Northwest National Laboratory. Analytical results for the 400 Area samples are reported in Section 4.2, "Surface Water and Sediment Surveillance," and are not discussed here.

All radiological analyses were performed onsite at the Waste Sampling and Characterization Facility near the 200-West Area in 1998. Radiological analyses of 200-East Area water samples included uranium, tritium, strontium-90, plutonium-238, plutonium-239,240, and gamma-emitting radionuclides. Radiological analyses of sediment and aquatic vegetation samples were performed for uranium, strontium-90, plutonium-239,240, and gamma-emitting radionuclides. Analyses for riverbank springs water included tritium, strontium-90, and gamma-emitting radionuclides. Nonradiological analyses were performed for pH, temperature, and nitrates. Analytes of interest were selected based on their presence in effluent discharges, their importance in verifying effluent control, and compliance with applicable effluent discharge standards.

The radiological results for liquid samples from the 200-East Area surface-water disposal unit are summarized in Table 3.2.4. In all cases, radionuclide levels were less than the DOE derived concentration guides.

Table 3.2.4. Radiological Results (pCi/L) for Liquid Samples from a Surface-Water Disposal Unit, 200 Areas, 1998

Sample Location	No. of Samples		^{3}H[a]	^{90}Sr	^{137}Cs	^{238}Pu	$^{239,240}Pu$	$^{Total}U$
200-East Area Powerhouse Ditch	6	Mean	ND[b]	2.5 ± 2.1	ND	0.36 ± 0.10	ND	0.13 ± 0.05
		Maximum	ND	2.5 ± 2.1	ND	0.36 ± 0.10	ND	0.46 ± 0.11
		DCG[c]	2,000,000	1,000	3,000	40	30	500[d]

(a) The detection limit for tritium was between 170 and 220 pCi/L. Samples were collected quarterly.
(b) ND = Not detected.
(c) DCG = DOE derived concentration guide (DOE Order 5400.5).
(d) Using uranium-234 as the most limiting DCG.

Radiological results for aquatic vegetation and sediment samples taken from the 200-East Area surface-water disposal units are summarized in Tables 3.2.5 and 3.2.6, respectively. Although there were some levels above background in both aquatic vegetation and sediment, all results were much less than the standards cited in the *Hanford Site Radiological Control Manual* (HSRCM-1, Rev. 2).

In the past, radioactive effluent streams sent to the 1301-N and 1325-N Liquid Waste Disposal Facilities in the 100-N Area contributed to the release of radionuclides to the Columbia River through their migration with the groundwater. Radionuclides from these facilities enter the Columbia River along the riverbank region sometimes called N Springs. The amount of radionuclides entering the river at these springs is calculated based on analyses of monthly samples collected from monitoring well 199-N-46 located near the shoreline. To verify releases, conservatively high radionuclide activities in samples collected from well 199-N-46 are multiplied by the estimated groundwater discharged into the river. The groundwater flow rate at these springs was estimated using a computer model developed by Gilmore et al. (PNL-8057). The estimated groundwater flow rate used to calculate 1998 releases from the springs was 43 L/min (11 gal/min). The results of the spring samples can then be compared to the activities measured in well 199-N-46 to ensure that activities in the well reflect the highest activities of radionuclides in the groundwater. A more detailed discussion of the release calculations may be found in HNF-EP-0527-8.

Groundwater springs and/or shoreline seepage wells along the 100-N Area shoreline are sampled annually to verify that the reported radionuclide releases to the Columbia River are conservative (i.e., not underreported). In September 1998, 10 samples were collected. At the time of sample collection, 3 of the 13 shoreline wells were dry, and no samples were collected at these locations. The shoreline seepage well samples were collected using a bailer, carefully lowered into each well water column to avoid sediment suspension, and a 4-L (1-gal) sample was obtained.

In 1998, the levels of tritium and strontium-90 detected in samples from riverbank springs were highest in N Springs well Y303, which is nearest well 199-N-46. Strontium-90 exceeded the DOE derived concentration guide value at well Y303, and the highest tritium level was also measured at this location, though it was well below its derived concentration guide value. The highest cobalt-60 levels, though very low, were from a location approximately 200 m (656 ft) downriver (northeast) of well

Table 3.2.5. Radiological Results (pCi/g, dry wt.)[a] for Aquatic Vegetation Samples from Surface-Water Disposal Units, 200 Areas, 1998

Sample Location	No. of Samples	^{90}Sr	^{137}Cs	$^{239,240}Pu$	^{234}U	^{235}U	^{238}U
216-B-3C Expansion Pond, 200-East Area	1	0.24 ± 0.12	36.0 ± 5.8	0.35 ± 0.06	0.44 ± 0.08	0.03 ± 0.01	0.36 ± 0.07
200-East Area Powerhouse Ditch	1	0.38 ± 0.15	ND[b]	ND	0.81 ± 0.14	0.06 ± 0.02	0.72 ± 0.12

(a) ± overall analytical error.
(b) ND = Not detected.

Table 3.2.6. Radiological Results (pCi/g, dry wt.)[a] for Sediment Samples from Surface-Water Disposal Units, 200 Areas, 1998

Sample Location	No. of Samples	^{90}Sr	^{137}Cs	$^{239,240}Pu$	^{234}U	^{235}U	^{238}U
216-B-3C Expansion Pond, 200-East Area	1	ND[b]	0.23 ± 0.09	ND	0.006 ± 0.005	0.006 ± 0.004	ND
200-East Area Powerhouse Ditch	1	ND	ND	ND	0.01 ± 0.005	0.003 ± 0.002	0.004 ± 0.003

(a) ± overall analytical error.
(b) ND = Not detected.

199-N-46. All of the riverbank springs activities were lower than those measured in well 199-N-46. The data from riverbank springs sampling are summarized in Table 3.2.7.

Nonradiological results for water samples taken from the 200-East Area surface-water disposal unit are summarized in Table 3.2.8. The results for pH were well within the standard of 2.0 to 12.5 for liquid effluent discharges based on the limits given in the Resource Conservation and Recovery Act of 1976. The analytical results for nitrates were all less than the 45-mg/L federal and state drinking water standards for public water supplies (40 CFR 141, WAC 246-249).

3.2.3 Radiological Surveys

Radiological surveys are used to monitor and detect contamination on the Hanford Site. The main types of posted radiologically controlled areas are underground radioactive materials, contamination areas, soil contamination areas, and high contamination areas.

Table 3.2.7. Radionuclide Activities (pCi/L) in 100-N Area Riverbank Springs, 1998

Radionuclide	Facility Effluent Monitoring Well 199-N-46[a]	Shoreline Springs Maximum[b]	Shoreline Springs Average[a]	DCG[c]
Tritium	16,000 ± 5,200	1,400 ± 364	540 ± 200	2,000,000
Cobalt-60	<-6.8 ± 5.7	<5.3 ± 4.6	<0.69 ± 1.8	5,000
Strontium-90	14,000 ± 2,100	1,900 ± 228	220 ± 370	1,000

(a) ±2 standard error of the mean.
(b) ± overall analytical error.
(c) DCG = DOE derived concentration guide (DOE Order 5400.5).

Table 3.2.8. Nonradiological Results for Water Samples from a Surface-Water Disposal Unit, 200 Areas, 1998

Sample Location	No. of Samples	pH Mean	pH Maximum	pH Minimum	Nitrate (NO_3^-), mg/L No. of Samples	Nitrate Mean	Nitrate Maximum
200-East Area Powerhouse Ditch	24	7.2	9.1	6.0	2	0.17	0.24

Underground radioactive material areas are posted areas that have contamination contained below the soil surface. These areas are typically "stabilized" cribs, burial grounds, covered ponds, trenches, and ditches. Barriers over the contamination sources are used to inhibit radionuclide transport to the surface environs. These areas are surveyed at least annually to document the current radiological status.

Contamination/soil contamination areas may or may not be associated with an underground radioactive material structure. A breach in the barrier of an underground radioactive materials area may result in the growth of contaminated vegetation. Insects or animals may burrow into an underground radioactive materials area and bring contamination to the surface. Vent pipes or risers from an underground structure may be a source of speck contamination. Areas of contamination not related to subsurface structures can include sites contaminated with fallout from effluent stacks and sites that are the result of unplanned releases (e.g., contaminated tumbleweeds, animal feces). All radiologically controlled areas may be susceptible to contamination migration and are surveyed at least annually to document the current radiological status (locations of radiologically controlled areas are illustrated in PNNL-12088, APP. 2).

In 1998, the Hanford Site had approximately 3,641 ha (8,999 acres) of posted outdoor contamination areas (all types) and 587 ha (1,450 acres) of posted underground radioactive materials areas not including active facilities. The number of hectares (acres) of contamination areas (all types) is approximately six times larger than the underground

radioactive materials areas. This is primarily because of the BC Cribs controlled area located south of the 200-East Area. This area was initially posted as a radiologically controlled area in 1958 because of widespread speck contamination and encompassed approximately 1,000 ha (2,500 acres). Investigative radiological surveys begun in 1996 and completed in 1998 adjacent to the BC Cribs area established that the size of the area was 3,482 ha (8,604 acres). Table 3.2.9 lists the contamination areas and underground radioactive materials areas in 1998. A global positioning system was used in 1998 to measure more accurately the extent of the radiologically controlled areas. Area measurements are entered into the Hanford Geographical Information System, a computer database maintained by Bechtel Hanford, Inc.

The number and size of radiologically controlled areas vary from year to year because of efforts to clean, stabilize, and remediate areas of known contamination. During this time, new areas of contamination are also being identified. Table 3.2.10 indicates the

Table 3.2.9. Outdoor Contamination Status, 1998

Area	Contamination Areas,[a] ha	(acres)	Underground Radioactive Materials Areas,[b] ha	(acres)
100-B,C	8	(20)	39	(96)
100-D,DR	0.1	(0.2)	39	(96)
100-F	0.1	(0.2)	5	(12)
100-H	0.1	(0.2)	14	(35)
100-K	9	(22)	62	(153)
100-N	29	(73)	0.2	(0.5)
200-East[c]	62	(153)	142	(351)
200-West[c]	34	(84)	218	(539)
300	19	(47)	13	(32)
400	0	0	0	0
600[d]	3,480	(8,599)	55	(136)
Totals	3,641	(8,999)	587	(1,450)

(a) Includes areas posted as contamination/soil contamination or as radiologically controlled and areas designated both as underground radioactive material and contamination/soil contamination.
(b) Includes areas with only underground contamination. Does not include areas that had contamination/soil contamination as well as underground radioactive material.
(c) Includes tank farms.
(d) Includes BC Cribs controlled area and inactive waste disposal facilities outside the 200-East Area boundary that received waste from 200-East Area facilities (e.g., 216-A-25 [Gable Mountain Pond], 216-B-3 [B Pond]) and inactive waste disposal facilities outside the 200-West Area boundary that received waste from 200-West Area facilities (e.g., 216-S-19 [S Pond], 216-U-11 Ditch). The first cell of the Environmental Restoration Disposal Facility was added during 1997.

Table 3.2.10. Zone Status Change of Posted Contamination Areas, 1998[a]

Areas	Zone Changes[b]	Area, ha (acres)	
100	CA to URM	1.1	(2.7)
200-East	CA to URM	1.4	(3.5)
200-East	NP to RBA	2.5	(6.2)
200-West	CA to URM	2.6	(6.4)
300	CA to URM	0	0
400	CA to URM	0	0
600	CA to NP	352	(870)

(a) Changes from stabilization activities, newly discovered sites, or resurvey using a global positioning system.
(b) CA = Contamination/soil contamination area.
URM = Underground radioactive materials area.
NP = No posting.
RBA = Radiological buffer area.

changes resulting from stabilization activities during 1998. Approximately 5.1 ha (12.6 acres) were reclassified from contamination/soil contamination areas to underground radioactive materials areas. A newly identified 2.5-ha (6.2-acre) radiological buffer area was established in 1998. A radiological buffer area is described as "an intermediate area established to prevent the spread of contamination and to protect personnel from radiation exposure" (HSRCM-1, Rev. 2). Newly identified areas may have resulted from contaminant migration or an increased effort to investigate outdoor areas for radiological contamination. Vehicles equipped with radiation detection devices and an ultrasonic ranging and data system have identified areas of contamination that were previously undetected.

It was estimated that the external dose rate at 80% of the identified outdoor contamination areas was >1 mrem/h, though direct dose rate readings from isolated radioactive specks (a diameter >0.6 cm [0.25 in.]) could have been considerably higher. Contamination levels of this magnitude did not significantly add to dose rates for the public or Hanford Site workers in 1998.

3.2.4 Soil and Vegetation Sampling from Operational Areas

Soil and vegetation samples were collected on or adjacent to waste disposal units and from locations downwind and near or within the boundaries of operating facilities and remedial action activity sites. Samples were collected to evaluate long-term trends in environmental accumulation of radioactivity and to detect potential migration and deposition of facility effluents. Special samples were also collected where physical or biological transport problems were identified. Contaminant movement can occur as the result of resuspension from radioactively contaminated surface areas, absorption of radionuclides by the roots of vegetation growing on or near underground and surface-water disposal units, or waste site intrusion by animals. The sampling methods and locations used are discussed in detail in WMNW-CM-004. Radiological analyses of soil and vegetation samples included strontium-90, isotopic uranium, isotopic plutonium, and gamma-emitting radionuclides.

Seventy-eight soil samples (7 in the 100-N Area, 55 in the 200/600 Areas, 15 in the 300/400 Areas, and 1 at the Environmental Restoration Disposal Facility) and 72 vegetation samples (9 in the 100-N Area, 48 in the 200/600 Areas, and 15 in the 300/400 Areas) were collected and the data obtained from the samples are presented in PNNL-12088, APP. 2. Only those radionuclide activities above analytical detection limits are provided in this section.

The number of locations for soil and vegetation sampling in the 100-N Area environs was reduced in 1996. Analyses of the data collected at sites not associated with the retired 1301-N and 1325-N Liquid

Waste Disposal Facilities indicated decreasing trends for contaminant migration and prompted a determination that sampling at these locations was no longer needed. For these same reasons, some N Springs sample locations were also abandoned.

Each soil sample represents a composite of five plugs of soil 2.5 cm (1 in.) deep and 10 cm (4 in.) in diameter collected from each site. Each vegetation sample consists of new-growth leaf cuttings taken from the available species of interest at each sample location. Often, the vegetation sample consisted of a composite of several like members of the sampling site plant community to avoid decimation of any individual plant through overharvesting.

Early in the summer of each year, soil and vegetation samples are collected and submitted for radioanalyses. The analyses include those for radionuclides expected to be found in the areas sampled (i.e., gamma-emitting radionuclides, strontium isotopes, uranium isotopes, and/or plutonium isotopes). The results are then compared to levels found at various offsite sample locations in Yakima and in Benton and Franklin Counties. These levels are obtained from data reported from these locations by the Pacific Northwest National Laboratory (PNNL-10574, PNNL-11795) to determine the difference between contributions from site operations and remedial action activity sites and contributions from natural causes and worldwide fallout. Special sampling for selected radionuclides in soil and vegetation was conducted in Franklin County by the Pacific Northwest National Laboratory during 1998. For more detail, see Section 4.6, "Soil and Vegetation Surveillance."

Soil sampling results are also compared to the "accessible soil" limits included in HNF-PRO-454, developed specifically for use at the Hanford Site (see PNNL-12088, APP. 2 for complete listing). These radioactive limits were established to ensure that effective dose equivalents to the public do not exceed the established limits for any reasonable scenario, such as direct exposure, inadvertent ingestion, inhalation, and ingestion of food crops, including animal products. Conservatism inherent in pathway programming ensures that the required degrees of protection are in place. These limits apply specifically to the Hanford Site with respect to onsite disposal operations, stabilization and cleanup, and decontamination and decommissioning operations.

In general, activities in soil and vegetation samples collected from or adjacent to waste disposal facilities were higher than activities in samples collected farther away and were significantly higher than historical activities measured off the site. The data also show, as expected, that activities of certain radionuclides were higher within different operational areas when compared to activities measured in distant communities. Generally, the predominant radionuclides were activation and fission products in the 100-N Area, fission products in the 200 Areas, and uranium in the 300/400 Areas.

3.2.4.1 Radiological Results for Soil Samples

Of the radionuclide analyses performed, cobalt-60, strontium-90, cesium-137, plutonium-239,240, and uranium were consistently detectable. Activities of these radionuclides in soil samples were elevated near and within facility boundaries when compared to activities measured off the site. Figure 3.2.2 shows average soil values for 1998 and the preceding 5 yr. The activities show a large degree of variability.

Surface soil samples collected near the retired 1301-N Liquid Waste Disposal Facility contained radionuclides that were typically present in past effluent stream discharges. Generally, the samples collected near this facility exhibited relatively higher radionuclide activities than those collected at the other soil sampling locations in the 100-N Area. As in 1997, radionuclide activities from sampling site Y602, located on the eastern side of the retired 1301-N facility, exhibited slightly elevated levels of

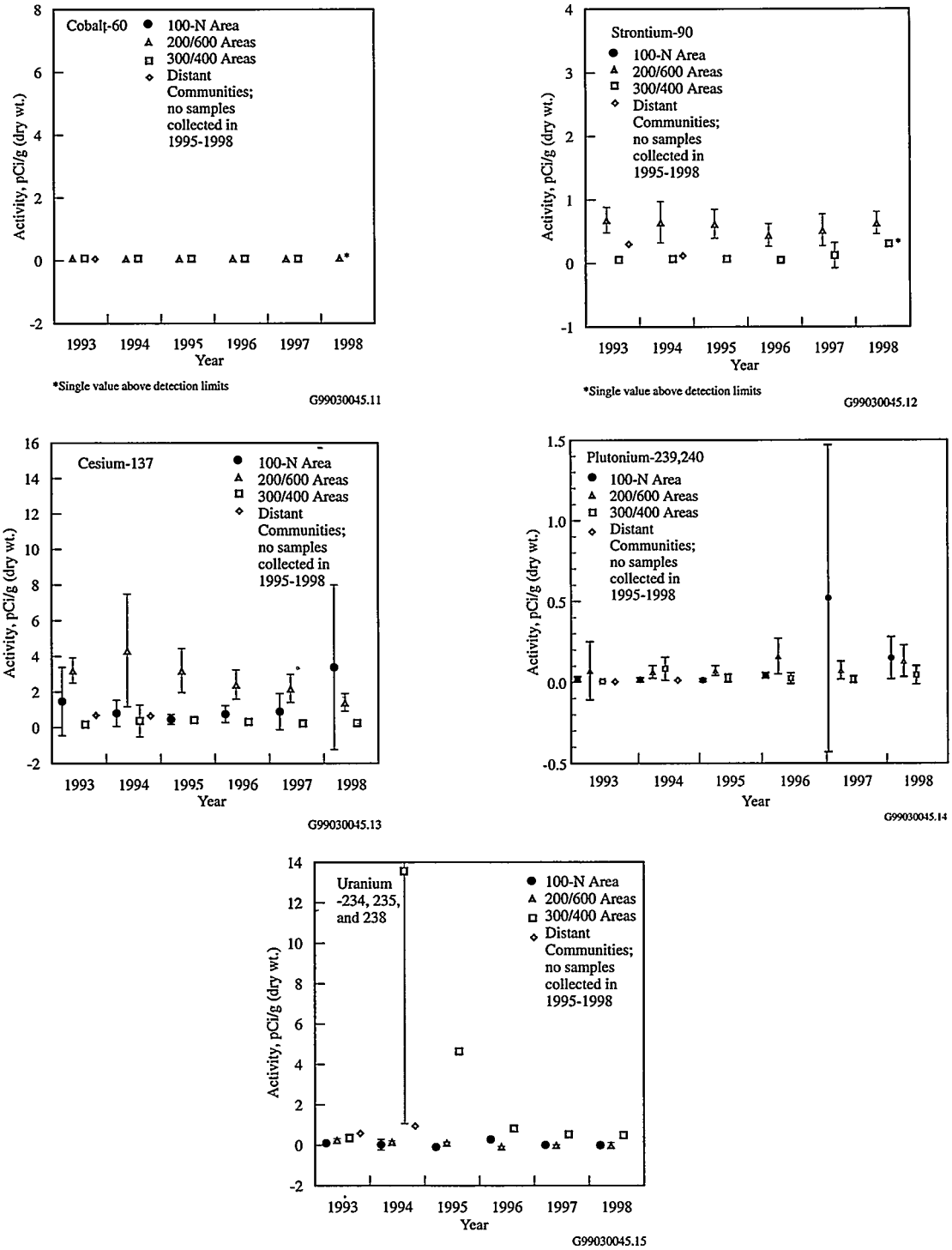


Figure 3.2.2. Average Activities (±2 standard error of the mean) of Selected Radionuclides in Near-Facility Soil Samples Compared to Those in Distant Communities, 1993 Through 1998. As a result of figure scale, some uncertainties (error bars) are concealed by point symbol. The 1994, 1995, 1996, 1997, and 1998 100 Areas data include the 100-N Area only.

cobalt-60, strontium-90, and cesium-137. It is likely that these increased levels are due to resuspension of contaminated material from the facility itself because the vegetation in the immediate vicinity of Y602 (i.e., Y702 vegetation sampling site) did not exhibit a corresponding pattern of elevated radionuclide activities. Average radionuclide activities detected in the surface soil samples near the facility from 1993 through 1998 are presented in Table 3.2.11. Generally, results were at or near historical onsite levels. However, activities of cobalt-60, strontium-90, plutonium-238, and plutonium-239,240 were noticeably elevated at a sampling location near the retired 1301-N facility. Additionally, contamination levels for these radionuclides were greater than those previously measured off the site and in the 200 and 300/400 Areas. The cobalt-60, strontium-90, and plutonium-239,240 activities in the 100-N Area soils resulted from past discharges to waste disposal structures, primarily the 1301-N facility.

Average radionuclide activities detected in all of the surface soil samples collected in the 100-N Area from 1993 through 1998 are presented in Table 3.2.12. The 1998 maximum, average, offsite average activities, and accessible soil limits are compared in Table 3.2.13. Offsite averages for isotopic uranium, strontium-90, and cesium-137 are from PNNL-11795 and offsite values for plutonium-239,240 are contained in PNL-10574. Complete listings of radionuclide activities and sample location maps are provided in PNNL-12088, APP. 2.

Soil samples from 55 of 111 sample locations in the 200/600 Areas were collected in 1998. A follow-up sample location (D146) was again included this year from the southern end of the Environmental Restoration Disposal Facility and will now be sampled on an annual basis. The 1998 maximum, average, offsite average, and accessible soil limits are compared in Table 3.2.14. Complete listings of radionuclide activities and sample location maps are provided in PNNL-12088, APP. 2.

Analytical results from soil samples taken from the 200/600 Areas demonstrated a general downward trend for most radionuclides. However, the cesium-137 results in the 200 Areas were greater than previous offsite measurements and values obtained from the 100 and 300/400 Areas.

Soil samples from 15 sample locations in the 300/400 Areas were collected in 1998; 14 from the

Table 3.2.11. Average Radionuclide Activities (pCi/g)[a] Detected in Surface Soil Samples Near the 1301-N Liquid Waste Disposal Facility, 1993 Through 1998

Year	^{60}Co	^{90}Sr	^{137}Cs	$^{239,240}Pu$
1993	9.8 ± 10.9	0.09 ± 1.3	6.2 ± 10.2	0.069 ± 0.086
1994	3.7 ± 4.8	0.33 ± 0.34	1.5 ± 1.5	0.028 ± 0.030
1995	2.1 ± 2.2	0.15 ± 0.17	0.77 ± 0.53	0.010 ± 0.013
1996	2.5 ± 1.5	0.23 ± 0.11	0.98 ± 0.57	0.048 ± 0.026
1997	4.3 ± 5.2	5.8 ± 10.8	1.5 ± 1.5	0.98 ± 1.79
1998	8.5 ± 14.4	1.6 ± 1.2	5.2 ± 7.4	0.19 ± 0.19

(a) ±2 standard error of the mean.

Table 3.2.12. Average Radionuclide Activities (pCi/g)[a] Detected in 100-N Area Surface Soil Samples, 1993 Through 1998

Year	^{60}Co	^{90}Sr	^{137}Cs	$^{239,240}Pu$
1993	0.030 ± 0.016	0.12 ± 0.06	0.16 ± 0.08	0.0034 ± 0.0019
1994	1.6 ± 2.1	0.19 ± 0.15	0.81 ± 0.65	0.016 ± 0.013
1995	0.94 ± 0.98	0.13 ± 0.07	0.51 ± 0.24	0.014 ± 0.009
1996	1.5 ± 1.1	0.20 ± 0.08	0.077 ± 0.042	0.043 ± 0.016
1997	2.5 ± 3.0	3.9 ± 7.2	0.89 ± 0.90	0.91 ± 1.79
1998	4.9 ± 8.4	1.2 ± 1.2	3.1 ± 4.4	0.15 ± 0.14

(a) ±2 standard error of the mean.

Table 3.2.13. Activities of Selected Radionuclides in 100-N Area Soils, 1998 (pCi/g)

	^{60}Co	^{90}Sr	^{137}Cs	^{234}U	^{235}U	^{238}U	$^{239,240}Pu$
Sampling locations[a]	Site Y602	Site Y604	Site Y604	Site Y602	Site Y602	Site Y602	Site Y605
Maximum[b]	30 ± 2.3	4.0 ± 0.6	16 ± 2.2	0.39 ± 0.07	0.047 ± 0.017	0.22 ± 0.04	0.42 ± 0.05
Average[c]	4.9 ± 7.7	1.2 ± 1.1	3.1 ± 4.1	0.21 ± 0.06	0.033 ± 0.007	0.17 ± 0.03	0.15 ± 0.13
Offsite average[c,d]	NR[e]	0.062 ± 0.052	0.30 ± 0.30	0.24 ± 0.09	0.11 ± 0.04	0.25 ± 0.10	0.011 ± 0.001
Accessible soil activity limits (HNF-PRO-454)[f]	7.1	2,800	30	630	170	370	190

(a) See PNNL-12088, APP. 2.
(b) ± counting error.
(c) ±2 standard error of the mean.
(d) PNNL-10574 and PNNL-11795.
(e) NR = Not reported.
(f) Hanford soils that are not behind security fences.

300 Area and 1 from the 400 Area. The 1998 maximum, average, offsite average activities, and accessible soil limits are compared in Table 3.2.15. Complete listings of radionuclide activities and sample location maps are provided in PNNL-12088, APP. 2.

Analytical results from soil samples taken from the 300/400 Areas were compared to results for other operational areas and to those measured off the site. Uranium levels in the 300/400 Areas were higher than those measured from the 100 and 200 Areas. Cobalt-60 and cesium-137 values were slightly higher than those previously measured off the site. Uranium was expected in these samples because it was used during past fuel fabrication operations in the 300 Area.

In 1998, a single soil sample was collected from the Environmental Restoration Disposal Facility

Table 3.2.14. Activities of Selected Radionuclides in 200/600 Areas Soils, 1998 (pCi/g)

	^{60}Co	^{90}Sr	^{137}Cs	^{234}U	^{235}U	^{238}U	$^{239,240}Pu$
Sampling locations[a]	Site D050	Site D064	Site D034	Site D068	Site D068	Site D068	Site D008
Maximum[b]	0.019 ± 0.006[c]	1.5 ± 0.3	10 ± 1.4	0.29 ± 0.06	0.044 ± 0.015	0.29 ± 0.06	1.4 ± 0.1
Average[d]	--	0.50 ± 0.14	1.1 ± 0.4	0.19 ± 0.01	0.021 ± 0.002	0.19 ± 0.01	0.13 ± 0.01
Offsite average[d,e]	NR[f]	0.062 ± 0.052	0.30 ± 0.30	0.24 ± 0.09	0.11 ± 0.04	0.25 ± 0.10	0.011 ± 0.001
Accessible soil activity limits (HNF-PRO-454)[g]	7.1	2,800	30	630	170	370	190

(a) See PNNL-12088, APP. 2.
(b) ± counting error.
(c) Single value above detection limits.
(d) ±2 standard error of the mean.
(e) PNNL-10574 and PNNL-11795.
(f) NR = Not reported.
(g) Hanford soils that are not behind security fences.

Table 3.2.15. Activities of Selected Radionuclides in 300/400 Areas Soils, 1998 (pCi/g)

	^{60}Co	^{90}Sr	^{137}Cs	^{234}U	^{235}U	^{238}U	$^{239,240}Pu$
Sampling locations[a]	--	Site D127	Site D127	Site D119	Site D119	Site D119	Site D119
Maximum[b]	ND[c]	0.24 ± 0.12[d]	0.58 ± 0.08	7.9 ± 1.3	0.49 ± 0.10	7.9 ± 1.3	0.23 ± 0.05
Average[e]	ND	--	0.086 ± 0.075	0.85 ± 0.98	0.065 ± 0.060	0.82 ± 0.98	0.045 ± 0.057
Offsite average[e,f]	NR[g]	0.062 ± 0.052	0.30 ± 0.30	0.24 ± 0.09	0.11 ± 0.04	0.25 ± 0.10	0.011 ± 0.001
Accessible soil activity limits (HNF-PRO-454)[h]	7.1	2,800	30	630	170	370	190

(a) See PNNL-12088, APP. 2.
(b) ± counting error.
(c) ND = Not detected.
(d) Single value above detection limits.
(e) ±2 standard error of the mean.
(f) PNNL-10574 and PNNL-11795.
(g) NR = Not reported.
(h) Hanford soils that are not behind security fences.

(location D146) to determine the effectiveness of contamination controls. The sample collected from this facility in 1997 represented the initial (baseline) sample, with the 1998 sample to be used for comparison. The 1998 data are reported in PNNL-12088, APP. 2.

3.2.4.2 Radiological Results for Vegetation Samples

Of the radionuclide analyses performed, cobalt-60, strontium-90, cesium-137, plutonium-239,240, and uranium were consistently detectable. Activities of these radionuclides in vegetation were elevated near and within facility boundaries compared to the activities measured off the site. Figure 3.2.3 shows average vegetation values for 1998 and the preceding 5 yr. The activities show a large degree of variability.

Average radionuclide activities detected in the vegetation samples near the retired 1301-N Liquid Waste Disposal Facility from 1993 through 1998 are presented in Table 3.2.16. The contaminants near the 1301-N facility were at or near historic levels. Average radionuclide activities detected in all of the vegetation samples collected in the 100-N Area from 1993 through 1998 are presented in Table 3.2.17.

Vegetation samples collected along the 100-N Area shoreline (N Springs) contain radionuclides that were not completely retained in the soil columns beneath the retired 1301-N and 1325-N Liquid Waste Disposal Facilities. Biotransport, via root uptake of cobalt-60, strontium-90, and cesium-137, was evident in the reed canary grass samples collected from this area. Most notable were the average levels of strontium-90 and cesium-137, which exhibited activities that were orders of magnitude higher than the offsite averages. Average radionuclide activities detected in the vegetation samples collected along N Springs in 1998 and during the previous 5 yr are presented in Table 3.2.18. The 1998 maximum, average, and offsite average are compared in Table 3.2.19. Complete listings of radionuclide activities and sample location maps are provided in PNNL-12088, APP. 2. Analytical results from vegetation samples collected from the 100-N Area in 1998 were within the ranges observed in previous years. The values observed for strontium-90 in samples collected near N Springs were typically higher than those seen at other locations in the 100-N Area.

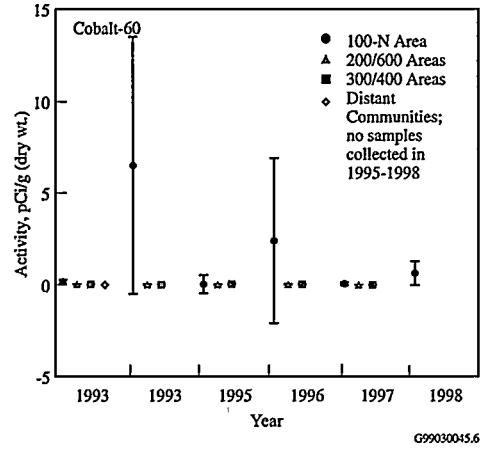
Generally, 1998 radionuclide levels in 100-N Area vegetation were greater than those previously measured off the site; levels for cobalt-60, strontium-90, and cesium-137 were higher compared to the activities measured in the 200 and 300/400 Areas.

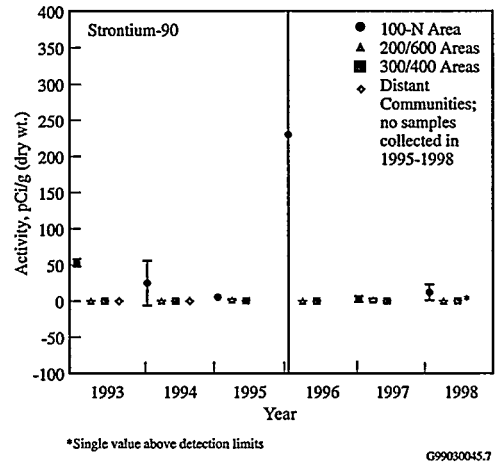
In 1998, 41 vegetation samples were collected from the 200/600 Areas. The 1998 maximum, average, and offsite average are compared in Table 3.2.20. Complete listings of radionuclide activities and sample location maps are provided in PNNL-12088, APP. 2.

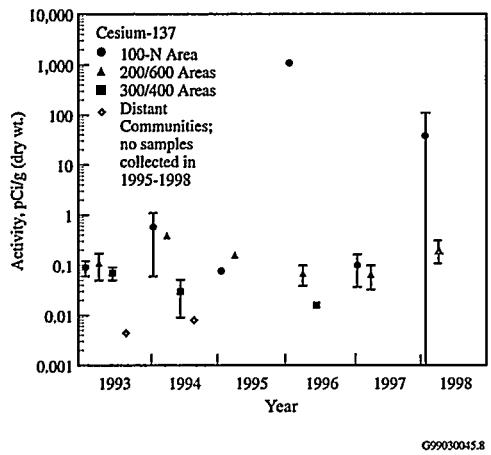
Analytical results from vegetation samples taken in 1998 from the 200/600 Areas were generally comparable to those observed in previous years. Radionuclide levels for strontium-90, cesium-137, and plutonium-239,240 were greater than those measured off the site previously and were higher for cesium-137 and plutonium-239,240 compared to the 100 and 300/400 Areas.

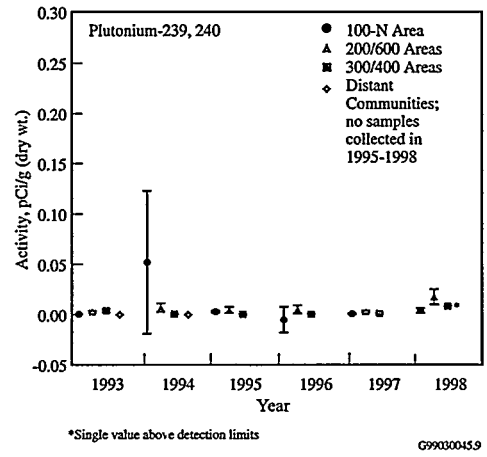
This was the seventh year of sampling from locations established to more directly monitor facilities and active/inactive waste sites in the 300 and 400 Areas. The 1998 maximum, average, offsite average, and accessible soil limits for 300/400 Areas samples are compared in Table 3.2.21. Complete listings of radionuclide activities and sample location maps are provided in PNNL-12088, APP. 2.

Generally, the levels of most radionuclides measured in the 300 Area were greater than those measured off the site, and uranium levels were higher than measured in the 100 and 200 Areas. The higher









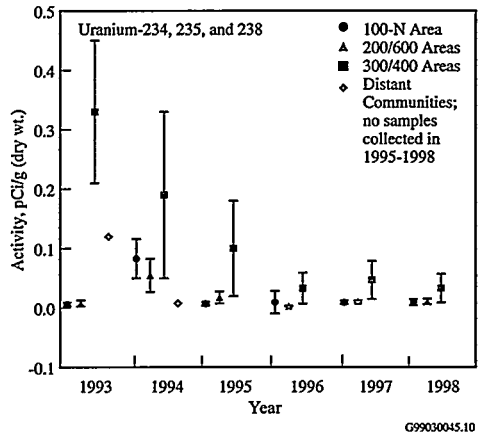


Figure 3.2.3. Average Activities (±2 standard error of the mean) of Selected Radionuclides in Near-Facility Vegetation Samples Compared to Those in Distant Communities, 1993 Through 1998. As a result of figure scale, some uncertainties (error bars) are concealed by point symbol. The 1994, 1995, 1996, 1997, and 1998 100 Areas data include the 100-N Area only. The 1997 cesium-137 data point for the 300/400 Areas is less than zero and cannot be plotted on a log scale.

Table 3.2.16. Average Radionuclide Activities (pCi/g)[a] Detected in Vegetation Samples Collected Near the 1301-N Liquid Waste Disposal Facility, 1993 Through 1998

Year	^{60}Co	^{90}Sr	^{137}Cs	$^{239,240}Pu$
1993	0.22 ± 0.21	0.057 ± 0.008	0.22 ± 0.09	0.00041 ± 0.00016
1994	24.8 ± 31.6	4.8 ± 6.9	1.8 ± 1.8	0.20 ± 0.27
1995	0.054 ± 0.10	0.064 ± 0.019	0.12 ± 0.14	0.008 ± 0.003
1996	6.1 ± 11.9	575 ± 1,150	2,750 ± 5,500	-0.013 ± 0.38[b]
1997	0.42[c]	0.49[c]	0.14 ± 0.06	ND[d]
1998	0.54 ± 0.93	13.6 ± 26.4	50.1 ± 99.8	0.0071[c]

(a) ±2 standard error of the mean.
(b) Negative value indicates results at or below background levels of radioactivity.
(c) Single value above detection limit.
(d) ND = Not detected.

Table 3.2.17. Average Radionuclide Activities (pCi/g)[a] Detected in 100-N Area Vegetation Samples, 1993 to 1998

Year	^{60}Co	^{90}Sr	^{137}Cs	$^{239,240}Pu$
1993	0.10 ± 0.09	0.036 ± 0.027	0.066 ± 0.033	0.00033 ± 0.00033
1994	6.5 ± 8.5	25 ± 33	0.58 ± 0.52	0.053 ± 0.071
1995	0.03 ± 0.05	5.4 ± 4.8	0.081 ± 0.044	0.0033 ± 0.0016
1996	2.4 ± 4.5	230 ± 430	1,100 ± 2,000	-0.0051 ± 0.013[b]
1997	0.42 ± 0.05	3.6 ± 5.3	0.16 ± 0.008	ND[c]
1998	0.62 ± 0.73	11.7 ± 11.1	37.6 ± 74.9	0.0042 ± 0.0029

(a) ±2 standard error of the mean.
(b) Negative value indicates results at or below background levels of radioactivity.
(c) ND = Not detected.

uranium levels were expected because it was released during past fuel fabrication operations in the 300 Area. The levels recorded for all other radionuclides in the 400 Area were at or slightly higher than those measured off the site in previous years.

Table 3.2.18. Average Radionuclide Activities (pCi/g)[a] Detected in N Springs Vegetation Samples, 1993 to 1998

Year	^{60}Co	^{90}Sr	^{137}Cs	$^{239,240}Pu$
1993	0.45 ± 0.50	258 ± 208	0.20 ± 0.12	-0.00085 ± 0.00071[b]
1994	0.14 ± 0.10	60 ± 81	0.15 ± 0.14	0.002 ± 0.001
1995	0.014 ± 0.045	13.4 ± 10.2	0.094 ± 0.059	0.0028 ± 0.0008
1996	0.01 ± 0.01	2.4 ± 4.2	0.038 ± 0.010	-0.0015 ± 0.002
1997	ND[c]	6.2 ± 9.9	0.18 ± 0.17	ND
1998	0.068[d]	21.0 ± 19.0	ND	0.0028[d]

(a) ±2 standard error of the mean.
(b) Negative value indicates results at or below background levels of radioactivity.
(c) ND = Not detected.
(d) Single value above detection limit.

Table 3.2.19. Activities of Selected Radionuclides in 100-N Areas Vegetation, 1998 (pCi/g)

	^{60}Co	^{90}Sr	^{137}Cs	^{234}U	^{235}U	^{238}U	$^{239,240}Pu$
Sampling locations[a]	Site Y711	Sites Y704 and Y724	Site Y704	Site Y719	Site Y702	Site Y719	Site Y702
Maximum[b]	1.9 ± 0.2	40 ± 4.8	150 ± 20	0.033 ± 0.009	0.010 ± 0.005	0.024 ± 0.007	0.0071 ± 0.0044
Average[c]	0.62 ± 0.65	12 ± 6	38 ± 65	0.014 ± 0.006	0.0055 ± 0.0022	0.0087 ± 0.0044	0.0042 ± 0.0023
Offsite averages[c,d]	NR[e]	0.025 ± 0.012	0.0072 ± 0.0083	0.014 ± 0.006	ND[f]	0.013 ± 0.004	0.00018 ± 0.00013

(a) See PNNL-12088, APP. 2.
(b) ± counting error.
(c) ±2 standard error of the mean.
(d) PNNL-10574 and PNNL-11795.
(e) NR = Not reported.
(f) ND = Not detected.

3.2.5 External Radiation

External radiation fields were monitored near facilities and waste handling, storage, and disposal sites to measure, assess, and control the impacts of operations. Thermoluminescent dosimeters are used at numerous fixed locations to gather dose rate information over longer periods of time. Thermoluminescent dosimeter results can be used individually or averaged to determine dose rates in a given area for a particular sampling period. A summary of the 1998 thermoluminescent dosimeter results can be found in Table 3.2.22. Individual thermoluminescent dosimeter results and locations are provided

Table 3.2.20. Activities of Selected Radionuclides in 200/600 Areas Vegetation, 1998 (pCi/g)

	^{60}Co	^{90}Sr	^{137}Cs	^{234}U	^{235}U	^{238}U	$^{239,240}Pu$
Sampling locations[a]		Site V058	Site V034	Site V002	Site V104	Site V022	Site V008
Maximum[b]	ND[c]	1.2 ± 0.2	0.49 ± 0.08	0.042 ± 0.011	0.021 ± 0.008	0.021 ± 0.007	0.061 ± 0.014
Average[d]	ND	0.33 ± 0.13	0.21 ± 0.09	0.016 ± 0.003	0.0086 ± 0.0016	0.0097 ± 0.0013	0.018 ± 0.008
Offsite averages[d,e]	NR[f]	0.025 ± 0.012	0.0072 ± 0.0083	0.014 ± 0.006	ND	0.013 ± 0.004	0.00018 ± 0.00013

(a) See PNNL-12088, APP. 2.
(b) ± counting error.
(c) ND = Not detected.
(d) ±2 standard error of the mean.
(e) PNNL-10574 and PNNL-11795.
(f) NR = Not reported.

Table 3.2.21. Activities of Selected Radionuclides in 300/400 Areas Vegetation, 1998 (pCi/g)

	^{60}Co	^{90}Sr	^{137}Cs	^{234}U	^{235}U	^{238}U	$^{239,240}Pu$
Sampling locations[a]		Site V130		Site V119	Site V117	Site V119	Site V118
Maximum[b]	ND[c]	0.10 ± 0.06[d]	ND	0.28 ± 0.05	0.0.17 ± 0.009	0.28 ± 0.05	0.0084 ± 0.0045[d]
Average[e]	ND	--	ND	0.046 ± 0.033	0.0092 ± 0.0028	0.044 ± 0.036	--
Offsite averages[e,f]	NR[g]	0.025 ± 0.012	0.0072 ± 0.0083	0.014 ± 0.006	ND	0.013 ± 0.004	0.00018 ± 0.00013

(a) See PNNL-12088, APP. 2.
(b) ± counting error.
(c) ND = Not detected.
(d) Single value above detection limits.
(e) ±2 standard error of the mean.
(f) PNNL-10574 and PNNL-11795.
(g) NR = Not reported.

in PNNL-12088, APP. 2. Specific information regarding external radiation sampling methods and locations can be found in WMNW-CM-004.

The environmental thermoluminescent dosimeters measure dose rates from all types of external radiation sources. These include cosmic radiation, naturally occurring radioactivity in air and soil, and fallout from nuclear weapons testing, as well as any contribution from Hanford Site activities. These outside radiation sources cause an estimated 20% deviation in results from the thermoluminescent dosimeter analyses. The results are reported in units of millirems per year.

Near-facility monitoring uses the Harshaw thermoluminescent dosimeter system, which includes the Harshaw 8807 dosimeter and the Harshaw 8800 reader. The reader has a better signal-to-noise ratio than those used in the past. The packaging, which uses an O-ring seal, protects the dosimeter from light, heat, moisture, and dirt. The thermoluminescent

Table 3.2.22. Thermoluminescent Dosimeter Results for Waste Handling Facilities, 1997 and 1998, mrem/yr based on 24 h/d

Area	No. of Locations, 1998	1997 Maximum	1997 Mean	1998 Maximum	1998 Mean	% Change[a]
100-B	4	96	93	110	97	4
100-D	5	93	88	125	96	9
100-K	11	2,250	470	720	180	-61
100-N	18	7,700	1,300	7,000	1,600	22
200/600	63	350	110	320	100	-5
TWRS[b]	10	81	78	88	86	10
ERDF[c]	3	100	95	100	95	0
300	8	200	110	210	110	0
300 TEDF[d]	6	87	82	89	83	1
400	7	88	86	87	84	-2

(a) Numbers indicate a decrease (-) or increase from the 1997 mean.
(b) TWRS = Tank Waste Remediation System Phase I demonstration project.
(c) ERDF = Environmental Restoration Disposal Facility.
(d) TEDF = 300 Area Treated Effluent Disposal Facility.

dosimeters were placed 1 m (3.3 ft) above the ground near facilities, active and inactive surface-water disposal sites, and remedial action projects. The dosimeters were exchanged and analyzed each calendar quarter. The Pacific Northwest National Laboratory's Radiological Calibrations Facility in the 318 Building (300 Area) calibrates the response of the chips; results are reported in terms of external dose.

To evaluate environmental restoration activities at the former 116-B-11 and 116-C-1 Liquid Waste Disposal Facilities, four new thermoluminescent dosimeter monitoring sites were established during the fourth quarter of 1997. Dose rates measured at these locations were elevated 4% compared to the extrapolated data from 27 d of data collection during the fourth quarter of 1997. The 1998 average dose rate was 97 mrem/yr, which is comparable to offsite ambient background levels.

In the 100-D,DR Area, this is the third year that thermoluminescent dosimeters have been placed to evaluate cleanup activities at the former 116-D-7 and 116-DR-9 Liquid Waste Disposal Facilities. Dose rates measured at these locations were 9% higher than the results of 1997, with an average dose of 96 mrem/yr, which is comparable to offsite ambient background levels.

The cleanup activities at the K Basins and adjacent retired reactor buildings in the 100-K Area continue to be monitored. Dose rates in this area decreased 61%, with an average of 180 mrem/yr, because of the removal of radioactive waste stored in proximity to the three thermoluminescent dosimeter locations.

The 1998 results for the 100-N Area indicate that direct radiation levels are highest near facilities that had contained or received liquid effluent from N Reactor. These facilities primarily include the retired 1301-N and 1325-N Liquid Waste Disposal Facilities. While the results for these two facilities were noticeably higher than those for other 100-N Area thermoluminescent dosimeter locations, they were approximately 17% lower than dose levels measured at these locations in 1997. Overall, the average

dose rate measured in the 100-N Area in 1998 was approximately 22% higher than that measured in 1997 because of the removal of eight dosimeters in low-background areas.

Dose rates were measured at the N Springs shoreline to determine potential external radiation doses to the public as well as to onsite workers. Because of the "skyshine" effect (i.e., radiation reflected by the atmosphere back to the earth's surface) from the retired 1301-N facility, dose rates at the N Springs shoreline were elevated (>100 mrem/yr), which is the DOE annual external dose limit to members of the public. However, neither a member of the public nor a Hanford worker would conceivably spend an entire year at the N Springs; therefore, the values shown in Figure 3.2.4 are for comparison only. N Springs dose reduction measures are being studied.

Annual average thermoluminescent dosimeter results at 100-N Area from 1987 through 1998 are presented in Figure 3.2.5.

The highest dose rates in the 200/600 Areas were measured near waste handling facilities such as tank farms in the 200 Areas. The location within the 200/600 Areas exhibiting the highest dose rate was at the A Tank Farm in the 200-East Area. The average annual dose rate measured in the 200/600 Areas in 1998 (104 mrem/yr) was 5% lower than the average 1997 measurement. The annual average thermoluminescent dosimeter results from 1987 through 1998 are presented in Figure 3.2.6.

Ten new thermoluminescent dosimeter locations were established around the perimeter of the Tank Waste Remediation System Phase I demonstration project site during the fourth quarter of 1997 to collect preoperational monitoring data. Dose rates measured at these locations in 1998 were comparable to the results of 1997, with an average of 86 mrem/yr. This is comparable to offsite ambient background levels.

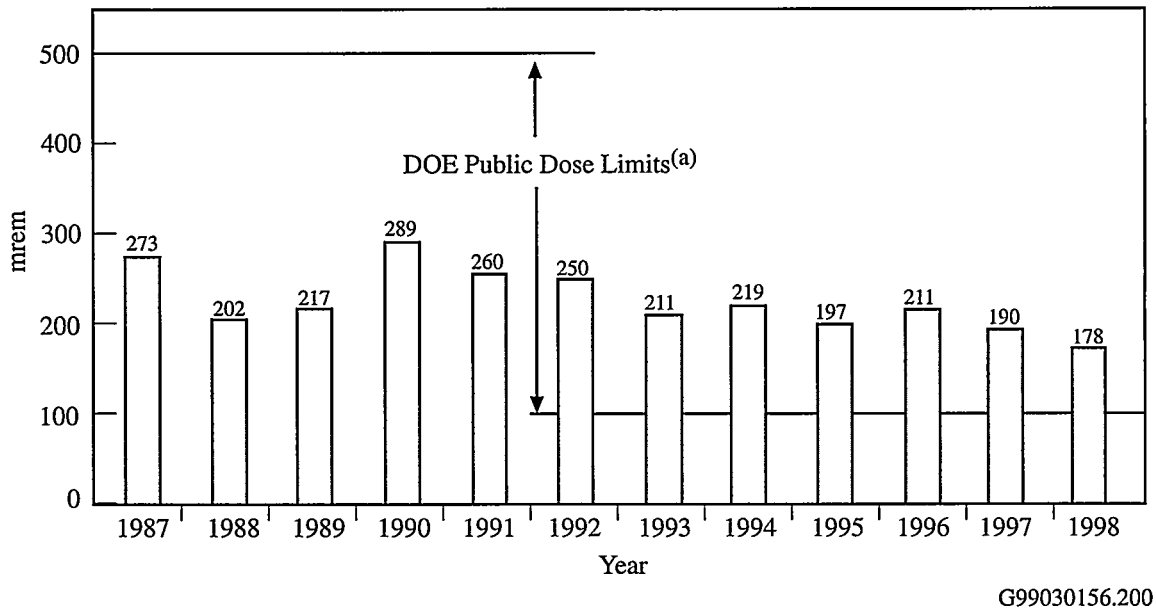


Figure 3.2.4. Average Annual Dose Rate at N Springs. (a) DOE limits were reduced from 500 mrem/yr in 1992. The lower value was selected in recognition of the International Commission of Radiation Protection recommendation to limit the long-term average effective dose equivalence to 100 mrem (1 mSv)/yr or less (DOE Order 5400.5)

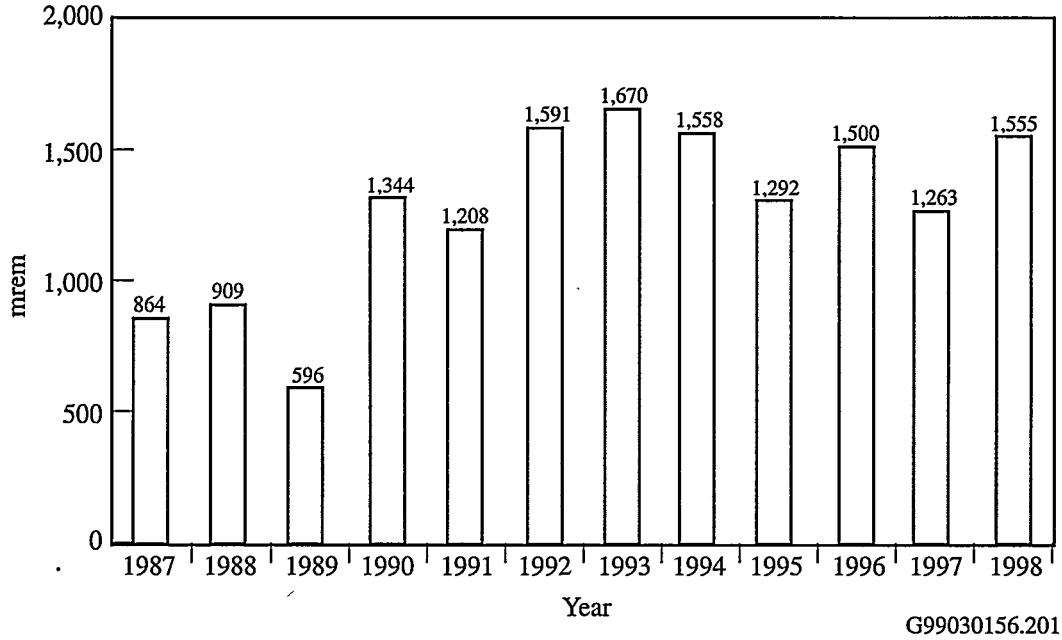


Figure 3.2.5. Annual Average Thermoluminescent Dosimeter Results in the 100-N Area

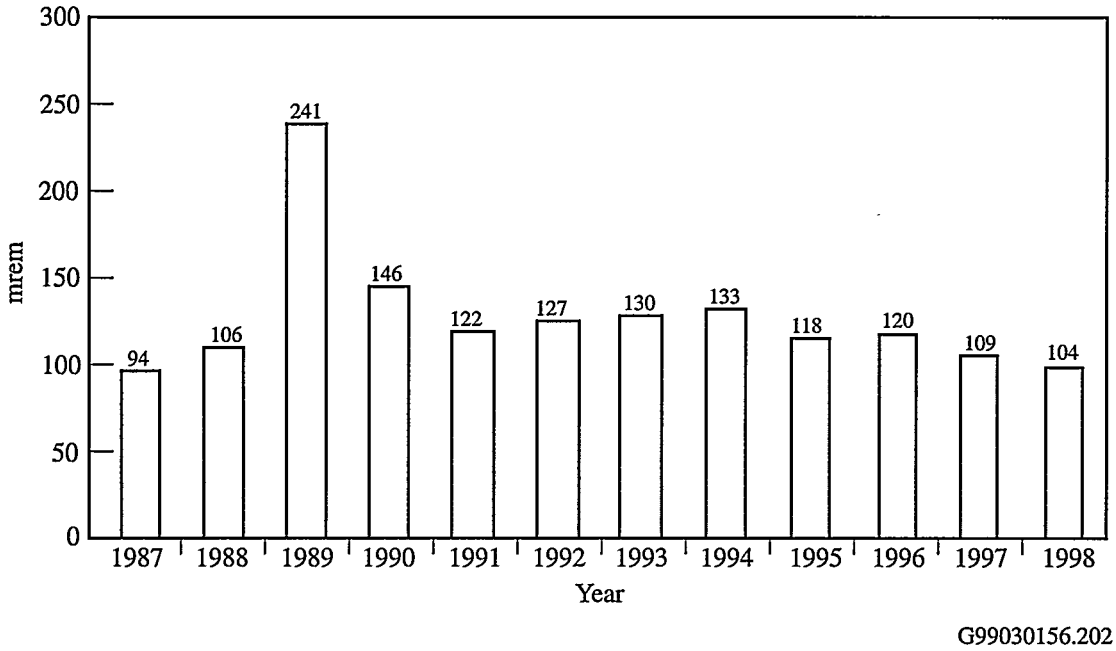


Figure 3.2.6. Annual Average Thermoluminescent Dosimeter Results in the 200/600 Areas

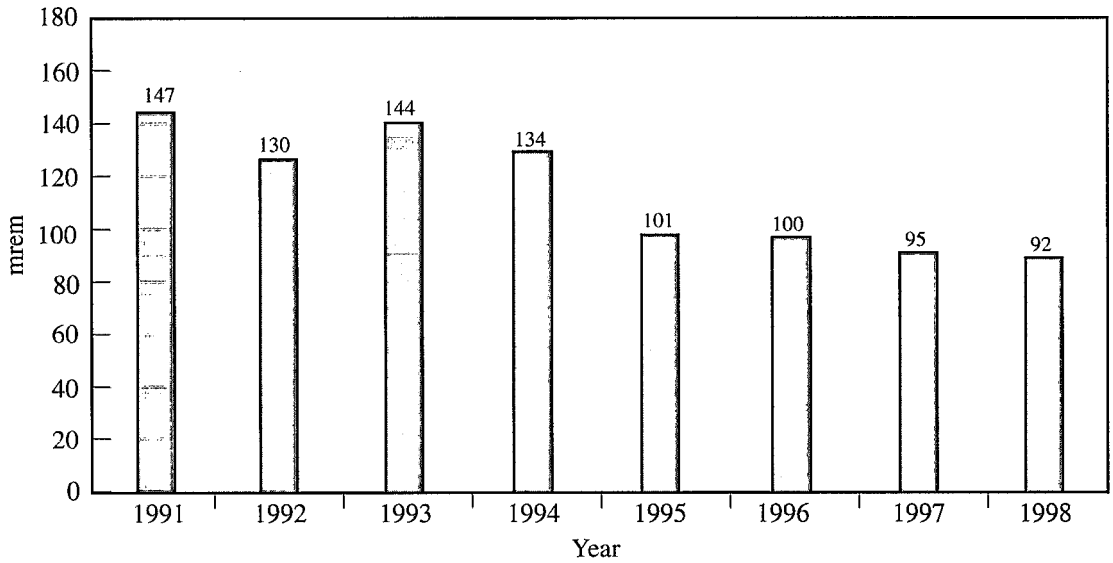
This is the second year that thermoluminescent dosimeters have been placed at the Environmental Restoration Disposal Facility to evaluate ongoing activities. Dose rates measured in 1998 were slightly lower than the 1997 results, with an average of 92 mrem/yr, which is comparable to offsite ambient background levels.

The highest dose rates in the 300 Area in 1998 were measured near the 340 Waste Handling Facility. The average dose rate measured in the 300 Area in 1998 was 110 mrem/yr, which is equal to the average dose rate measured in 1997. The average dose rate at the 300 Area Treated Effluent Disposal Facility in 1998 was 82 mrem/yr, which is a 1% increase compared to the average dose rate measured in 1997. The average dose rate measured in the 400 Area in 1998 was 84 mrem/yr, which is a 2% decrease to the average dose of 86 mrem/yr measured in 1997. The annual average thermoluminescent dosimeter results from 1991 through 1998 are presented in Figure 3.2.7.

3.2.6 Investigative Sampling

Investigative sampling was conducted in the operations areas to confirm the absence or presence of radioactive and/or hazardous contaminants where known or suspected radioactive contamination was present or to verify radiological conditions at specific project sites. Investigative sampling took place near facilities such as storage and disposal sites for at least one of the following reasons:

- to follow up radiological surface surveys that had indicated radioactive contamination was present
- to conduct preoperational surveys to characterize the radiological/chemical conditions at a site before facility construction, operation, or ultimate remediation



G99030156.203

Figure 3.2.7. *Annual Average Thermoluminescent Dosimeter Results in the 300/400 Areas and at the 300 Area Treated Effluent Disposal Facility*

- to determine if biotic intrusion (e.g., animal burrows or deep-rooted vegetation) has created a potential for contaminants to spread
- to determine the integrity of waste containment systems.

Generally, the predominant radionuclides discovered during these efforts were activation and fission products in the 100 and 200 Areas and uranium in the 300 Area. Hazardous chemicals generally have not been identified above background levels in preoperational environmental monitoring samples.

Investigative samples collected in 1998 included vegetation (tumbleweeds), nests (bird, wasp, ant), mammal feces (rabbit), mammals (mice, bat), and insects (fruit flies).

Methods for collecting or otherwise obtaining investigative samples are described in WMNW-CM-004. Field monitoring was conducted to detect radioactivity in samples before they were submitted for analysis. Field monitoring results are expressed as disintegrations per minute when a Geiger-Müeller detector is used or as millirad per hour when an ion chamber is used. To obtain the field instrument readings, measured background radioactivity was subtracted from the Geiger-Müeller readings (in counts per minute) and converted to disintegrations per minute per 100 cm^2. Laboratory sample analysis results are expressed in picocuries per gram, except for extremely small samples. Small samples are expressed in picocuries per sample. Maximum activities, rather than averages, are presented in this section.

In 1998, 51 investigative samples were analyzed for radionuclides at the 222-S Laboratory in the 200-West Area. Of the samples analyzed, 50 showed measurable levels of activity. Analytical results are provided in PNNL-12088, APP. 2. Another 133 contaminated investigative environmental samples were reported and disposed of without isotopic analyses (though field instrument readings were recorded) during cleanup operations. These results are also provided in PNNL-12088, APP. 2. Only radionuclide activities above analytical detection limits are provided in this section.

In 1998, there were 41 instances of radiological contamination in investigative soil samples. Of the 41, 18 were identified only as "speck" contamination. Seven investigative samples were collected for radioisotopic analysis, and 33 contaminated soils or specks were found during cleanup operations and disposed of in low-level burial grounds without analysis. External radioactivity levels ranged from slightly above background (approximately 9,250 dpm/100 cm^2) to >1,000,000 dpm/100 cm^2. The contaminated areas were radiologically posted or cleaned up.

The number of investigative soil contamination incidents, range of radiation dose levels, and radionuclide activities in 1998 were generally within historical values. Areas of special soil sampling that were outside radiological control areas and had levels greater than radiological control limits were posted as surface contamination areas.

In 1998, there were 51 instances of radiological contamination in investigative vegetation samples. Of the 51, 47 were identified as tumbleweed, 1 as sagebrush/rabbitbrush, and 3 as vegetation. Nine tumbleweed samples and the sagebrush/rabbitbrush sample were analyzed for radionuclide activities. Three of those samples showed field readings in excess of 1,000,000 dpm/100 cm^2. Of the three tumbleweed samples with the highest field readings, two were wind blown weeds collected from the 200-East Area fence and the third was collected from the diversion box on the transfer line between the 200-East and 200-West Areas. Analysis of contaminated tumbleweeds showed strontium-90 levels as high as 7,360,000 pCi/g and cesium-137 levels as high as 1,410,000 pCi/g.

Investigative vegetation samples not sent to the laboratory for analysis were disposed of in low-level burial grounds. The number of contaminated investigative vegetation incidents in 1998 (51) was

comparable to those observed in 1997 (46). The radioactivity levels and range of radionuclide activities were all within historical levels (WHC-MR-0418).

Investigative wildlife samples were collected directly from or near facilities to monitor and track the effectiveness of measures designed to deter animal intrusion. Wildlife is collected either as part of an integrated pest management program, designed to limit the exposure to and potential contamination of animals with radioactive material, or as a result of finding radiologically contaminated wildlife-related material (e.g., feces, nests) during a radiation survey.

Surveys were performed after collection of wildlife to determine whether an animal was radioactively contaminated. If a live animal was found to be free of contamination, it was taken to an area of suitable habitat, still in a controlled area, and released. If an animal was contaminated, a decision was made based on the level of contamination, location, and frequency of occurrence either to collect the animal as a sample or to dispose of the animal in a low-level burial ground.

In 1998, 34 wildlife and wildlife-related samples were submitted for analysis. This compares to 22 samples collected in 1997, 37 in 1996, 22 in 1995, and 16 in 1994. The number of samples submitted for analysis depended on opportunity (i.e., resulting from the pest control activities at facilities) rather than prescheduled sampling at established sampling points. Fifteen fruit flies were gathered as a result of a newly identified pathway of contamination.

All 34 wildlife-related samples showed detectable levels of contamination, except for a sample of crystalline material thought to be associated with contaminated fruit flies. One sample, composed of six mice, showed very low detectable levels of strontium-90 (0.3 pCi/g) and uranium (0.0032 pCi/g).

The maximum radionuclide activities in 1998 were in mouse feces collected near the 241-ER-151 Diversion Box south of B Plant in the 200-East Area. Contaminants included strontium-90 (450,000 pCi/g), cesium-137 (460,000 pCi/g), europium-154 (560 pCi/g), plutonium-238 (45 pCi/g), plutonium-239,240 (170 pCi/g), and total uranium (2.0 pCi/g). The numbers of animals found to be contaminated with radioactivity, their radioactivity levels, and the range of radionuclide activities were within historical levels (WHC-MR-0418).

There were 21 cases of contaminated wildlife or related samples found during cleanup operations that were not analyzed. These samples included anthills, mouse feces, coyote urine, rabbit feces, mice, fruit flies, and a beetle. The field instrument readings for the unanalyzed samples ranged from approximately 1,000 to >10,000,000 dpm/100 cm^2.

Special characterization projects conducted or completed in 1998 to verify the radiological, and in some cases, potential hazardous chemical status of operations included those listed below.

- A preoperational environmental survey was initiated for the Project W-314 pipeline, which is to be constructed in the 200-East Area for the Tank Waste Remediation System Project to provide needed upgrades for waste transfer control and instrumentation for existing tank farm facilities. A sample and analysis plan (HNF-3594) was prepared and issued.
- A preoperational environmental survey is planned in support of the Spent Nuclear Fuels Project Facilities during 1999 and 2000. The surveys will concentrate on areas near the Cold Vacuum Drying Facility in the 100-K Area and the Canister Storage Building and Interim Storage Area in the 200-East Area.

3.3 References

10 CFR 835. U.S. Department of Energy. "Occupational Radiation Protection." *Code of Federal Regulations.*

40 CFR 61. U.S. Environmental Protection Agency. "National Emission Standards for Hazardous Air Pollutants." *Code of Federal Regulations.*

40 CFR 122. U.S. Environmental Protection Agency. "EPA Administered Permit Programs: The National Pollutant Discharge Elimination System." *Code of Federal Regulations.*

40 CFR 141. U.S. Environmental Protection Agency. "National Primary Drinking Water Regulations; Radionuclides; Proposed Rule." *Code of Federal Regulations.*

AP-42. 1995. *Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources.* Office of Air Quality Planning and Standards, Office of Air and Radiation, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, Fifth Edition.

Comprehensive Environmental Response, Compensation, and Liability Act. 1980. Public Law 96-150, as amended, 94 Stat. 2767, 42 USC 9601 et seq.

DOE Order 5400.1. "General Environmental Protection Program."

DOE Order 5400.5. "Radiation Protection of the Public and the Environment."

DOE Order 5484.1. "Environmental Protection, Safety, and Health Protection Information Reporting Requirements."

DOE Order 5820.2A. "Radioactive Waste Management."

DOE/RL-91-50, Rev. 2. 1997. *Environmental Monitoring Plan, United States Department of Energy Richland Operations Office.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-99-41. 1999. *Radionuclide Air Emissions Report for the Hanford Site, Calendar Year 1998.* B. P. Gleckler and K. Rhoads, Waste Management Federal Services of Hanford, Inc. for U.S. Department of Energy, Richland Operations Office, Richland, Washington.

HNF-3594. 1999. *Sampling and Analysis Plan for the Preoperational Environmental Survey of the Project W-314 Pipeline.* B. M. Mitchell, B. M. Markes, and C. J. Perkins, Waste Management Federal Services, Inc., Northwest Operations for Fluor Daniel Hanford, Inc., Richland, Washington.

HNF-EP-0527-8. 1999. *Environmental Releases for Calendar Year 1998.* B. P. Gleckler, Waste Management Federal Services of Hanford, Inc., Richland, Washington.

HNF-PRO-454. 1997. *Project Hanford Procedures: Inactive Waste Sites.* Fluor Daniel Hanford, Inc., Richland, Washington.

HSRCM-1, Rev. 2. 1994. *Hanford Site Radiological Control Manual.* HSRCM Project, Richland, Washington.

PNL-8057. 1992. *Calculation of Groundwater Discharge to the Columbia River in the 100 Area.* T. J Gilmore, D. R. Newcomer, S. K. Wurstner, and F. A. Spane, Pacific Northwest Laboratory, Richland, Washington.

PNL-10574. 1995. *Hanford Site Environmental Report for Calendar Year 1994.* R. L. Dirkes and R. W. Hanf, Pacific Northwest Laboratory, Richland, Washington.

PNNL-11795. 1998. *Hanford Site Environmental Report for Calendar Year 1997*. R. L. Dirkes and R. W. Hanf (eds.), Pacific Northwest National Laboratory, Richland, Washington.

PNNL-12088, APP. 2. 1999. *Hanford Site Near-Facility Environmental Monitoring Data Report for Calendar Year 1998*. C. J. Perkins, Waste Management Federal Services, Inc., Northwest Operations for Pacific Northwest National Laboratory, Richland, Washington.

Resource Conservation and Recovery Act. 1976. Public Law 94-580, as amended, 90 Stat. 2795, 42 USC 6901 et seq.

Washington Administrative Code (WAC) 173-216. "State Waste Discharge Program." Olympia, Washington.

Washington Administrative Code (WAC) 173-303-145. "Spills and Discharges Into the Environment." Olympia, Washington.

Washington Administrative Code (WAC) 173-400. "General Regulations for Air Pollution Sources." Olympia, Washington.

Washington Administrative Code (WAC) 246-247. "Radiation Protection–Air Emissions." Olympia, Washington.

Washington Administrative Code (WAC) 246-249. "Radioactive Waste Use of the Commercial Disposal Site." Olympia, Washington.

WHC-MR-0418. 1994. *Historical Records of Radioactive Contamination in Biota at the 200 Areas of the Hanford Site*. A. R. Johnson, B. M. Markes, J. W. Schmidt, A. N. Shah, S. G. Weiss, and K. J. Wilson, Westinghouse Hanford Company, Richland, Washington.

WMNW-CM-004. 1998. *Operational Environmental Monitoring*. S. M. McKinney, Waste Management Federal Services, Inc., Northwest Operations, Richland, Washington.

4.0 Environmental Surveillance Information

Environmental surveillance of the Hanford Site and the surrounding region is conducted to demonstrate compliance with environmental regulations, confirm adherence to U.S. Department of Energy (DOE) environmental protection policies, support DOE environmental management decisions, and provide information to the public.

Sections 4.1 through 4.7 describe results of the Hanford Site surface environmental surveillance and drinking water surveillance projects for 1998 and include, where applicable, information on both radiological and nonradiological constituents. The objectives, criteria, design, and description of these projects are summarized below and provided in detail in the Hanford Site environmental monitoring plan (DOE/RL-91-50, Rev. 2). Radiological doses associated with the surveillance results are discussed in Section 5.0, "Potential Radiological Doses from 1998 Hanford Operations." The quality assurance and quality control programs developed for ensuring the value of surveillance data are described in Section 8.0, "Quality Assurance."

Many samples are collected and analyzed for the Hanford Site environmental surveillance project, and data obtained from the analytical laboratories are compiled in a large database. It is not practical nor desirable to list individual results in this report; therefore, only summary information, emphasizing those radionuclides or chemicals of Hanford origin that are important to environmental or human health concerns, are included. Supplemental data for some sections can be found in Appendix A. More detailed results for specific surface environmental surveillance sampling locations are contained in *Hanford Site Environmental Surveillance Data Report for Calendar Year 1998* (PNNL-12088, APP. 1). The intent of these sections (Sections 4.1 through 4.7) is to provide current surveillance data, to compare 1998 data to past data and existing and accepted standards so that concentrations can be viewed in perspective and to present a general overview of Hanford Site surveillance activities.

In addition to Hanford Site environmental surveillance activities, environmental monitoring is conducted at or near facilities on the site. These near-facility monitoring efforts are discussed in Section 3.0, "Facility-Related Monitoring."

4.0.1 Surface Environmental Surveillance

The Surface Environmental Surveillance Project is a multimedia environmental monitoring effort to measure the concentrations of radionuclides and chemicals in environmental media and assess the integrated potential effects of these materials on the environment and the public. Samples of air, surface water, sediments, soil and natural vegetation, agricultural products, fish, and wildlife are collected. Analyses include the measurement of radionuclides at very low environmental activities and nonradiological chemicals, including metals and anions. In addition, ambient external radiation is measured.

Activities inherent in the operation of the Surface Environmental Surveillance Project include design and implementation, sample collection, sample analysis, database management, data review and evaluation, exposure assessment, and reporting. Other elements of the project include project management, quality assurance/control, training, and records management.

The project focuses on routine releases from DOE facilities on the Hanford Site; however, the project is also responsive to unplanned releases and releases from non-DOE operations on and near the site. Surveillance results are provided annually through this report series. In addition, unusual results or trends are reported to DOE and the appropriate facility managers when they occur. Whereas effluent and near-facility environmental monitoring are conducted by the facility operating contractor or designated subcontractor, environmental surveillance is conducted under an independent program that reports directly to the DOE Richland Operations Office Environmental Assurance, Permits and Policy Division.

4.0.1.1 Surveillance Objectives

The general requirements and objectives for environmental surveillance are contained in DOE Orders 5400.1, "General Environmental Protection Program," and 5400.5, "Radiation Protection of the Public and the Environment." The broad objectives (DOE Order 5400.1) are to demonstrate compliance with legal and regulatory requirements, to confirm adherence to DOE environmental protection policies, and to support environmental management decisions.

These requirements are embodied in the surveillance objectives stated in the DOE Orders and DOE/EH-0173T, "Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance," and include the following:

- determine compliance with applicable environmental quality standards and public exposure limits and applicable laws and regulations; the requirements of DOE Orders; and the environmental commitments made in environmental impact statements, environmental assessments, safety analysis reports, or other official DOE documents. Additional objectives that derive from the DOE Orders and this primary objective include the following:
  - conduct preoperational assessments
  - assess radiological doses to the public and aquatic biota from site operations
  - assess doses from other local sources
  - report alarm levels and potential doses exceeding reporting limits (DOE Order 5400.5, Chapter II, Section 7)
  - maintain an environmental monitoring plan
- determine background levels and site contributions of contaminants in the environment
- determine long-term accumulation of site-related contaminants in the environment and predict trends; characterize and define trends in the physical, chemical, and biological conditions of environmental media
- determine effectiveness of treatment and controls in reducing effluents and emissions
- determine validity and effectiveness of models to predict the concentrations of pollutants in the environment
- detect and quantify unplanned releases
- identify and quantify new environmental quality problems.

DOE/EH-0173T indicates that subsidiary objectives for surveillance should be considered. Subsidiary objectives applicable to the site include the following:

- obtain data and maintain the capability to assess the consequence of accidents
- provide public assurance; address issues of concern to the public, stakeholders, regulators, and business community
- enhance public understanding of site environmental impacts, primarily through public involvement and by providing public information

- provide environmental data and assessments to assist the DOE Richland Operations Office in environmental management of the site.

4.0.1.2 Surveillance Design

The DOE Orders require that the content of surveillance programs be determined on a site-specific basis by the DOE Richland Operations Office. The surveillance programs must reflect facility characteristics; applicable regulations; hazard potential; quantities and concentrations of materials released; extent and use of affected air, land, and water; and specific local public interest and concern. Environmental surveillance at the Hanford Site is designed to meet the listed objectives while considering the environmental characteristics of the site and potential and actual releases from site operations. Surveillance activities focus on determining environmental impacts and compliance with public health and environmental standards or protection guides rather than on providing detailed radiological and chemical characterization. Experience gained from environmental surveillance activities and studies conducted at the Hanford Site for >50 yr provides valuable technical background for planning the surveillance design.

The Hanford Site environmental surveillance program has focused historically on radionuclides in various media and nonradiological water quality parameters. In recent years, surveillance for nonradiological constituents, including hazardous chemicals, has been expanded significantly. A detailed chemical pathway and exposure analysis for the Hanford Site was completed in 1995 (PNL-10714). The analysis helped guide the selection of chemical surveillance media, sampling locations, and chemical constituents.

Each year, a radiological pathway analysis and exposure assessment is performed. The 1998 pathway analysis was based on 1998 source-term data and on the comprehensive pathway and dose assessment methodology included in the Generation II (GENII) computer code (PNL-6584) used for estimating radiation doses to the public from Hanford Site operations. The CRITRII computer code (PNL-8150) was used to calculate doses to animals, and manual calculations were used to compute the doses not addressed in the computer codes. The results of the pathway analysis and exposure assessment serve as a basis for future years' surveillance program design.

Exposure is defined as the interaction of an organism with a physical or chemical agent of interest. Thus, exposure can be quantified as the amount of chemical or physical agent available for absorption at the organism's exchange boundaries (i.e., skin contact, lungs, gut). An exposure pathway is identified based on 1) examination of the types, location, and sources (contaminated soil, raw effluent) of contaminants; 2) principal release mechanisms; 3) probable environmental fate and transport (including persistence, partitioning, and intermediate transfer) of contaminants of interest; and, most important, 4) location and activities of the potentially exposed populations. Mechanisms that influence the fate and transport of a chemical through the environment and influence the amount of exposure a person might receive at various receptor locations are listed below.

Once a radionuclide or chemical is released into the environment, it may be

- transported (e.g., migrate downstream in solution or on suspended sediment, travel through the atmosphere, or be carried off the site by contaminated wildlife)
- physically or chemically transformed (e.g., deposition, precipitation, volatilization, photolysis, oxidation, reduction, hydrolysis or radionuclide decay)
- biologically transformed (e.g., biodegradation)
- accumulated in the receiving media (e.g., sorbed strongly in the soil column, stored in organism tissues).

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

public are the atmosphere and surface water. Figure 4.0.1 illustrates these potential routes and exposure pathways to humans.

The significance of each pathway was determined from measurements and calculations that estimated the amount of radioactive material or chemical transported along each pathway and by comparing the concentrations or potential doses to environmental and public health protection standards or guides. Pathways were also evaluated based on prior studies and observations of radionuclide and chemical movement through the environment and food chains. Calculations based on effluent data showed the expected concentrations off the Hanford Site to be low for all Hanford-produced radionuclides and chemicals and to be frequently below the level that could be detected by monitoring technology. To ensure that radiological and chemical analyses of samples were sufficiently sensitive, minimum detectable concentrations of key radionuclides and chemicals were established at levels well below applicable health standards.

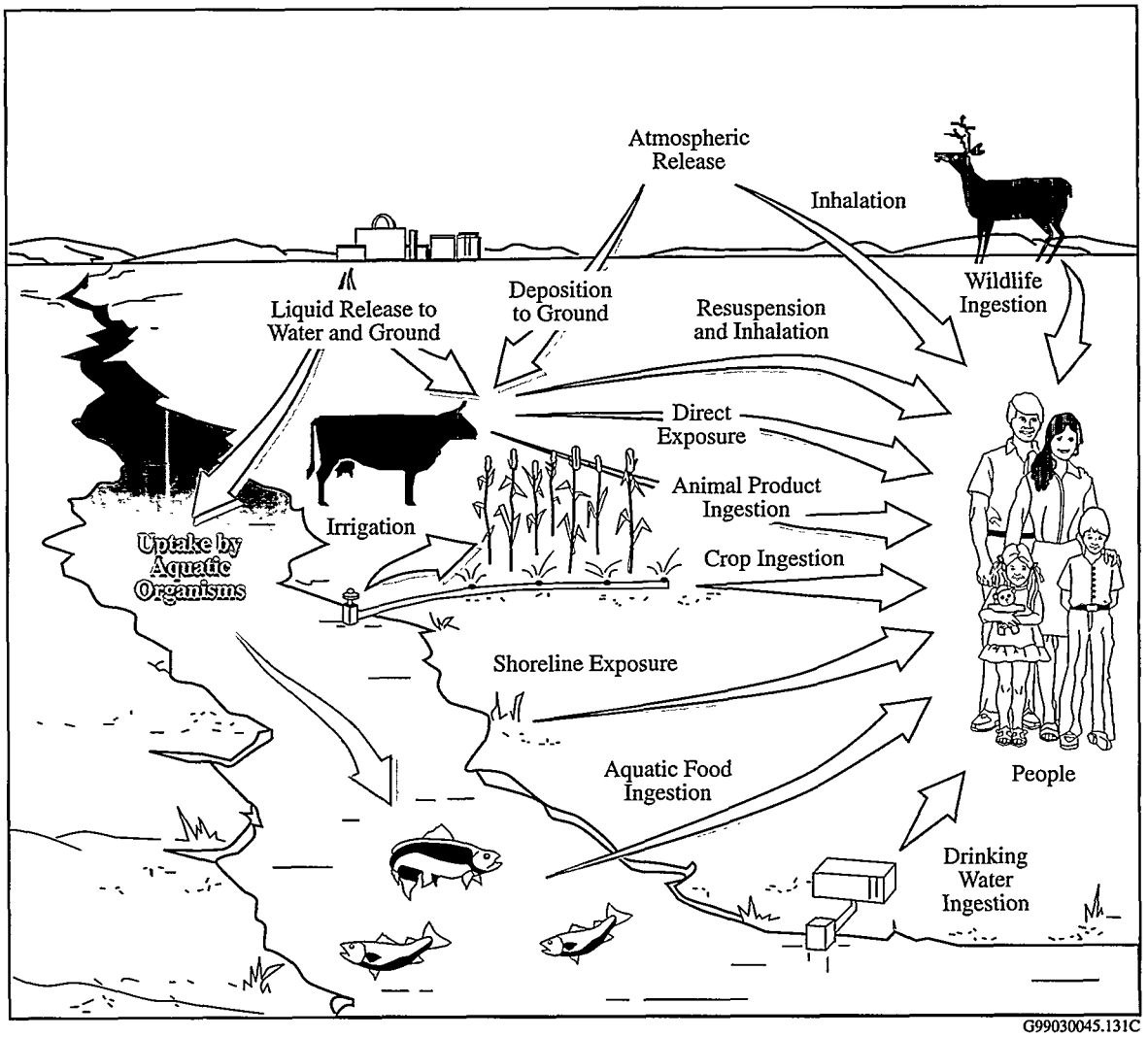


Figure 4.0.1. Primary Exposure Pathways

Environmental and food chain pathways were monitored near facilities releasing effluents and at potential offsite receptor locations. The surveillance design at Hanford used a stratified sampling approach to monitor these pathways. Samples were collected, and radionuclide and chemical concentrations were measured in three general surveillance zones that extended from onsite operational areas to the offsite environs.

The first surveillance zone extended from near the operational areas to the site perimeter. The environmental concentrations of releases from facilities and fugitive sources (those released from other than monitored sources such as contaminated soils) generally would be the highest and, therefore, most easily detected in this zone. The second surveillance zone consisted of a series of perimeter sampling stations positioned near or just inside the site boundary, along State Highway 240, which runs through the site from Richland to the Vernita Bridge, and along the Columbia River (see Figure 1.0.1). Exposures at these locations were typically the maximum that any member of the public could receive. The third surveillance zone consisted of nearby and distant community locations within an 80-km (50-mi) radius of the site. Surveillance was conducted in communities to obtain measurements at locations where a large number of people potentially could be exposed to Hanford Site releases and to document that contaminant levels were well below standards established to protect public health. Table 4.0.1 summarizes the sample types and measurement locations in all three zones for 1998.

Background concentrations were measured at distant locations and compared with concentrations measured on the site and at perimeter and community locations. Background locations were essentially unaffected by Hanford Site operations (i.e., these locations could be used to measure ambient environmental levels of chemicals and radionuclides). Comparing concentrations at these background locations to concentrations measured on or near the site indicated the impact, if any, of Hanford Site operations.

To the extent possible, radiological dose assessments should be based on direct measurements of dose rates and radionuclide activities in environmental media. However, the amounts of most radioactive materials released from Hanford Site operations in recent years generally have been too small to be measured directly once dispersed in the offsite environment. For the measurable radionuclides, often it was not possible to distinguish levels resulting from worldwide fallout and natural sources from those associated with Hanford Site releases. Therefore, offsite doses in 1998 were estimated using the following methods:

- Doses from monitored air emissions and liquid effluents released to the Columbia River were estimated by applying environmental transport and dose calculation models to measured effluent monitoring data and selected environmental measurements.
- Doses from fugitive air emissions (e.g., from unmonitored, resuspended, contaminated soils) were estimated from measured airborne concentrations at site perimeter locations.
- Doses from fugitive liquid releases (e.g., unmonitored groundwater seeping into the Columbia River) were estimated by evaluating differences in measured concentrations in Columbia River water upstream and downstream from the Hanford Site.

The surveillance design is reviewed annually based on the above considerations as well as an awareness of planned waste management and environmental restoration activities. The final sampling design and schedule are documented annually in the environmental surveillance master sampling schedule (PNNL-11803).

Table 4.0.1. Routine Environmental Surveillance Sample Types and Measurement Locations, 1998

		Sample Locations						
						Columbia River		
Type	Total Number	Onsite[a]	Site Perimeter[b]	Nearby[c]	Distant[c]	Upstream[c]	Hanford Reach[b]	Downstream[c]
Air	39	20	9	8[d]	2[e]			
Springs water	8						8	
Springs sediment	2						2	
Columbia River	7					2	4	1
Irrigation water	1		1					
Drinking water	6	6						
River sediments	7					2[f]	3	2
Ponds	2	2						
Foodstuffs	16			12	4			
Wildlife	7	2				1[g]	4	
Soil	20	13	4	2[h]	1			
Vegetation	10[i]	4	4		2			
TLDs[j]	69	26	33[k]	8[d]	2[e]			
Shoreline surveys	13		13					
Gamma measurements (PIC)[l]	4			3[d]	1[d]			

(a) Surveillance zone 1.
(b) Surveillance zone 2.
(c) Surveillance zone 3.
(d) Community-operated environmental surveillance stations.
(e) Includes one community-operated environmental surveillance station.
(f) Includes one Snake River location above Ice Harbor Dam.
(g) Sample collected from the Columbia River near the Vantage Bridge.
(h) Fitzner-Eberhardt Arid Lands Ecology Reserve.
(i) Does not include shoreline samples or fruit tree samples.
(j) TLDs = thermoluminescent dosimeters.
(k) Includes locations along the Columbia River.
(l) PIC = Pressurized ionization chamber.

4.1 Air Surveillance

B. M. Gillespie

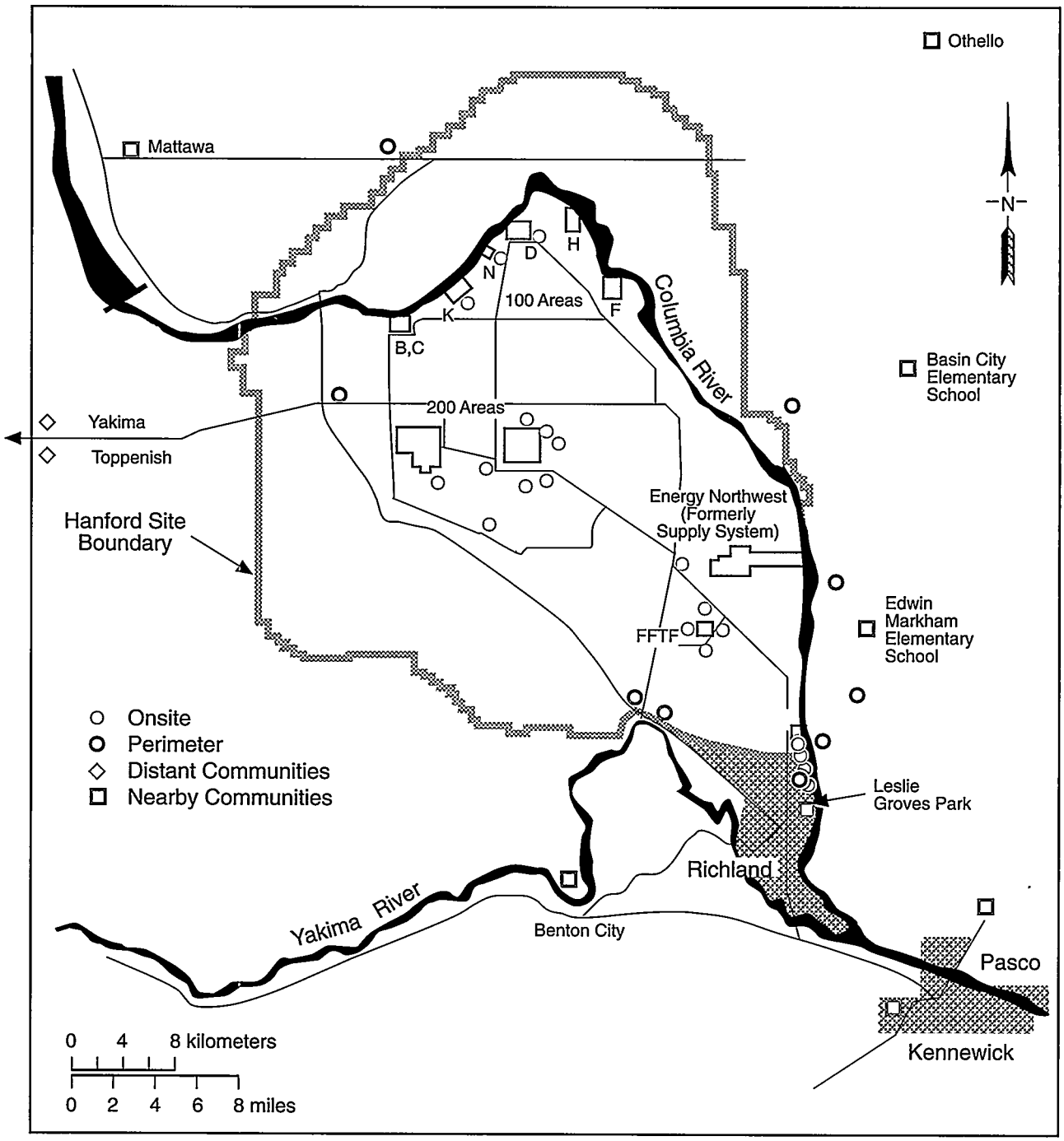
Atmospheric releases of radioactive material from the Hanford Site to the surrounding region are a potential source of human exposure. Radioactive constituents in air are monitored at a number of locations on and around the site. The influence of Hanford emissions on the local environment was evaluated by comparing air concentrations measured at distant locations within the region to concentrations measured at the site perimeter. This section discusses sample collection techniques and analytes tested for at each location and summarizes the analytical results of the air surveillance program. A complete listing of all analytical results summarized in this section is reported separately (PNNL-12088, APP. 1). A detailed description of all radiological sampling and analytical techniques is provided in the environmental monitoring plan (DOE/RL-91-50, Rev. 2).

4.1.1 Collection of Air Samples and Analytes Tested for at Each Sample Location

Airborne radionuclide samples were collected at 39 continuously operating samplers: 20 on the Hanford Site, 9 near the site perimeter, 8 in nearby communities, and 2 in distant communities (Figure 4.1.1 and Table 4.1.1). Nine of the stations were community-operated environmental surveillance stations (discussed in Section 7.4, "Community-Operated Environmental Surveillance Program") that were managed and operated by local school teachers. Air samplers on the Hanford Site were located primarily around major operational areas to maximize the ability to detect radiological contaminants resulting from site operations. Perimeter samplers were located around the site, with emphasis on the prevailing downwind directions to the south and east of the site (discussed in Section 7.1, "Climate and Meteorology"). Continuous samplers located in Benton City, Kennewick, Mattawa, Othello, Pasco, and Richland provided data for the nearest population centers. Samplers in the distant communities of Toppenish and Yakima provided background data for communities essentially unaffected by site operations.

Samples were collected according to a schedule established before the monitoring year (PNNL-11803). The air sampling locations and the analytes tested for at each location are given in Table 4.1.1. Airborne particles were sampled at each of these locations by continuously drawing air through a high-efficiency glass-fiber filter. The samples were transported to an analytical laboratory and stored for at least 72 h. The storage period was necessary to allow for the decay of short-lived, naturally occurring radionuclides (e.g., radon gas decay products) that would otherwise obscure detection of longer-lived radionuclides potentially present from Hanford Site emissions. The filters were then analyzed for gross beta radioactivity, and most filters were also analyzed for gross alpha radioactivity.

For most radionuclides, the amount of radioactive material collected on the filter during the 2-wk period was too small to be readily measured. The sensitivity and accuracy of sample results were increased by combining biweekly samples for nearby locations (or, in some cases, a single location) into



G99030045.1aa

Figure 4.1.1. Air Sampling Locations, 1998 (see Table 4.1.1 for location names)

Table 4.1.1. Air Sampling Locations, Sample Composite Groups, and Analyses, 1998

Map[a] Location	Sampling Location	Analytes[b]	Composite Group	Analytes[c]
Onsite				
1	100-K Area	Alpha, beta, ^{3}H	100 Areas	Gamma, Sr, Pu
2	100-N, 1325 Crib	Alpha, beta, ^{3}H		
3	100-D Area	Alpha, beta		
4	N of 200 East	Beta	North of 200-East	Gamma - Annual
5	E of 200E	Alpha, beta	200 E Area	Gamma, Sr, Pu, U
6	200 ESE	Alpha, beta, ^{3}H, ^{129}I		
7	S of 200E	Alpha, beta		
8	B Pond	Alpha, beta	B Pond	Gamma, Sr, Pu, U
9	Army Loop Camp	Alpha, beta	200 West South East	Gamma, Sr, Pu, U
10	200 Tel. Exchange	Alpha, beta, ^{3}H		
11	200 West SE	Alpha, beta	200 West	Gamma, Sr, Pu, U
12	300 Water intake	Beta	300 Area	Gamma, Sr, Pu, U
13	300 South Gate	Alpha, beta, ^{3}H		
14	300 Trench	Alpha, beta, ^{3}H	300 NE	Gamma, Sr, Pu, U
15	300 NE			
16	400-East	Alpha, beta, ^{3}H	400 Area	Gamma, Sr, Pu
17	400-West	Alpha, beta		
18	400-South	Alpha, beta		
19	400-North	Alpha, beta		
20	Wye Barricade	Alpha, beta	Wye Barricade	Gamma, Sr, Pu, U
Perimeter				
21	Ringold Met. Tower	Alpha, beta, ^{3}H, ^{129}I	Ringold Met. Tower	Gamma, Sr, Pu
22	W End of Fir Road	Alpha, beta	W End of Fir Road	Gamma, Sr, Pu, U
23	Dogwood Met. Tower	Alpha, beta, ^{3}H	Dogwood Met. Tower	Gamma, Sr, Pu, U
24	Byers Landing	Alpha, beta, ^{3}H, ^{129}I	Byers Landing	Gamma, Sr, Pu, U
25	Battelle Complex	Beta	Battelle Complex	Gamma - Annual
26	Horn Rapids Substation	Alpha, beta	Prosser Barricade	Gamma, Sr, Pu, U
27	Prosser Barricade	^{3}H		
28	Yakima Barricade	Alpha, beta	Yakima Barricade	Gamma, Sr, Pu
29	Wahluke Slope	Alpha, beta, ^{3}H	Wahluke Slope	Gamma, Sr, Pu

Table 4.1.1. (contd)

Map[a] Location	Sampling Location	Analytes[b]	Composite Group	Analytes[c]
Nearby Communities				
30	Basin City[d]	Alpha, beta, ^{3}H	Basin City Elem. School	Gamma, Sr, Pu, U
31	Richland[d]	Alpha, beta, ^{3}H	Leslie Groves Park	Gamma, Sr, Pu, U
32	Pasco[d]	Beta	Tri-Cities	Gamma, Sr, Pu
33	Kennewick[d]	Alpha, beta		
34	Benton City[d]	Beta	Benton City	Gamma - Annual
35	North Franklin County[d]	Alpha, beta, ^{3}H	Edwin Markham Elem. School	Gamma, Sr, Pu, U
36	Mattawa[d]	Beta	Mattawa	Gamma - Annual
37	Othello[d]	Beta	Othello	Gamma - Annual
Distant Communities				
38	Yakima	Alpha, beta, ^{3}H, ^{129}I	Yakima	Gamma, Sr, Pu, U
39	Toppenish[d] (Heritage College)	Alpha, beta, ^{3}H	Toppenish	Gamma, Sr, Pu, U

(a) See Figure 4.1.1.
(b) Alpha (gross) and beta (gross) samples are collected and analyzed every 2 wk, ^{3}H samples are collected and analyzed every 4 wk, and ^{129}I samples are collected every 4 wk, combined into a quarterly composite sample and analyzed for each location.
(c) Gamma scans are performed on quarterly composite samples (or on annual composite samples [gamma - annual]); strontium-90, isotopic plutonium, and isotopic uranium analyses are performed on annual composite samples.
(d) A community-operated environmental surveillance station.

quarterly or annual composite samples. The quarterly composite samples were analyzed for specific gamma-emitting radionuclides (Appendix E). The quarterly composites were then used to form annual composite samples (Table 4.1.2). Annual composites were analyzed for strontium-90 and plutonium isotopes, with selected annual composites also analyzed for uranium isotopes or gamma-emitting radionuclides.

Samples were collected for iodine-129 at four locations by drawing air through a cartridge containing chemically treated, special, low-background petroleum-charcoal positioned downstream of a particle filter. Samples were collected monthly and combined to form quarterly composite samples for each location.

Atmospheric water vapor was collected for tritium analysis at 19 locations by continuously passing air through cartridges containing silica gel, which were exchanged every 4 wk. The collection efficiency of the silica gel adsorbent is discussed in Patton et al. (1997). The collected water was distilled from the silica gel and analyzed for its tritium content.

Table 4.1.2. Airborne Radionuclide Activities in the Hanford Environs, 1998 Compared to Previous Years

Radionuclide	Location Group[a]	1998 No. of Samples	1998 No. of Detections[b]	1998 Maximum[c]	1998 Average[d]	1995-1997 No. of Samples	1995-1997 No. of Detections[b]	1995-1997 Maximum[c]	1995-1997 Average[d]	Derived Concentration Guide[e]
				pCi/m³	pCi/m³			pCi/m³	pCi/m³	pCi/m³
Tritium	300 Area	54	49	25 ± 3.0	4.1 ± 1.2	141	32	5 ± 2	0.81 ± 0.18	100,000
	Onsite	65	40	7.9 ± 1.9	1.7 ± 0.37	187	47	24 ± 20	1.1 ± 0.34	
	Perimeter	66	36	6.1 ± 2.1	1.4 ± 0.28	184	21	12 ± 22	0.92 ± 0.28	
	Nearby communities	39	21	14 ± 2.0	1.7 ± 0.68	116	13	16 ± 15	1.2 ± 0.48	
	Distant communities	26	10	5.1 ± 2.1	1.2 ± 0.41	91	6	5.2 ± 5	0.57 ± 0.19	
		1998				1993-1997				
				pCi/m³	pCi/m³			pCi/m³	pCi/m³	
Gross beta	Onsite	531	531	0.035 ± 0.0052	0.015 ± 0.00051	2,457	2,455	0.070 ± 0.0070	0.018 ± 0.00044	No standard
	Perimeter	204	204	0.037 ± 0.0055	0.015 ± 0.00086	995	992	0.098 ± 0.010	0.018 ± 0.00071	
	Nearby communities	210	210	0.052 ± 0.0080	0.014 ± 0.00089	874	874	0.079 ± 0.0082	0.018 ± 0.00070	
	Distant communities	58	58	0.034 ± 0.0050	0.013 ± 0.0017	281	281	0.095 ± 0.0099	0.016 ± 0.0013	
				aCi/m³	aCi/m³			aCi/m³	aCi/m³	aCi/m³
Gross alpha	Onsite	484	353	3,100 ± 1,000	680 ± 36	2,253	1,748	5,500 ± 1,300	500 ± 15	No standard
	Perimeter	181	140	2,000 ± 710	700 ± 53	922	757	2,200 ± 600	530 ± 21	
	Nearby communities	112	83	1,900 ± 730	660 ± 65	515	428	1,800 ± 530	540 ± 25	
	Distant communities	58	32	1,400 ± 830	530 ± 88	279[f]	210	4,800 ± 920	470 ± 60	
Strontium-90	Onsite	10	6	290 ± 58	61 ± 56	51	13	300 ± 96	24 ± 18	9,000,000
	Perimeter	7	5	390 ± 79	89 ± 100	35	3	35 ± 11	-3.4 ± 6.5	
	Nearby communities	4	3	69 ± 32	47 ± 31	20	2	16 ± 16	-3.2 ± 6.2	
	Distant communities	2	1	78 ± 27	53 ± 49	11	0	68 ± 120	2.6 ± 15	
Iodine-129	Onsite	4	4	22 ± 1.1	23 ± 1.7	20	20	52 ± 4.5	36 ± 4.9	70,000,000
	Perimeter	8	8	1.5 ± 0.12	0.65 ± 0.41	40	40	2.3 ± 0.28	1.1 ± 0.17	
	Distant communities	4	4	0.088 ± 0.0056	0.065 ± 0.022	20	20	0.10 ± 0.010	0.053 ± 0.010	
Plutonium-238	Onsite	10	1	2.9 ± 0.94	0.25 ± 0.52	52	1	0.68 ± 2.2	-0.14 ± 0.11	30,000
	Perimeter	7	0	0.18 ± 0.3	-0.034 ± 0.092	36	0	3.1 ± 4.1	-0.021 ± 0.24	
	Nearby communities	4	0	0.097 ± 0.37	-0.04 ± 0.11	24	1	0.76 ± 3.3	-0.0060 ± 0.15	
	Distant communities	2	0	0.14 ± 0.44	0.0010 ± 0.28	13	0	0.86 ± 3.5	0.09 ± 0.20	

Table 4.1.2. (contd)

Radionuclide	Location Group[a]	1998 No. of Samples	1998 No. of Detections[b]	1998 Maximum[c]	1998 Average[d]	1993-1997 No. of Samples	1993-1997 No. of Detections[b]	1993-1997 Maximum[c]	1993-1997 Average[d]	Derived Concentration Guide[e]
				aCi/m³	aCi/m³			aCi/m³	aCi/m³	aCi/m³
Plutonium-239,240	Onsite	10	5	2.0 ± 1.3	0.69 ± 0.44	51	22	12.4 ± 2.5	1.4 ± 0.64	20,000
	Perimeter	7	2	0.74 ± 0.52	0.28 ± 0.24	35	11	1.8 ± 1.7	0.45 ± 0.17	
	Nearby communities	4	0	0.44 ± 0.5	0.18 ± 0.19	20	7	1.8 ± 1.7	0.39 ± 0.31	
	Distant communities	2	0	0.51 ± 0.57	0.30 ± 0.42	11	1	1.2 ± 1.2	0.17 ± 0.30	
Uranium-234	Onsite	9	9	52 ± 13	28 ± 11	42	41	140 ± 210	25 ± 6.8	90,000
	Perimeter	4	4	35 ± 6.3	26 ± 13	20	20	54 ± 18	28 ± 5.5	
	Nearby communities	3	3	31 ± 6.4	27 ± 5.8	15	15	37 ± 13	24 ± 3.8	
	Distant communities	2	2	19 ± 4.9	19 ± 1.1	11	11	31 ± 10	20 ± 4.4	
Uranium-235	Onsite	9	5	6.3 ± 5.7	1.8 ± 1.3	42	10	51 ± 130	2 ± 2.4	100,000
	Perimeter	4	3	2.4 ± 1.6	1.4 ± 1.1	20	8	4.3 ± 4.8	1.4 ± 0.51	
	Nearby communities	3	0	0.98 ± 1.3	0.77 ± 0.36	15	6	4.3 ± 4.8	1.3 ± 0.6	
	Distant communities	2	0	0.37 ± 0.98	0.13 ± 0.48	11	0	3.3 ± 4.0	0.68 ± 0.7	
Uranium-238	Onsite	9	9	50 ± 8.4	25 ± 10	42	41	58 ± 14	19 ± 3.6	100,000
	Perimeter	4	4	41 ± 6.9	27 ± 14	20	20	43 ± 8.6	26 ± 4.3	
	Nearby communities	3	3	32 ± 6.5	28 ± 4.8	15	15	36 ± 13	24 ± 4.0	
	Distant communities	2	2	20 ± 4.9	20 ± 0.30	11	10	30 ± 7.5	17 ± 3.8	
Cobalt-60	Onsite	43	0	700 ± 470	84 ± 82	197	27	880 ± 490	66 ± 37	80,000,000
	Perimeter	29	0	1,000 ± 530	-56 ± 176	143	11	740 ± 870	41 ± 45	
	Nearby communities	20	0	630 ± 720	4.1 ± 170	89	5	800 ± 560	7.0 ± 57	
	Distant communities	9	0	640 ± 460	219 ± 140	44	5	680 ± 440	148 ± 81	
Cesium-137	Onsite	43	0	710 ± 530	-55 ± 80	197	17	570 ± 420	30 ± 39	400,000,000
	Perimeter	29	0	600 ± 550	53 ± 111	143	9	660 ± 620	2.0 ± 40	
	Nearby communities	20	0	860 ± 580	8.9 ± 145	89	5	710 ± 330	45 ± 44	
	Distant communities	9	0	190 ± 530	-6.2 ± 98	44	1	390 ± 290	26 ± 66	

(a) Location groups are identified in Table 4.1.1 and located on Figure 1.1.1.
(b) Detection is defined as the result reported greater than the 2-sigma total propagated analytical uncertainty except for gamma-emitting radioisotopes (e.g., cobalt-60, cesium-137). Detect is greater than minimum detectable activity.
(c) Maximum single sample result ± total propagated analytical uncertainty at 2-sigma. Negative concentration values are explained in the section "Helpful Information."
(d) Average of all samples ±2 times the standard error of the mean.
(e) DOE derived concentration guide (DOE Order 5400.5; see Appendix C, Table C.5).
(f) Two results from the distant communities were excluded as anomalous values through the use of a Q-test (26,300 ± 3,400 aCi/m³ at Sunnyside and 8,000 ± 1,000 aCi/m³ at Yakima [Skoog and West 1980]).

Some air samples were collected at nine community-operated environmental surveillance stations (see Section 7.4, "Community-Operated Environmental Surveillance Program"). These samples were collected by local teachers as part of an ongoing DOE-sponsored program to promote public awareness of Hanford Site environmental monitoring programs. The samples were submitted to the analytical laboratory and treated the same as all other submitted samples.

4.1.2 Radiological Results for Air Samples

Radiological air sampling results for onsite, site perimeter, nearby communities, and distant communities for gross alpha, gross beta, and specific radionuclides are summarized in Table 4.1.2.

A detectable value is defined in this section as a value reported above the 2-sigma total propagated analytical uncertainty for all analytes of interest, except for gamma-emitting radionuclides. A gamma-emitting radionuclide is detectable if the radionuclide library of the software determines an isotope activity above the minimum detectable activity of a sample. The nominal detection limit is defined as the average 2-sigma total propagated analytical uncertainty of the population of reported values.

The average gross alpha radioactivity at the site perimeter was slightly elevated compared to the levels measured at distant stations (see Table 4.1.2) and was similar to values reported for 1993 through 1997 (Figure 4.1.2). The highest onsite gross alpha radioactivity was at the S of 200E sampling location (7 on Figure 4.1.1).

Tritium activities measured in 1998 (excluding 300 Area samples) were similar to values reported for 1995 through 1997 (see Table 4.1.2) and did not show the highly elevated activities and widely variable results reported for 1991 through 1994 (Section 4.1 in PNL-11139). For 1998, approximately 60% of the samples analyzed for tritium had results reported above the detection limit (the methodology is capable of detecting activities of no less than 1 pCi/m^3). Sample results above the detection limit were consistently determined for the 300 Area samples. Tritium releases in the 300 Area are associated with research and development activities (see Section 3.1, "Facility Effluent Monitoring"). These activities are expected to continue for the next 2 yr; therefore, higher tritium activities are expected for the 300 Area samples. Table 4.1.2 shows the slightly elevated 300 Area average tritium activity with respect to other onsite average tritium activities.

The annual average tritium activity measured at the site perimeter (1.4 ± 0.28 pCi/m^3) was slightly higher than the annual average value at the distant locations (1.2 ± 0.41 pCi/m^3); however, the difference was not statistically significant (log transformed, two-tailed t-test, 5% significance level). The annual average tritium measured at the site perimeter in 1998 was <0.002% of the 100,000-pCi/m^3 DOE derived concentration guide (DOE Order 5400.5).

Gross beta levels in air for 1998 (Figure 4.1.3) peaked during the winter, repeating a pattern of natural annual radioactivity fluctuations (Eisenbud 1987). The average gross beta activity was slightly higher at the site perimeter than the annual average value at the distant location; however, the difference was not statistically significant (log transformed, two-tailed t-test, 5% significance level), indicating that the observed levels were predominantly a result of natural sources and worldwide radioactive fallout.

For samples analyzed for strontium-90 in 1998, 15 of the 23 samples were above the detection limit (see Table 4.1.2). This number of samples (65%) above the detection limit is abnormally high compared to the previous 5 yr (15%) (Figure 4.1.4). These apparently anomalous results are probably due to an error or sample contamination during the

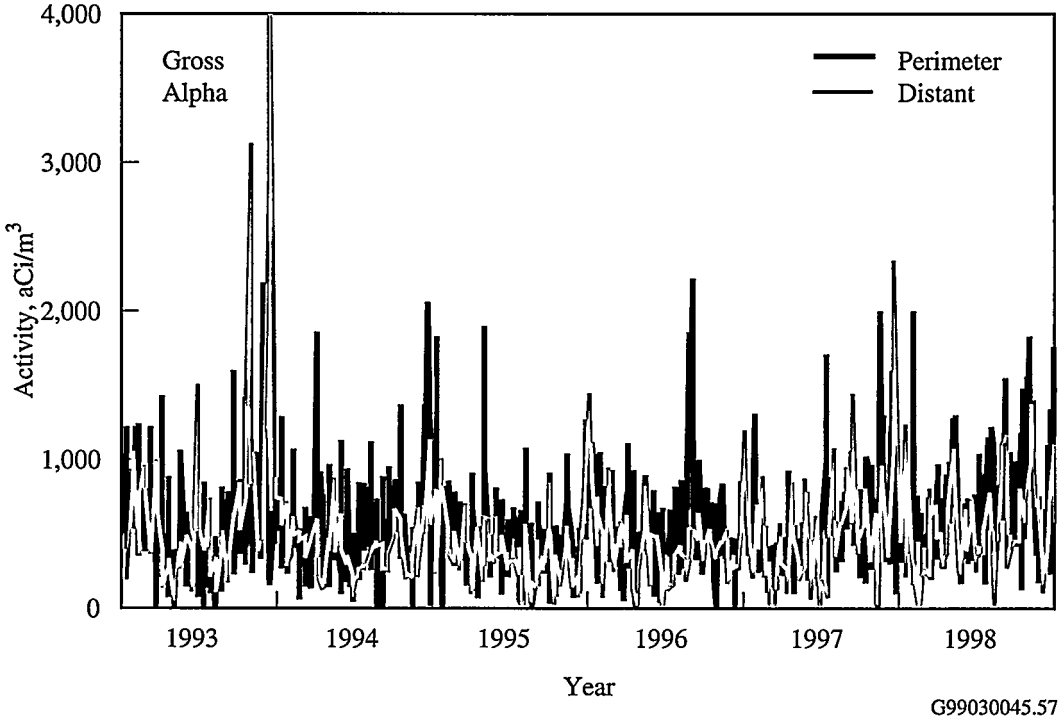


Figure 4.1.2. Gross Alpha in Airborne Particulate Samples, 1993 Through 1998

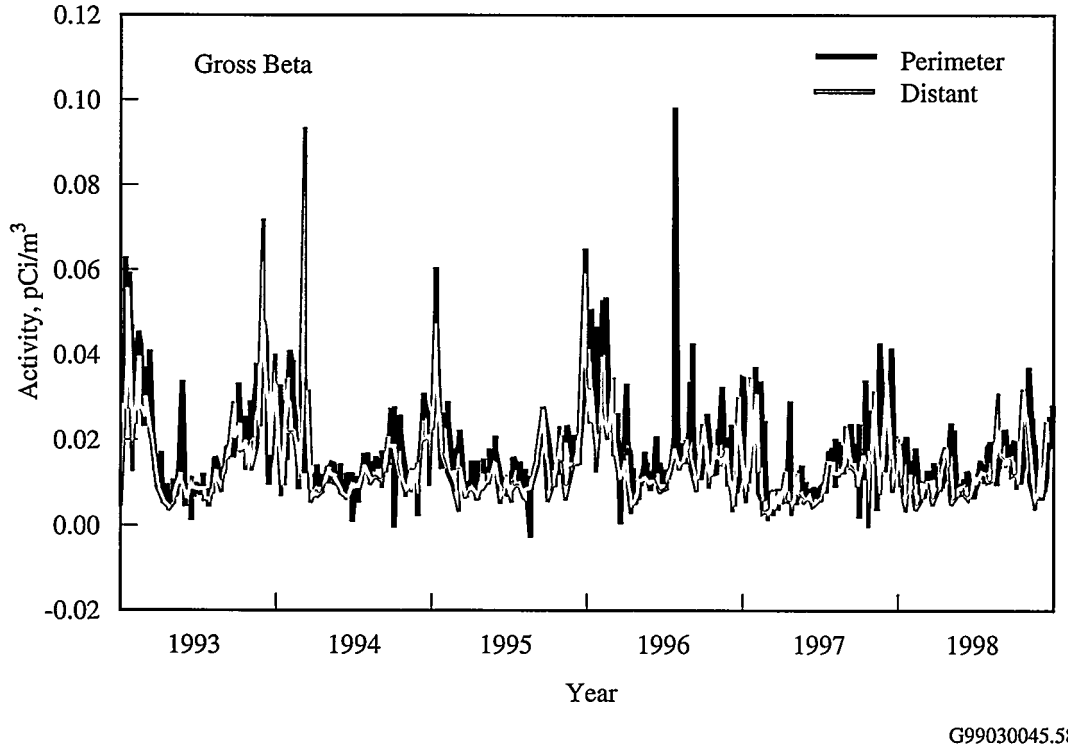


Figure 4.1.3. Gross Beta in Airborne Particulate Samples, 1993 Through 1998

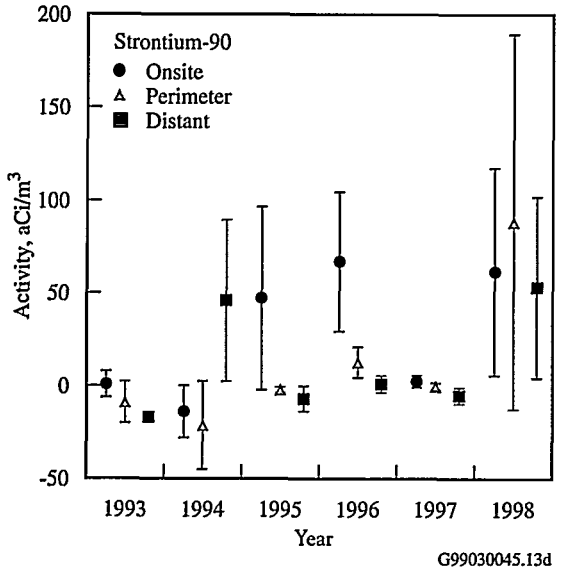


Figure 4.1.4. Annual Average Strontium-90 Activities (±2 standard error of the mean) in Air, 1993 Through 1998

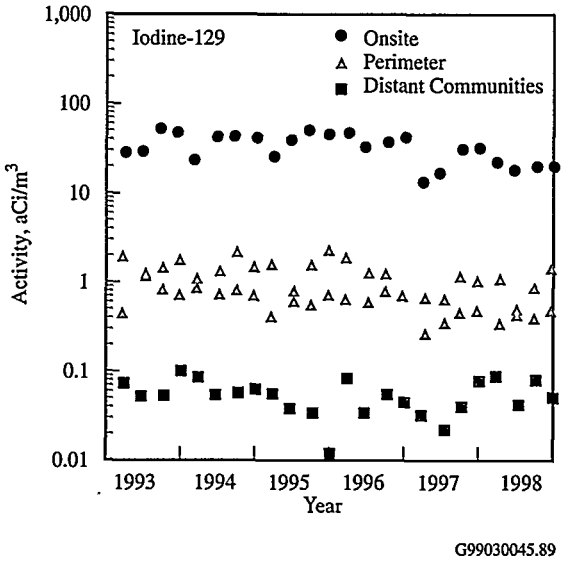


Figure 4.1.5. Iodine-129 Activities in Air, 1993 Through 1998

analytical process. No significant Hanford Site effluent source was reported for strontium-90 in 1998 (see Table 3.1.1 in Section 3.1, "Facility Effluent Monitoring"). The perimeter average appears to be elevated with respect to both the onsite average and the distant activities; however, the difference was not statistically significant (log transformed, two-tailed t-test, 5% significance level). The highest level (390 ± 79 aCi/m^3) was determined for the Ringold Met. Tower composite sample (location 21 on Figure 4.1.1), which is 0.004% of the 9,000,000-aCi/m^3 derived concentration guide.

Iodine-129 analyses were performed on samples collected downwind of the Plutonium-Uranium Extraction Plant, at two downwind perimeter locations, and at a distant location (Yakima) in 1998 (see Figure 4.1.1). Onsite levels in 1998 were elevated compared to those measured at the site perimeter, and perimeter levels were higher than those measured at Yakima, the distant location (Figure 4.1.5 and see Table 4.1.2). Iodine-129 activity differences between these locations were statistically significant (log transformed, two-tailed t-test, 5% significance level) and indicated a Hanford source. Onsite and perimeter air activities have remained at their respective levels from 1993 through 1998 (see Figure 4.1.5). Onsite air activities of iodine-129 were influenced by minor emissions (0.00031 Ci; see Table 3.1.1) from the Plutonium-Uranium Extraction Plant and possible releases from waste storage tanks and cribs. The annual average iodine-129 activity at the downwind perimeter in 1998 (0.65 ± 0.41 aCi/m^3) was <0.000001% of the 70,000,000-aCi/m^3 derived concentration guide.

Plutonium-238 was detected in only 1 of the 23 air samples for 1998 (nominal detection limit of 0.4 aCi/m^3). The highest activity (2.9±0.94 aCi/m^3) was determined for the 300 Area composite sample (locations 12 and 13 on Figure 4.1.1), which is 0.01% of the 30,000-aCi/m^3 derived concentration guide.

The average plutonium-239,240 activities detected in onsite and offsite air samples are given in Table 4.1.2 and Figure 4.1.6. The annual average air activity of plutonium-239,240 at the site perimeter was 0.28 ± 0.24 aCi/m^3, which is <0.002% of the

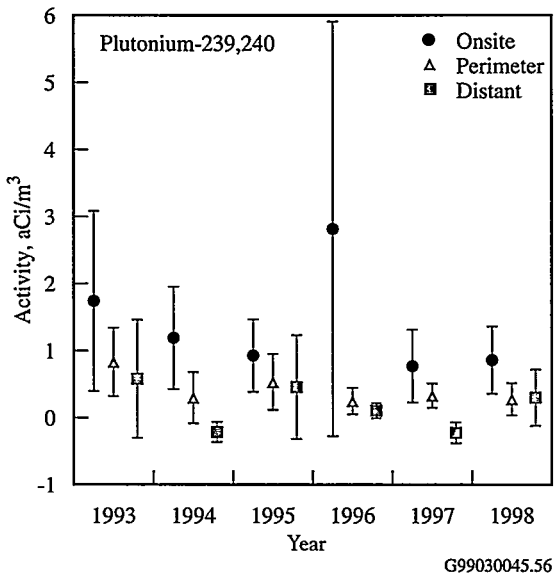


Figure 4.1.6. Annual Average Plutonium-239,240 Activities (±2 standard error of the mean) in Air, 1993 Through 1998

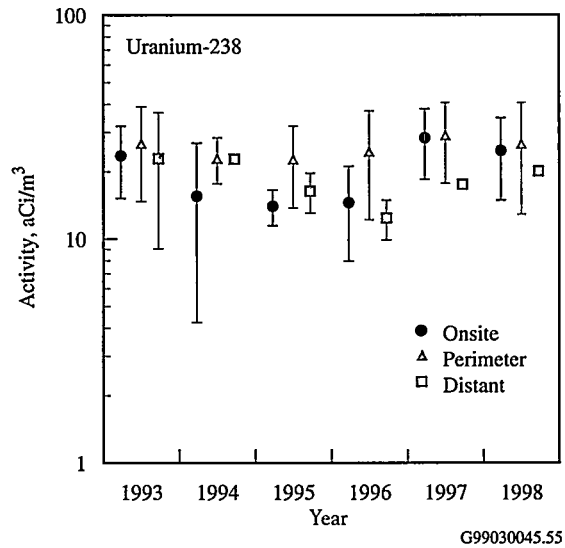


Figure 4.1.7. Annual Average Uranium-238 Activities (±2 standard error of the mean) in Air, 1993 Through 1998

20,000-aCi/m³ derived concentration guide. The annual average air activity was slightly lower for the site perimeter locations than the distant locations (0.30 ± 0.42 aCi/m³). The maximum Hanford Site plutonium-239,240 air activity (2.0 ± 1.3 aCi/m³) was observed for the 200-West Area composite sample (location 11 on Figure 4.1.1). This represents <0.02% of the 20,000-aCi/m³ derived concentration guide.

Average isotopic uranium activities (uranium-234, -235, and -238) in airborne particulate matter in 1998 were similar on the site, at the site perimeter, and at distant communities (see Table 4.1.2 and Figure 4.1.7). The 1998 annual average uranium-238 activity for the site perimeter was 27 ± 14 aCi/m³, which is 0.03% of the 100,000-aCi/m³ derived concentration guide.

Samples were analyzed quarterly, and at some locations annually, by gamma spectroscopy. Naturally occurring beryllium-7 and potassium-40 were routinely identified. The potential Hanford-origin gamma-emitting radionuclides of cobalt-60 and cesium-137 associated with airborne particulate matter were monitored by gamma spectroscopy. Of the 101 samples analyzed by gamma spectroscopy, none of the samples had activities above the minimum detectable activity for the sample for that isotope. The cobalt-60 and cesium-137 results for 1998 samples are included in Table 4.1.2. Even the maximum estimated individual measurements for these radionuclides (1,000 ± 530 and 860 ± 580 aCi/m³, respectively) were <0.002% of their derived concentration guides.

4.2 Surface Water and Sediment Surveillance

G. W. Patton

Samples of surface water and sediment on and near the Hanford Site are collected and analyzed to determine the potential impacts of Hanford-originated radiological and chemical contaminants to the public and to the aquatic environment. Surface-water bodies included in routine surveillance are the Columbia River, riverbank springs, onsite ponds, and irrigation water. Sediment surveillance is conducted for the Columbia River and riverbank springs. Tables 4.2.1 and 4.2.2 summarize the sampling locations, types, frequencies, and analyses included in surface-water and sediment surveillance activities during 1998. Sampling locations are identified in Figure 4.2.1. This section describes the surveillance effort and summarizes the results for these aquatic environments. Detailed analytical results are reported in PNNL-12088, APP. 1.

4.2.1 Columbia River Water

The Columbia River is the second largest river in the continental United States in terms of total flow and is the dominant surface-water body on the Hanford Site. The original selection of the Hanford Site for plutonium production and processing was based, in part, on the abundant water supply offered by the river. The river flows through the northern edge of the site and forms part of the site's eastern boundary. The river is used as a source of drinking water for onsite facilities and communities located downstream from the Hanford Site. Water from the river downstream of the site is also used for crop irrigation. In addition, the Hanford Reach of the Columbia River is used for a variety of recreational activities, including hunting, fishing, boating, water-skiing, and swimming.

Originating in the mountains of eastern British Columbia, the Columbia River drains a total area of approximately 670,000 km^2 (260,000 mi^2) en route to the Pacific Ocean. The flow of the river is regulated by three dams in Canada and 11 dams in the United States, seven upstream and four downstream of the site. Priest Rapids Dam is the nearest upstream dam and McNary Dam is the nearest downstream dam from the site. The Hanford Reach of the Columbia River extends from Priest Rapids Dam to the head of Lake Wallula (created by McNary Dam) near Richland, Washington. The Hanford Reach is the last stretch of the Columbia River in the United States above Bonneville Dam that remains unimpounded.

Flows through the Hanford Reach fluctuate significantly and are controlled primarily by operations at Priest Rapids Dam. Annual average flows of the Columbia River below Priest Rapids Dam are nearly 3,400 m^3/s (120,000 ft^3/s) (WA-94-1). In 1998, the Columbia River had normal flows; the average daily flow rate below Priest Rapids Dam was 3,260 m^3/s (115,000 ft^3/s). The peak monthly average flow rate occurred during June (4,870 m^3/s [172,000 ft^3/s]) (Figure 4.2.2). The lowest monthly average flow rate occurred during October (2,040 m^3/s [72,200 ft^3/s]). Daily flow rates varied from 1,270 to 7,220 m^3/s (44,900 to 255,000 ft^3/s) during 1998. As a result of fluctuations in discharges, the depth of the river varies significantly over time. River stage may change along the Hanford Reach by up to 3 m (10 ft) within a few hours (Section 3.3.7 in PNL-10698). Seasonal changes of approximately the same magnitude are also observed. River-stage fluctuations measured at

Table 4.2.1. Surface-Water Surveillance, 1998

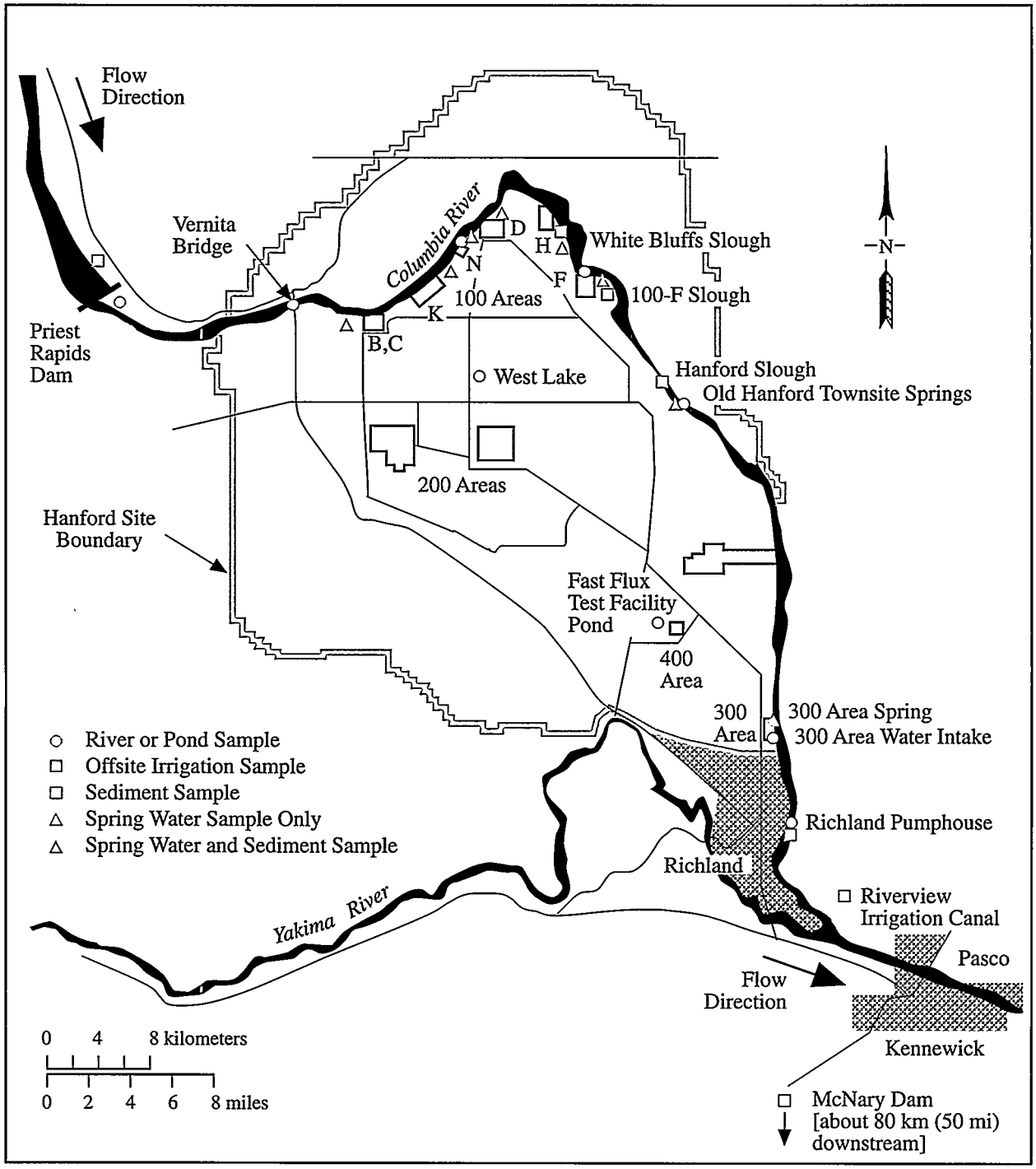
Location	Sample Type	Frequency[a]	Analyses
Columbia River - Radiological			
Priest Rapids Dam and Richland Pumphouse	Cumulative	M Comp[b]	Alpha, beta, lo ^{3}H,[c] gamma scan, ^{90}Sr, ^{99}Tc, U[d]
	Particulate (filter)	Q Cont[e]	Gamma scan, Pu[f]
	Soluble (resin)	Q Cont	Gamma scan, ^{129}I, Pu
Vernita Bridge and Richland Pumphouse	Grab (transects)	Q	lo ^{3}H, ^{90}Sr, U
100-F, 100-N, 300, and Old Hanford Townsite	Grab (transects)	A	lo ^{3}H, ^{90}Sr, U
Columbia River - Nonradiological			
Vernita Bridge and Richland Pumphouse[g]	Grab	Q	NASQAN, temperature, dissolved oxygen, turbidity, pH, alkalinity, anions, suspended solids, dissolved solids, specific conductance, hardness (as $CaCO_3$), Ca, P, Cr, Mg, N-Kjeldahl, Fe, NH_3, NO_3 + NO_2
	Grab (transects)	Q	ICP[h] metals, anions
	Grab (transects)	A	Cyanide (CN^-)
100-F, 100-N, 300, and Old Hanford Townsite	Grab (transects)	A	ICP metals, anions
Onsite Ponds			
West Lake	Grab	Q	Alpha, beta, ^{3}H, ^{90}Sr, ^{99}Tc, U, gamma scan
Fast Flux Test Facility pond	Grab	Q	Alpha, beta, ^{3}H, gamma scan
Offsite Water			
Riverview irrigation canal	Grab	3[i]	Alpha, beta, ^{3}H, ^{90}Sr, U, gamma scan
Riverbank Springs			
100-H Area	Grab	A	Alpha, beta, ^{3}H, ^{90}Sr, ^{99}Tc, U, gamma scan, ICP metals, anions
100-B Area	Grab	A	Alpha, beta, ^{3}H, ^{90}Sr, ^{99}Tc, gamma scan, ICP metals, anions
100-D, 100-K, and 100-N Areas	Grab	A	Alpha, beta, ^{3}H, ^{90}Sr, gamma scan, ICP metals, anions
Old Hanford Townsite and 300 Area	Grab	A	Alpha, beta, ^{3}H, ^{129}I, ^{90}Sr, ^{99}Tc, U, gamma scan, ICP metals, anions

(a) A = annually; M = monthly; Q = quarterly; Comp = composite.
(b) M Comp indicates river water was collected hourly and composited monthly for analysis.
(c) lo ^{3}H = low-level tritium analysis (10-pCi/L detection limit), which includes an electrolytic preconcentration.
(d) U = isotopic uranium-234, -235, and -238.
(e) Q Cont = river water was sampled for 2 wk by continuous flow through a filter and resin column and multiple samples were composited quarterly for analysis.
(f) Pu = isotopic plutonium-238 and -239,240.
(g) Numerous water quality analyses are performed by the U.S. Geological Survey in conjunction with the National Stream Quality Accounting Network (NASQAN) Program.
(h) ICP = inductively coupled plasma analysis method.
(i) Three samples during irrigation season.

Table 4.2.2. Sediment Surveillance, 1998

Location[a]	Frequency	Analyses
River		All river sediment analyses included gamma scan, ^{90}Sr, U[b], Pu[c], ICP[d] metals, SEM/AVS[e]
Priest Rapids Dam: 4 equally spaced (approximate) stations on a transect from the Grant County shore to the Yakima County shore	A[f]	
White Bluffs Slough	A	
100-F Slough	A	
Hanford Slough	A	
Richland	A	
McNary Dam: 4 equally spaced (approximate) stations on a transect from the Oregon shore to the Washington shore	A	
Ice Harbor Dam 3 equally spaced (approximate) stations on a transect from the Walla Walla County shore to the Franklin County shore	A	
Springs[g]		All springs sediment analyses included gamma scan, ^{90}Sr, U, ICP metals
100-B Area	A	
100-K Area	A	
100-N Area, Spring No. 8-13	A	
100-F Area	A	
Old Hanford Townsite Springs	A	
300 Area, Spring No. 42-2	A	

(a) See Figure 4.2.1.
(b) U = uranium-235 and -238 analyzed by low-energy photon analysis.
(c) Pu = isotopic plutonium-238 and -239,240.
(d) ICP = inductively coupled plasma analysis method.
(e) SEM/AVS = simultaneously extracted metals and acid volatile sulfide.
(f) A = annually.
(g) Sediment is collected when available.



G99030045.25

Figure 4.2.1. Water and Sediment Sampling Locations, 1998

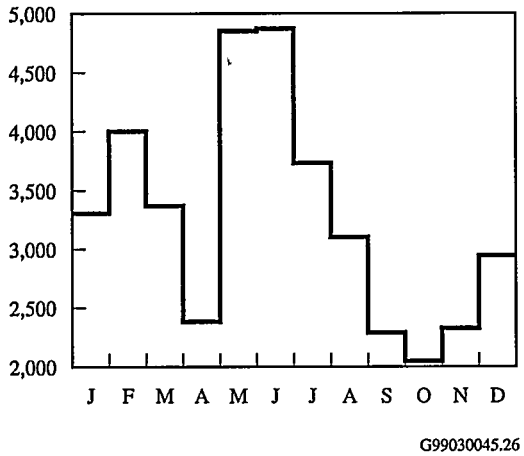


Figure 4.2.2. Mean Monthly Columbia River Flow Rates, 1998

the 300 Area are approximately half the magnitude of those measured near the 100 Areas because of the effect of the pool behind McNary Dam (PNL-8580) and the relative distance of each area from Priest Rapids Dam. The width of the river varies from approximately 300 to 1,000 m (980 to 3,300 ft) through the Hanford Site.

Pollutants, both radiological and nonradiological, are known to enter the Columbia River through the Hanford Reach. In addition to permitted direct discharges of liquid effluents from Hanford facilities, contaminants in groundwater from past discharges to the ground are known to seep into the river (DOE/RL-92-12, PNL-5289, PNL-7500, WHC-SD-EN-TI-006). Effluents from each direct discharge point are routinely monitored and reported by the responsible operating contractor; these were summarized in Section 3.1, "Facility Effluent Monitoring." Direct discharges are identified and regulated for nonradiological constituents under the National Pollutant Discharge Elimination System in compliance with the Clean Water Act of 1997. The National Pollutant Discharge Elimination System-permitted discharges at the Hanford Site are summarized in Section 2.2, "Compliance Status."

Washington State has classified the stretch of the Columbia River from Grand Coulee Dam to the Washington-Oregon border, which includes the Hanford Reach, as Class A, Excellent (Washington Administrative Code [WAC] 173-201A). Water quality criteria and water use guidelines have been established in conjunction with this designation and are provided in Appendix C (Table C.1).

4.2.1.1 Collection of River-Water Samples and Analytes of Interest

Samples of Columbia River water were collected throughout 1998 at the locations shown in Figure 4.2.1. Samples were collected from fixed-location monitoring stations at Priest Rapids Dam and the Richland Pumphouse and also from Columbia River transects established near the Vernita Bridge, 100-F Area, 100-N Area, Old Hanford Townsite, 300 Area, and Richland Pumphouse. Samples were collected upstream from Hanford Site facilities at Priest Rapids Dam and Vernita Bridge to provide background data from locations unaffected by site operations. Samples were collected from all other locations to identify any increase in contaminant concentrations attributable to Hanford operations. The Richland Pumphouse is the first downstream point of Columbia River water withdrawal for a municipal drinking water supply.

The fixed-location monitoring stations at Priest Rapids Dam and the Richland Pumphouse consisted of both an automated sampler and a continuous flow system. Using the automated sampler, unfiltered samples of Columbia River water (cumulative samples) were obtained hourly and collected weekly. Weekly samples were composited monthly for radiological analyses (see Table 4.2.1). Using the continuous flow system, particulate and soluble fractions of selected Columbia River water constituents were collected by passing water through a filter and then through a resin column. Filter and resin samples were exchanged approximately every 14 d and were

combined into quarterly composite samples for radiological analyses. The river sampling locations and the methods used for sample collection are discussed in detail in DOE/RL-91-50, Rev. 2.

Analytes of interest in water samples collected from Priest Rapids Dam and the Richland Pumphouse included gross alpha, gross beta, selected gamma emitters, tritium, strontium-90, technetium-99, iodine-129, uranium-234, 235, 238, plutonium-238, and plutonium-239, 240. Gross alpha and beta measurements are indicators of the general radiological quality of the river and provide a timely indication of change. Gamma scans provide the ability to detect numerous specific radionuclides (see Appendix E). Sensitive radiochemical analyses were used to determine the activities of tritium, strontium-90, technetium-99, iodine-129, uranium-234, -235, -238, plutonium-238, and plutonium-239, 240 in river water during the year. Radionuclides of interest were selected for analysis based on their presence in effluents discharged from site facilities or in near-shore groundwater underlying the Hanford Site and for their importance in determining water quality, verifying effluent control and monitoring systems, and determining compliance with applicable standards. Analytical detection levels for all radionuclides were <10% of their respective water quality criteria levels (see Appendix C, Table C.2).

Transect sampling was initiated as a result of findings of a special study conducted during 1987 and 1988 (PNL-8531). That study concluded that, under certain flow conditions, contaminants entering the river from the Hanford Site are not completely mixed when sampled at routine monitoring stations located downriver. Incomplete mixing results in a slightly conservative (high) bias in the data generated using the routine, single-point, sampling system at the Richland Pumphouse. The Vernita Bridge and the Richland Pumphouse transects were sampled quarterly during 1998. Annual transect sampling was conducted at the 100-F Area, 100-N Area, Old Hanford Townsite, and 300 Area locations in the late summer during low flow.

Columbia River transect water samples collected in 1998 were analyzed for both radiological and chemical contaminants (see Table 4.2.1). Metals and anions (listed in DOE/RL-93-94, Rev. 1) were selected for analysis following reviews of existing surface-water and groundwater data, various remedial investigation/feasibility study work plans, and preliminary Hanford Site risk assessments (DOE/RL-92-67, PNL-8073, PNL-8654, PNL-10400, PNL-10535). All radiological and chemical analyses of transect samples were performed on unfiltered water.

In addition to Columbia River monitoring conducted by Pacific Northwest National Laboratory in 1998, nonradiological water quality monitoring was also performed by the U.S. Geological Survey in conjunction with the National Stream Quality Accounting Network program. U.S. Geological Survey samples were collected along Columbia River transects quarterly at the Vernita Bridge and the Richland Pumphouse (Appendix A, Table A.4). Sample analyses were performed at the U.S. Geological Survey laboratory in Denver, Colorado for numerous physical and chemical constituents.

4.2.1.2 Radiological Results for River-Water Samples

Fixed Location Sampling. Results of the radiological analyses of Columbia River water samples collected at Priest Rapids Dam and Richland Pumphouse during 1998 are reported in PNNL-12088, APP. 1 and summarized in Appendix A (Tables A.1 and A.2). These tables also list the maximum and mean activities of selected radionuclides observed in Columbia River water in 1998 and during the previous 5 yr. All radiological contaminant activities measured in Columbia River water in 1998 were less than DOE derived concentration guides (DOE Order 5400.5) and Washington State ambient surface-water quality criteria (WAC 173-201A and

Title 40, Code of Federal Regulations, Part 141 [40 CFR 141]) levels (see Appendix C, Tables C.5, C.3, and C.2, respectively). Significant results are discussed and illustrated below, and comparisons to previous years are provided.

Radionuclide activities monitored in Columbia River water were extremely low throughout the year. The radionuclides consistently detected in river water during 1998 included tritium, strontium-90, iodine-129, uranium-234,238, and plutonium-239,240. The activities of all other measured radionuclides were below detection limits in >75% of samples collected. Tritium, strontium-90, iodine-129, and plutonium-239,240 exist in worldwide fallout, as well as in effluents from Hanford facilities. Tritium and uranium occur naturally in the environment, in addition to being present in Hanford Site effluents.

Figures 4.2.3 and 4.2.4 illustrate the average annual gross alpha and gross beta activities, respectively, at Priest Rapids Dam and Richland Pumphouse during the past 6 yr. The 1998 average

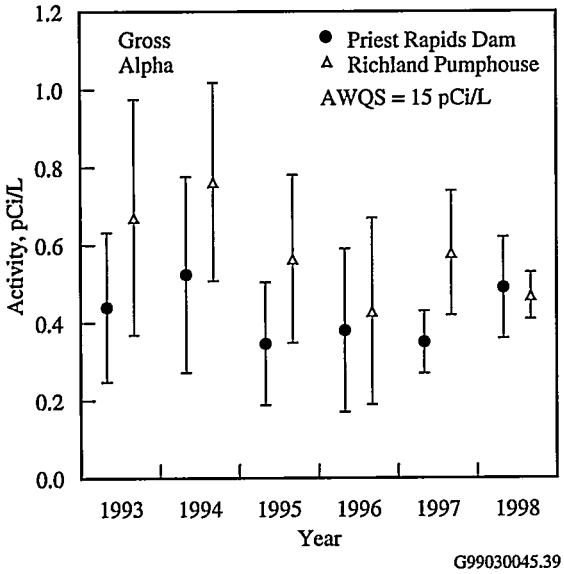


Figure 4.2.3. Annual Average Gross Alpha Activities (±2 standard error of the mean) in Columbia River Water, 1993 Through 1998 (AWQS = ambient water quality standard)

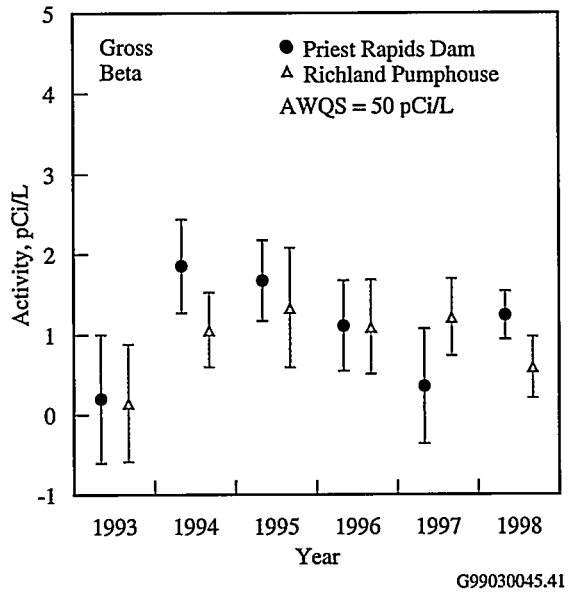


Figure 4.2.4. Annual Average Gross Beta Activities (±2 standard error of the mean) in Columbia River Water, 1993 Through 1998 (AWQS = ambient water quality standard)

gross alpha and gross beta activities were similar to those observed during recent years. Monthly measurements at the Richland Pumphouse in 1998 were not statistically different (unless otherwise noted in this section, the statistical tests for difference are paired sample comparison and two-tailed t-test, 5% significance level) from those measured at Priest Rapids Dam. The average activities in Columbia River water at Priest Rapids Dam and Richland Pumphouse in 1998 were <5% of their respective ambient surface-water quality criteria levels of 15 and 50 pCi/L, respectively.

Figure 4.2.5 compares the annual average tritium activities at Priest Rapids Dam and Richland Pumphouse from 1993 through 1998. Statistical analysis indicated that monthly tritium activities in river water at the Richland Pumphouse were higher than those at Priest Rapids Dam. However, 1998 average tritium activities in Columbia River water collected at the Richland Pumphouse were only 0.38% of the ambient surface-water quality criteria level of

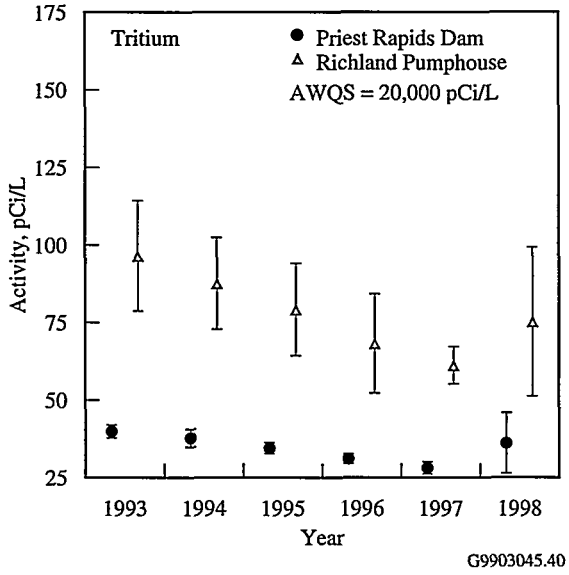


Figure 4.2.5. Annual Average Tritium Activities (±2 standard error of the mean) in Columbia River Water, 1993 Through 1998 (AWQS = ambient water quality standard)

20,000 pCi/L. Onsite sources of tritium entering the river include groundwater seepage and direct discharge from outfalls located in the 100 Areas (see Section 3.1, "Facility Effluent Monitoring," and Section 6.1, "Hanford Groundwater Monitoring Project"). Tritium activities measured at the Richland Pumphouse, while representative of river water used by the city of Richland for drinking water, tend to overestimate the average tritium activities across the river at this location (PNL-8531). This bias is attributable to the contaminated 200 Areas' groundwater plume entering the river along the portion of shoreline extending from the Old Hanford Townsite to below the 300 Area, which is relatively close to the Richland Pumphouse sample intake. This plume is not completely mixed within the river at the Richland Pumphouse. Sampling along a transect at the pumphouse during 1998 confirmed the existence of an activity gradient in the river under certain flow conditions and is discussed subsequently in this section. The extent to which samples taken from the Richland Pumphouse overestimate the average tritium activities in the Columbia River at this location is highly variable and appears to be related to the flow rate of the river just before and during sample collection.

The annual average strontium-90 activities in Columbia River water collected from Priest Rapids Dam and Richland Pumphouse from 1993 through 1998 are presented in Figure 4.2.6. Levels observed in 1998 were similar to those reported previously. Groundwater plumes containing strontium-90 enter the Columbia River throughout the 100 Areas (see Section 6.1.6.1, "Radiological Monitoring Results for the Unconfined Aquifer"). The highest strontium-90 levels that have been found in onsite groundwater are the result of past discharges to the 100-N Area liquid waste disposal facilities. Despite the Hanford Site source, the differences between monthly strontium-90 activities at Priest Rapids Dam and Richland Pumphouse in 1998 were not statistically different. Average strontium-90 activities in Columbia River water at the Richland Pumphouse

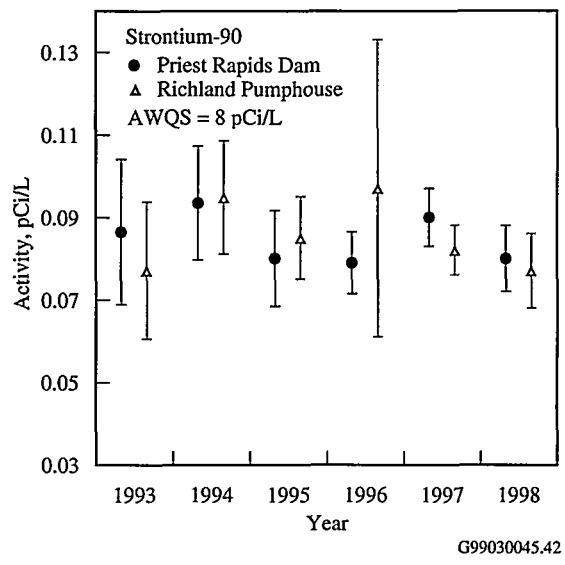


Figure 4.2.6. Annual Average Strontium-90 Activities (±2 standard error of the mean) in Columbia River Water, 1993 Through 1998 (AWQS = ambient water quality standard)

were 1.0% of the 8-pCi/L ambient surface-water quality criteria level.

Annual average total uranium activities (i.e., the sum of uranium-234, -235, -238) at Priest Rapids Dam and Richland Pumphouse for 1993 through 1998 are shown in Figure 4.2.7. The large error associated with 1994 results was attributed to an unusually low activity found in the December sample at each location. Total uranium activities observed in 1998 were similar to those observed during recent years. Monthly total uranium activities measured at the Richland Pumphouse in 1998 were statistically higher than those measured at Priest Rapids Dam. Although there is no direct discharge of uranium to the river, uranium is present in the groundwater beneath the 300 Area as a result of past Hanford operations (see Section 6.1, "Hanford Groundwater Monitoring Project") and has been detected at elevated levels in riverbank springs in this area (see Section 4.2.3, "Riverbank Springs Water"). Naturally occurring uranium is also known to enter the river across from the Hanford Site via irrigation return water and groundwater seepage associated with extensive irrigation north and east of the Columbia River (PNL-7500). There are no ambient surface-water quality criteria levels directly applicable to uranium. However, total uranium activities in the river during 1998 were well below the proposed U.S. Environmental Protection Agency (EPA) drinking water standard of 20 µg/L (13.4 pCi/L, Appendix C, Table C.2).

The annual average iodine-129 activities at Priest Rapids Dam and Richland Pumphouse for 1993 through 1998 are presented in Figure 4.2.8. Only one quarterly iodine-129 result was available for the Richland Pumphouse during 1995 because of construction activities at the structure. The average iodine-129 activity in Columbia River water at the Richland Pumphouse was extremely low during 1998 (0.012% of the ambient surface-water quality criteria level of 1 pCi/L [1,000,000 aCi/L]) and similar to levels observed during recent years. The onsite

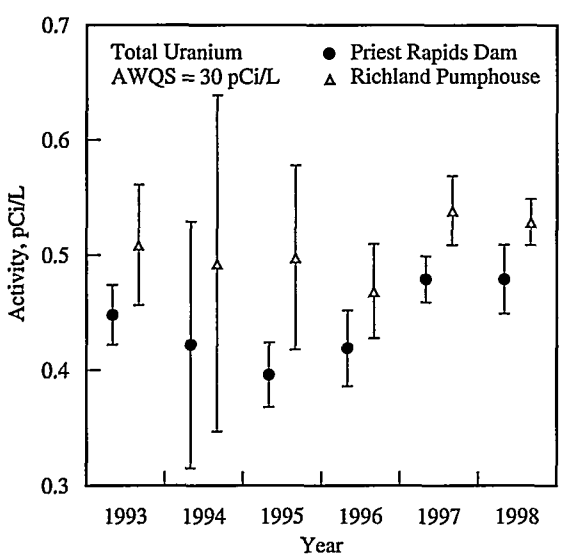


Figure 4.2.7. Annual Average Total Uranium Activities (±2 standard error of the mean) in Columbia River Water, 1993 Through 1998 (AWQS = ambient water quality standard)

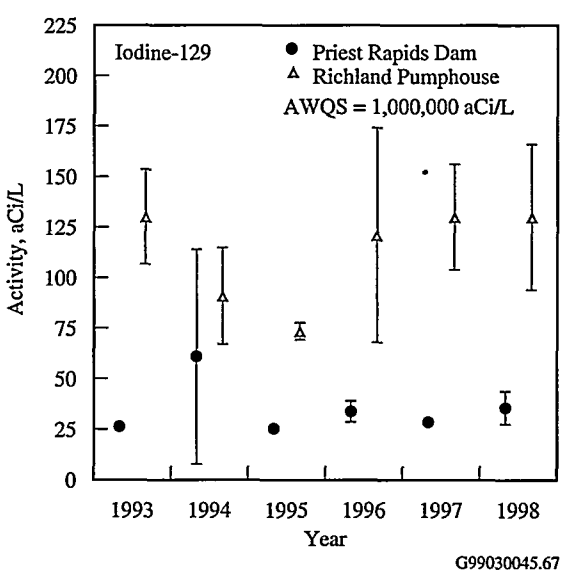


Figure 4.2.8. Annual Average Iodine-129 Activities (±2 standard error of the mean) in Columbia River Water, 1993 Through 1998 (AWQS = ambient water quality standard)

source of iodine-129 to the Columbia River is the discharge of contaminated groundwater along the portion of shoreline downstream of the Old Hanford Townsite (see Section 6.1, "Hanford Groundwater Monitoring Project"). The iodine-129 plume originated in the 200 Areas from past waste disposal practices. Quarterly iodine-129 activities in Columbia River water at the Richland Pumphouse were statistically higher than those at Priest Rapids Dam.

During 1998, average plutonium-239,240 activities at Priest Rapids Dam and Richland Pumphouse were 99 ± 120 and 66 ± 38 aCi/L, respectively. For both locations, plutonium was detected only for the particulate fraction of the continuous water sample (i.e., detected on the filters but not detected on the resin column). No ambient surface-water quality criteria levels exist for plutonium-239,240. However, if the DOE derived concentration guides (see Appendix C, Table C.5), which are based on a 100-mrem dose standard, are converted to the 4-mrem dose equivalent used to develop the drinking water standards and ambient surface-water quality criteria levels, 1,200,000 aCi/L would be the relevant guideline for plutonium-239,240. There was no statistical difference in plutonium-239, 240 activities at Priest Rapids Dam and Richland Pumphouse.

River Transect Sampling. Radiological results from samples collected along Columbia River transects established at the Vernita Bridge, 100-F Area, 100-N Area, Old Hanford Townsite, 300 Area, and Richland Pumphouse during 1998 are presented in Appendix A (Table A.3) and PNNL-12088, APP. 1. Constituents that were consistently detected at activities greater than two times their associated total propagated analytical uncertainty included tritium, strontium-90, uranium-234, and uranium-238. All measured activities of these radionuclides were less than applicable ambient surface-water quality criteria levels.

Tritium activities measured along Columbia River transects during September 1998 are depicted in Figure 4.2.9. The results are displayed such that the observer's view is upstream. Vernita Bridge is the most upstream transect. Stations 1 and 10 are located along the Benton County and Franklin/Grant Counties shorelines, respectively. The highest tritium activities observed in 1998 river transect water (see Figure 4.2.9) were detected along the shoreline of the Old Hanford Townsite, where groundwater containing tritium activities in excess of the ambient surface-water quality criteria level of 20,000 pCi/L is known to discharge to the river (see Section 6.1.6.1, "Radiological Monitoring Results for the Unconfined Aquifer"). Slightly elevated levels of tritium were also evident near the Hanford Site shoreline at the 100-N Area, 300 Area, and Richland Pumphouse. The presence of a tritium activity gradient in the Columbia River at the Richland Pumphouse supports previous conclusions made in HW-73672 and PNL-8531 that contaminants in the 200 Areas' groundwater plume entering the river at, and upstream of, the 300 Area are not completely mixed at the Richland Pumphouse. The gradient is most pronounced during periods of relatively low flow. As noted since transect sampling was initiated in 1987, the mean tritium activity measured along the Richland Pumphouse transect was less than that measured in monthly composited samples from the pumphouse, illustrating the conservative bias (i.e., overestimate) of the fixed-location monitoring station.

Strontium-90 activities in 1998 transect samples were fairly uniform across the width of the river and varied little between transects. The mean strontium-90 activity found during transect sampling at the Richland Pumphouse was similar to that measured in monthly composite samples from the pumphouse. The similarity indicates that strontium-90 activities in water collected from the fixed-location monitoring station are representative of the average strontium-90 activities in the river at this location.

Total uranium activities in 1998 were elevated along the Franklin County shoreline of the 300 Area

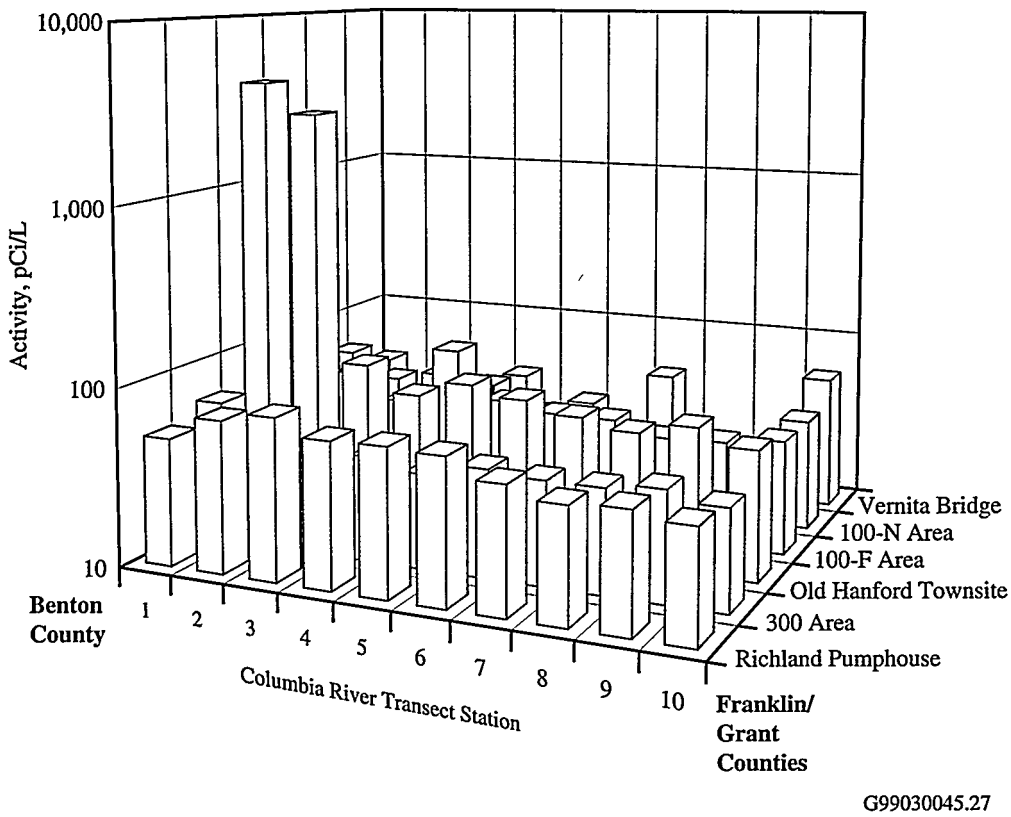


Figure 4.2.9. Tritium Activities in Water Samples from Columbia River Transects, September 1998

and Richland Pumphouse transects. The highest total uranium activity was measured near the Franklin County shoreline of the 300 Area transect and likely resulted from groundwater seepage and water from irrigation return canals on the east side of the river that contained naturally occurring uranium (PNL-7500). The mean activity of total uranium across the Richland Pumphouse transect was similar to that measured in monthly composited samples from the pumphouse.

4.2.1.3 Nonradiological Results for River-Water Samples

The U.S. Geological Survey and the Pacific Northwest National Laboratory compiled nonradiological water quality data during 1998. A number of the parameters measured have no regulatory limits; however, they are useful as indicators of water quality and contaminants of Hanford origin. Potential sources of pollutants not associated with Hanford include irrigation return water and groundwater seepage associated with extensive irrigation north and east of the Columbia River (PNL-7500).

U.S. Geological Survey. Figure 4.2.10 shows the Vernita Bridge and Richland Pumphouse U.S. Geological Survey results for 1993 through 1998 (1998 results are preliminary) for several water quality parameters with respect to their applicable standards. The complete list of preliminary results obtained through the U.S. Geological Survey National Stream Quality Accounting Network program is documented in PNNL-12088, APP. 1 and is summarized in Appendix A (Table A.4). Final results are published annually by the U.S. Geological Survey (e.g., Wiggins et al. 1996). The 1998 U.S. Geological Survey results were comparable to

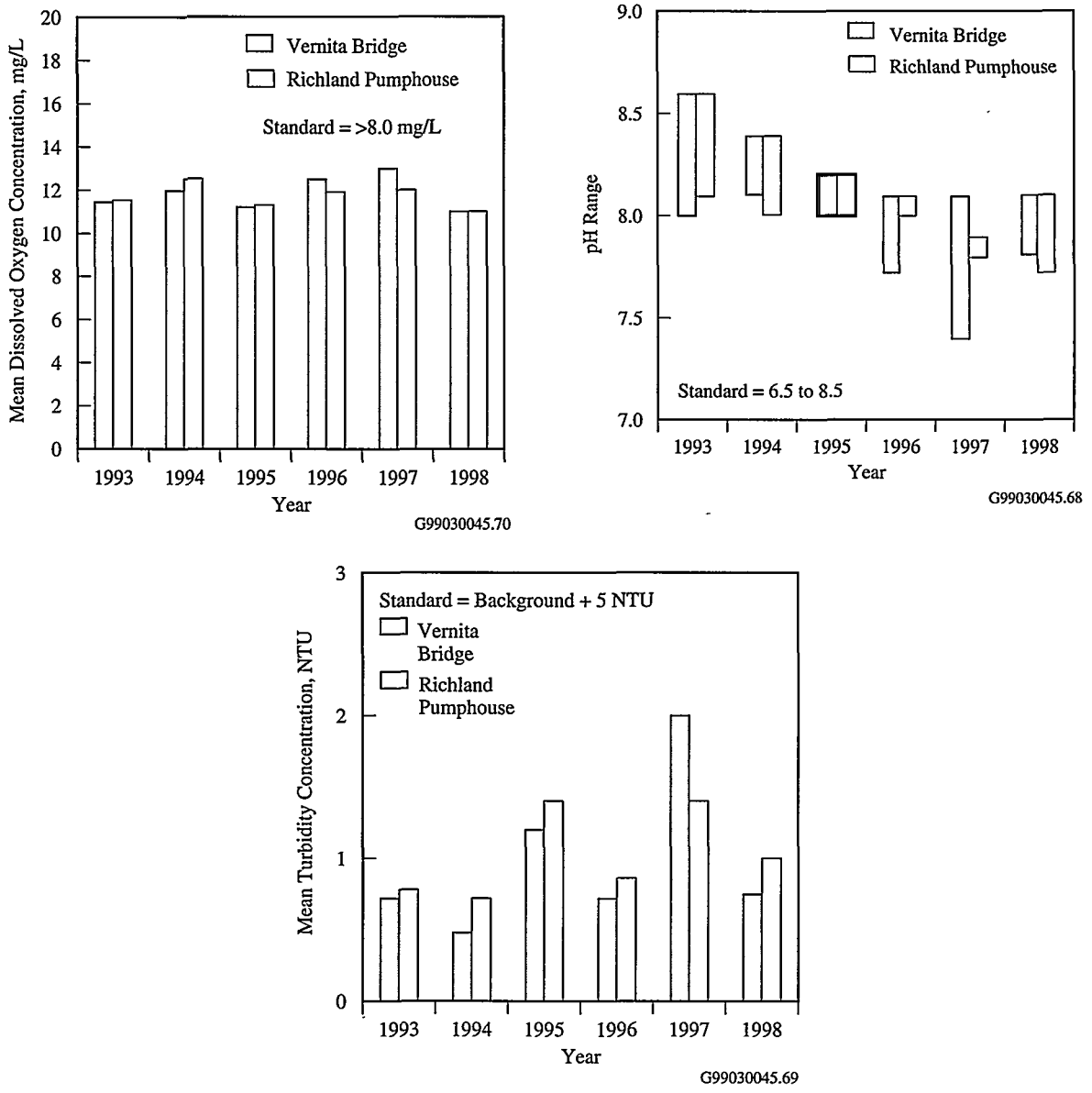


Figure 4.2.10. U.S. Geological Survey Columbia River Water Quality Measurements, 1993 Through 1998 (1998 results are preliminary; NTU = nephelometric turbidity unit)

those reported during the previous 5 yr. Applicable standards for a Class A-designated surface-water body were met. During 1998, there was no indication of any deterioration of water quality resulting from site operations along the Hanford Reach of the Columbia River (see Appendix C, Table C.1).

River Transect Samples. Results of nonradiological sampling conducted by Pacific Northwest National Laboratory along transects of the Columbia River in 1998 at Vernita Bridge, 100-F Area, 100-N Area, Old Hanford Townsite, 300 Area, and Richland Pumphouse are provided in PNNL-12088,

APP. 1. The concentrations of metals and anions observed in river water in 1998 were similar to those observed in the past. Several metals and anions were detected in Columbia River transect samples both upstream and downstream of the Hanford Site. Arsenic, antimony, cadmium, chromium, lead, nickel, thallium, and zinc were detected in the majority of samples, with similar levels at most locations. Beryllium, selenium, and silver were only occasionally detected. Nitrate concentrations in transect samples collected at the Old Hanford Townsite near the Benton County shoreline were slightly elevated, as were chloride levels at the 300 Area. Nitrate, sulfate, and chloride concentrations were slightly elevated along the Franklin County shoreline of the 300 Area and Richland Pumphouse transects and likely resulted from groundwater seepage associated with extensive irrigation north and east of the Columbia River. Nitrate contamination of some Franklin County groundwater has been documented by the U.S. Geological Survey (1995) and is associated with high fertilizer and water usage. Numerous wells in western Franklin County exceed the EPA maximum contaminant level for nitrate (40 CFR 141). Nitrate, sulfate, and chloride results were slightly higher for average quarterly concentrations at the Richland Pumphouse transect compared to the Vernita Bridge transect.

Washington State ambient surface-water quality criteria for cadmium, copper, lead, nickel, silver, and zinc are total-hardness dependent (WAC 173-201A; see Appendix C, Table C.3). Criteria for Columbia River water were calculated using a total hardness of 48 mg/L as $CaCO_3$ (calcium carbonate), the limiting value based on U.S. Geological Survey monitoring of Columbia River water near Vernita Bridge and the Richland Pumphouse over the past 6 yr. The total hardness reported by the U.S. Geological Survey at those locations from 1992 through 1997 ranged from 48 to 77 mg/L as $CaCO_3$. All metal and anion concentrations in river water were less than the ambient surface-water quality criteria levels for both acute and chronic toxicity levels (see Appendix C, Table C.3). Arsenic concentrations exceeded EPA standards; however, similar concentrations were found at Vernita Bridge and Richland Pumphouse (see Appendix C, Table C.3).

4.2.2 Columbia River Sediments

As a result of past operations at the Hanford Site, radioactive and nonradioactive materials were discharged to the Columbia River. On release to the river, the materials were dispersed rapidly, sorbed onto detritus and inorganic particles, incorporated into aquatic biota, deposited on the riverbed as sediment, or flushed out to sea. Fluctuations in the river flow rate, as a result of the operation of hydroelectric dams, annual spring freshets, and occasional floods, have resulted in the resuspension, relocation, and subsequent redeposition of the contaminated sediments (DOE/RL-91-50, Rev. 2). Sediments in the Columbia River contain low activities of radionuclides and metals of Hanford Site origin as well as radionuclides from nuclear weapons testing fallout (Beasley et al. 1981, BNWL-2305, PNL-8148, PNL-10535). Potential public exposures are well below the level at which routine surveillance of Columbia River sediments is required (PNL-3127, Wells 1994). However, periodic sampling is necessary to confirm the low levels and to ensure that no significant changes have occurred for this pathway. The accumulation of radioactive materials in sediment can lead to human exposure through ingestion of aquatic species, through sediment resuspension into drinking water supplies, or as an external radiation source irradiating people who are fishing, wading, sunbathing, or participating in other recreational activities associated with the river or shoreline (DOE/EH-0173T).

Since the shutdown of the original single-pass reactors in the early 1970s, the contaminant burden in the surface sediments has been decreasing as a result of radioactive decay and the subsequent deposition of uncontaminated material. However, discharges of some pollutants from the Hanford Site to the Columbia River still occur via permit-regulated liquid effluent discharges (see Section 3.1, "Facility Effluent Monitoring") and via contaminated groundwater seepage (see Section 4.2.3, "Riverbank Springs Water").

A special study was conducted in 1994 to investigate the difference in sediment grain-size composition and total organic carbon content at routine monitoring sites (PNL-10535). Physicochemical sediment characteristics were found to be highly variable among monitoring sites along the Columbia River. Samples containing the highest percentage of silts, clays, and total organic carbon were collected above McNary Dam and from White Bluffs Slough. All other samples primarily consisted of sand. Higher contaminant burdens were generally associated with sediments containing higher total organic carbon and finer grain-size distributions, which is consistent with other sediment investigations (Nelson et al. 1966, Lambert 1967, Richardson and Epstein 1971, Gibbs 1973, Karickhoff et al. 1978, Suzuki et al. 1979, Sinex and Helz 1981, Tada and Suzuki 1982, Mudroch 1983).

4.2.2.1 Collection of Sediment Samples and Analytes of Interest

During 1998, samples of Columbia River surface sediments (0 to 15-cm [0 to 6-in.] depth) were collected from six river locations that are permanently submerged and two riverbank springs locations that are periodically inundated (see Figure 4.2.1 and Table 4.2.2). In addition, sediment samples were collected behind Ice Harbor Dam on the Snake River. Samples were collected upstream of Hanford Site facilities above Priest Rapids Dam (the nearest upstream impoundment) to provide background data from an area unaffected by site operations. Samples were collected downstream of the Hanford Site above McNary Dam (the nearest downstream impoundment) to identify any increase in contaminant concentrations. Note that any increases in contaminant concentrations found in sediment above McNary Dam relative to that found above Priest Rapids Dam do not necessarily reflect a Hanford Site source. The confluences of the Columbia River with the Yakima, Snake, and Walla Walla Rivers lie between the Hanford Site and McNary Dam. Several towns, irrigation water returns, and factories in these drainages may also contribute to the contaminant load found in McNary Dam sediment; thus, sediments were taken at Ice Harbor Dam to assess Snake River inputs. Sediment samples were also collected along the Hanford Reach of the Columbia River from areas close to contaminant discharges (e.g., riverbank springs), from slackwater areas where fine-grained material is known to deposit (e.g., the White Bluffs, 100-F Area, Hanford Sloughs), and from the publicly accessible Richland shoreline.

Monitoring sites located at McNary and Priest Rapids Dams consisted of four stations spaced equidistant (approximately) on a transect line crossing the Columbia River. Three stations were sampled at Ice Harbor Dam. All other monitoring sites consisted of a single sampling location. Samples of permanently inundated river sediment, herein referred to as river sediment, were collected using a grab sampler with a 235-cm^2 (36.4 in^2 opening. Samples of periodically inundated river sediment, herein referred to as riverbank springs sediment, were collected using a large plastic spoon, immediately following the collection of riverbank springs water samples. Sampling methods are discussed in detail in DOE/RL-91-50, Rev. 2. All sediment samples were analyzed for gamma emitters (see Appendix E), strontium-90, uranium-235, uranium-238, and metals (DOE/RL-91-50, Rev. 2). River sediment samples were also analyzed for plutonium-238, plutonium-239,240, and simultaneously extracted metals/acid volatile sulfide. Sample analyses of

Columbia River sediments were selected based on findings of previous Columbia River sediment investigations, reviews of past and present effluents discharged from site facilities, and reviews of contaminant concentrations observed in near-shore groundwater monitoring wells.

4.2.2.2 Radiological Results for River Sediment Samples

Results of the radiological analyses on river sediment samples collected during 1998 are reported in PNNL-12088, APP. 1 and summarized in Appendix A (Table A.5). Radionuclides consistently detected in river sediment adjacent and downstream of the Hanford Site during 1998 included cobalt-60, strontium-90, cesium-137, europium-155, uranium-238, plutonium-238, and plutonium-239,240. The activities of all other measured radionuclides were below detection limits for most samples. Strontium-90 and plutonium-239,240 exist in worldwide fallout, as well as in effluents from Hanford Site facilities. Uranium occurs naturally in the environment in addition to being present in Hanford Site effluents. Comparisons of contaminant levels between sediment sampling locations are made below. Because of variations in the bioavailability of contaminants in various sediments, no federal or state freshwater sediment criteria are available to assess the sediment quality of the Columbia River (EPA 822-R-96-001).

Radionuclide activities reported in river sediment in 1998 were similar to those reported for previous years (see Appendix A, Table A.5). Median, maximum, and minimum activities of selected radionuclides measured in Columbia and Snake River sediments from 1993 through 1998 are presented in Figure 4.2.11. Sampling areas include stations at Priest Rapids, McNary, and Ice Harbor Dams as well as the Hanford Reach stations (White Bluffs, 100-F Area and Hanford Sloughs, and the Richland Pumphouse). Strontium-90 was the only radionuclide to exhibit consistently higher median activities at McNary Dam from 1993 through 1998. No other radionuclides measured in 1998 exhibited appreciable differences in activities between locations.

4.2.2.3 Radiological Results for Riverbank Springs Sediment Samples

Riverbank springs sediment sampling was initiated in 1993 at the Old Hanford Townsite and 300 Area. Sampling of the riverbank springs in the 100-B, 100-F, and 100-K Areas was initiated in 1995. Sediments at all other riverbank springs sampling locations consisted of predominantly large cobble and were unsuitable for sample collection.

Radiological results for riverbank springs sediment collected in 1998 are presented in PNNL-12088, APP. 1 and are summarized in Appendix A (Table A.5). Results were similar to those observed for previous years. In 1998, riverbank springs sediment samples were collected at 100-B and 100-F Areas. There were no sediments available for sampling at the 100-K and 100-N Areas. Radionuclide activities in riverbank springs sediments in 1998 were similar to those observed in 1998 river sediments.

4.2.2.4 Nonradiological Results for Columbia and Snake River Sediment Samples

Metal concentrations (total metals, reported on a dry weight basis) observed in Columbia and Snake River sediments in 1998 are reported in PNNL-12088, APP. 1 and are summarized in Appendix A (Table A.6). Detectable amounts of most metals were found in all river sediment samples (Figure 4.2.12). The highest median and maximum concentrations of chromium were found in riverbank springs sediments.

In 1997 and 1998, Columbia River sediments were also analyzed for simultaneously extracted metals/acid volatile sulfide (SEM/AVS). This

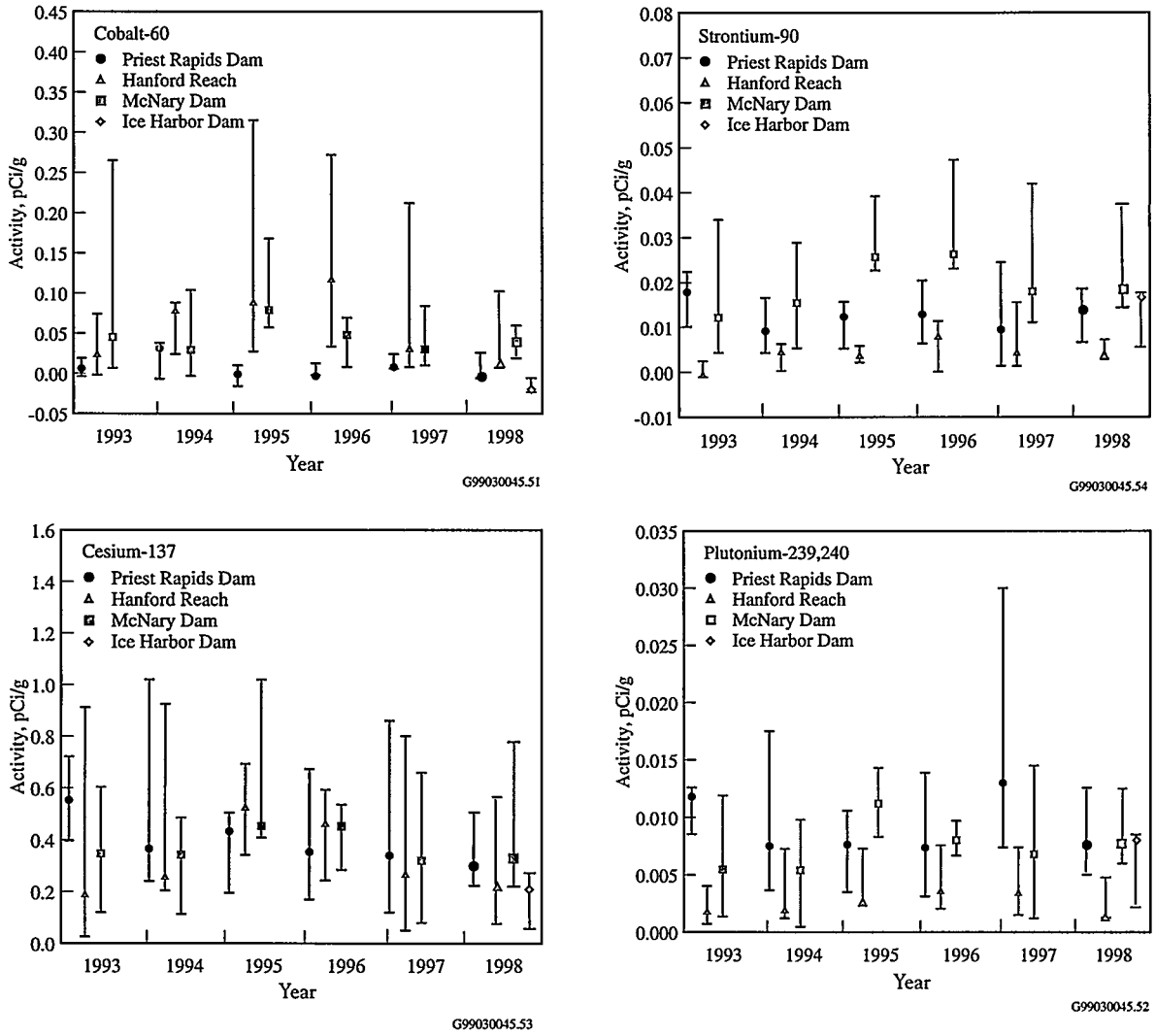


Figure 4.2.11. Median, Maximum, and Minimum Activities of Selected Radionuclides Measured in Columbia and Snake River Sediments, 1993 Through 1998

analysis involves a cold acid extraction of the sediments followed by analysis for sulfide and metals. The SEM/AVS ratios are typically a better indicator of potential sediment toxicity than total metal concentrations (DeWitt et al. 1996, Hansen et al. 1996). Acid volatile sulfide is an important binding phase for divalent metals (i.e., metals with a valance state of 2+, such as Pb^{2+}) in sediment. Metal sulfide precipitates are typically very insoluble, and this limits the amount of dissolved metal available in the sediment porewater. For an individual metal, when the amount of acid volatile sulfide exceeds the amount of the metal (i.e., the SEM/AVS molar ratio is below 1), the metal concentration in the sediment porewater will be low because of the limited solubility of the metal sulfide. For a suite of divalent metals, the sum of the simultaneously extracted metals must be considered, with the assumption that the metal with the lowest solubility will be the first to combine with the acid volatile sulfide.

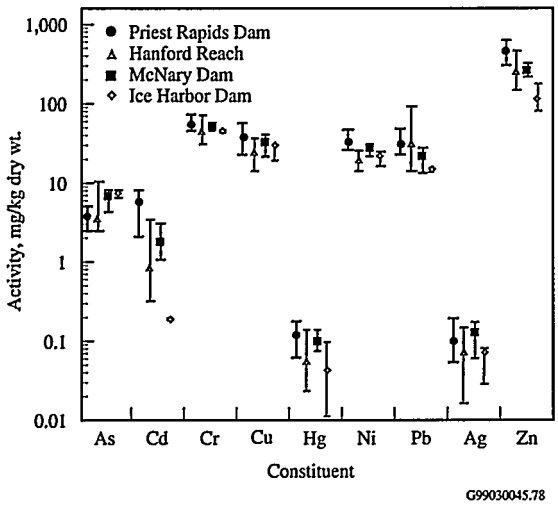


Figure 4.2.12. Median, Maximum, and Minimum Activities of Selected Metals Measured in Columbia and Snake River Sediments, 1993 Through 1998

For 1997 samples, the acid volatile sulfide results were similar for sediments from the Priest Rapids Dam reservoir and the Hanford Reach, with concentrations ranging from 1.2 to 21 µmol/g. Sediment from the McNary Dam reservoir had lower concentrations of acid volatile sulfide, with levels ranging from 0.075 to 2.6 µmol/g. When comparing the pool of available metals to the available sulfide (i.e., SEM/AVS molar ratio), both the Priest Rapid Dam and Hanford Reach sediments should have sufficient sulfide to limit the interstitial porewater concentrations of the divalent metals tested (Figure 4.2.13[a]), with zinc dominating the metal concentrations. However, for the McNary Dam sediments, there was more divalent metal (primarily zinc) available than the sulfide.

The SEM/AVS results for the 1998 samples were similar to 1997 (Figure 4.2.13[b]), with the exception of the average acid volatile sulfide concentration for Priest Rapid Dam sediment that decreased by a factor of two. For 1998, the acid volatile sulfide values were similar for sediments from the Priest Rapid Dam reservoir and the Hanford Reach, with concentrations ranging from 0.32 to 15 µmol/g. Sediments from the McNary Dam reservoir and the Ice Harbor Dam reservoir (Snake River) had lower concentrations of acid volatile sulfide, with values ranging from 0.033 to 2.4 µmol/g. For 1998, the SEM/AVS molar ratios were close to one for Priest Rapids Dam and Hanford Reach sediments, with zinc as the dominant metal. For 1998, the SEM/AVS molar ratios for sediment from McNary Dam were above one, indicating a potential for some metals to be present in the sediment porewater, with zinc as the primary metal present. Ice Harbor Dam sediment had similar concentrations of acid volatile sulfide as McNary Dam; however, the zinc concentrations for Ice Harbor Dam sediments were an order of magnitude below the Columbia River sediments.

These results reveal an apparent difference in the acid volatile sulfide concentrations in sediment from Priest Rapids Dam reservoir and the Hanford Reach, which have higher concentrations than McNary Dam and Ice Harbor Dam sediments. An apportionment of acid volatile sulfide by divalent metals according to solubility values revealed that sufficient acid volatile sulfide should exist in all locations to limit the porewater concentrations of cadmium, copper, lead, and mercury. For Priest Rapids Dam, Hanford Reach, and Ice Harbor Dam sediments, zinc values were of similar magnitude as the acid volatile sulfide concentrations. For McNary Dam sediment, the zinc concentrations were higher than the available acid volatile sulfide pool, indicating the potential for nickel and zinc (the two most soluble of the metals tested) to be available in the sediment porewater.

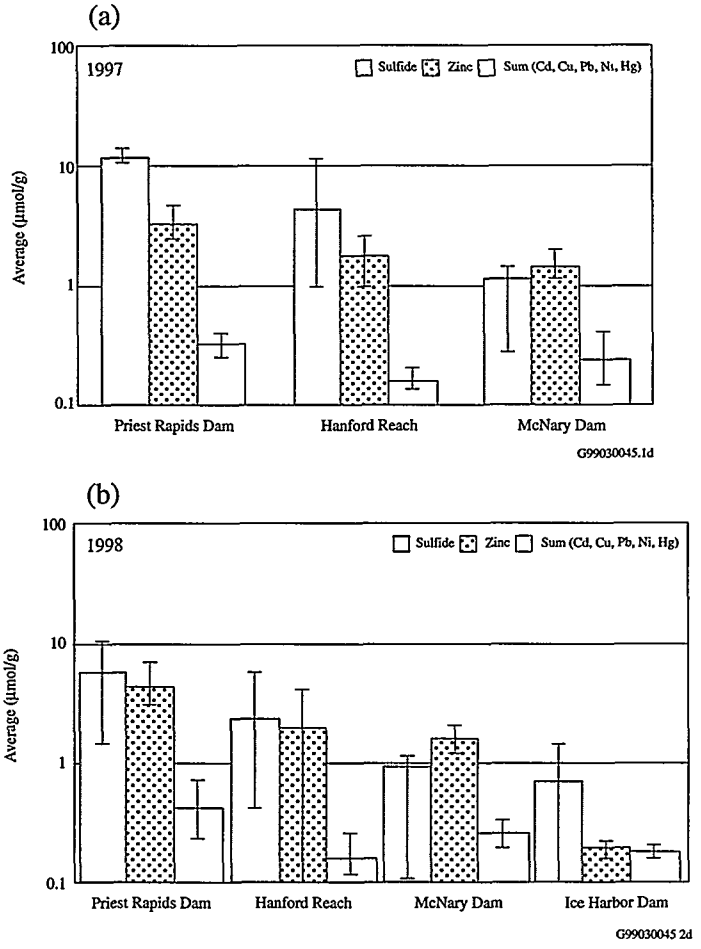


Figure 4.2.13. Average Acid Volatile Sulfide, Simultaneously Extracted Zinc, and Sum of Simultaneously Extracted Metals in Columbia River and Snake River (Ice Harbor Dam) Sediments for 1997 (a) and 1998 (b) (±1 standard deviation)

4.2.3 Riverbank Springs Water

The Columbia River is the primary discharge area for the unconfined aquifer underlying the Hanford Site (see Section 6.1.2, "Groundwater Hydrology). Groundwater provides a means for transporting Hanford-associated contaminants, which have leached into groundwater from past waste disposal practices, to the Columbia River (DOE/RL-92-12, PNL-5289, PNL-7500, WHC-SD-EN-TI-006). Contaminated groundwater enters the Columbia River via surface and subsurface discharge. Discharge zones located above the water level of the river are identified in this report as riverbank springs. Routine monitoring of riverbank springs offers the opportunity to characterize the quality of groundwater being discharged to the river and to assess the potential human and ecological risk associated with the springs water.

The seepage of groundwater into the Columbia River has occurred for many years. Riverbank springs were documented along the Hanford Reach long before Hanford Site operations began during World War II (Jenkins 1922). In the early 1980s, researchers walked the 66-km (41-mi) stretch of Benton County

shoreline of the Hanford Reach and identified 115 springs (PNL-5289). They reported that the predominant areas of groundwater discharge at that time were in the vicinity of the 100-N Area, Old Hanford Townsite, and 300 Area. The predominance of the 100-N Area may no longer be valid because of declining water-table elevations in response to the decrease in liquid waste discharges to the ground from Hanford Site operations. In recent years, it has become increasingly difficult to locate riverbank springs in the 100-N Area.

The presence of riverbank springs also varies with river stage. Groundwater levels in the 100 and 300 Areas are heavily influenced by river stage fluctuations (see Section 6.1, "Hanford Groundwater Monitoring Project"). Water levels in the Columbia River fluctuate greatly on annual and even daily cycles and are controlled by the operation of Priest Rapids Dam upstream of the site. Water flows into the aquifer (as bank storage) as the river stage rises and flows in the opposite direction as the river stage falls. Following an extended period of low river discharge, groundwater discharge zones located above the water level of the river may cease to exist once the level of the groundwater comes into equilibrium with the level of the river. Thus, springs are most readily identified immediately following a decline in river stage. Bank storage of river water also affects the contaminant concentration of the springs. Springs water discharge immediately following a river stage decline generally consists of river water or a river/groundwater mix. The percentage of groundwater in the springs water discharge is believed to increase over time following a drop in river stage.

Because of the effect of bank storage on groundwater discharge and contaminant concentration, it is difficult to estimate the volume of contaminated groundwater discharged to the Columbia River within the Hanford Reach. The estimated total groundwater discharge from the upstream end of the 100 Areas to south of the 300 Area is approximately 66,500 m^3/d (2,350,000 ft^3/d).[a] This represents only 0.02% of the long-term average flow rate of the Columbia River, which illustrates the tremendous dilution potential afforded by the river. It should be noted that not all of the groundwater discharged to the river contains contaminants originating from Hanford Site operations. Riverbank springs studies conducted in 1983 (PNL-5289) and in 1988 (PNL-7500) noted that discharges from the springs had a localized effect on river contaminant concentrations. Both studies reported that the volume of groundwater entering the river at these locations was very small relative to the flow of the river and that the impact of groundwater discharges to the river was minimal.

4.2.3.1 Riverbank Springs Water Samples and Analytes of Interest

Routine monitoring of selected riverbank springs was initiated in 1988 at the 100-N Area, Old Hanford Townsite, and 300 Area. Monitoring was expanded in 1993 to include riverbank springs in the 100-B, 100-D, 100-H, and 100-K Areas. A 100-F Area riverbank spring was added in 1994. The locations of all riverbank springs sampled in 1998 are identified in Figure 4.2.1. Sample collection methods are described in DOE/RL-91-50, Rev. 2. Analytes of interest for samples from riverbank springs were selected based on findings of previous investigations, reviews of contaminant concentrations observed in nearby groundwater monitoring wells, and results of preliminary risk assessments. Sampling is conducted annually when river flows are low, typically August through September.

For 1998, riverbank springs samples were collected in September and October. All samples from riverbank springs collected during 1998 were analyzed for gamma-emitting radionuclides, gross alpha,

(a) Stuart Luttrell, Pacific Northwest National Laboratory, Richland, Washington, January 1995.

gross beta, and tritium. Samples from selected springs were analyzed for strontium-90, technetium-99, iodine-129, and uranium-234, -235, and -238. All samples were analyzed for metals and anions. All analyses were conducted on unfiltered samples.

4.2.3.2 Results for Riverbank Springs Water

Hanford-origin contaminants continued to be detected in riverbank springs water entering the Columbia River along the Hanford Site during 1998. The locations and extent of contaminated discharges were consistent with recent groundwater surveys. Tritium, strontium-90, technetium-99, iodine-129, uranium-234, -235, and -238, metals (antimony, arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, thallium, zinc, and occasionally silver), and anions (chloride, fluoride, nitrate, and sulfate) were detected in springs water. The contaminant concentrations in springs water are typically lower than those found in near-shore groundwater wells because of bank storage effects.

Results of radiological and chemical analyses conducted on riverbank springs samples in 1998 are documented in PNNL-12088, APP. 1. Radiological results obtained in 1998 are summarized in Appendix A (Table A.7) and compared to those reported in 1993 through 1997. In the following discussion, radiological and nonradiological results are addressed separately. Selected contaminant concentration trends are illustrated for locations for which >3 yr of data are available.

4.2.3.3 Radiological Results for Riverbank Springs Water Samples

All radiological contaminant activities measured in riverbank springs in 1998 were less than the DOE derived concentration guides (DOE Order 5400.5; see Appendix C, Table C.5). However, the spring at the 100-N Area that has historically exceeded the DOE derived concentration guide for strontium-90 was not flowing during the 1998 sample collection visits; thus, an alternative spring was sampled in the 100-N Area. Tritium activities in riverbank springs water at the Old Hanford Townsite and the 100-N Area exceeded the ambient surface-water quality criteria levels (WAC 173-201A and 40 CFR 141). There are no ambient surface-water quality criteria levels directly applicable to uranium. However, total uranium activities exceeded the site-specific proposed EPA drinking water standard (EPA 822-R-96-001) in the 300 Area (see Appendix C, Table C.2). The gross alpha activity exceeded the ambient surface-water quality criteria level in riverbank springs water at the 300 Area, which is consistent with the elevated uranium levels. All other radionuclide activities in 300 Area springs water were less than ambient surface-water quality criteria levels. Gross beta activities in riverbank springs water at the 100-H Area exceeded the surface-water quality criteria level.

Tritium activities varied widely with location. The highest tritium activity detected in riverbank springs water was at the Old Hanford Townsite (120,000 ± 8,800 pCi/L), followed by the 100-N Area (24,000 ± 1,900 pCi/L), 100-B Area (14,000 ± 1,100 pCi/L), and 100-K Area (12,000 ± 970 pCi/L). The ambient surface-water quality criteria level for tritium is 20,000 pCi/L. Tritium activities in all riverbank springs water samples were elevated compared to the 1998 average Columbia River activities at Priest Rapids Dam (36 ± 7.2 pCi/L).

Samples from riverbank springs in the 100-B Area, 100-H Area, 300 Area, and Old Hanford Townsite were analyzed for technetium-99. The highest technetium-99 activity was found in water from the Old Hanford Townsite spring (100 ± 12 pCi/L), in agreement with the observed beta activity.

Iodine-129 was detected in the Old Hanford Townsite and 300 Area riverbank springs; the highest in water from the Old Hanford Townsite spring (0.22 ± 0.030 pCi/L). This value was elevated compared to

the 1998 average measured at Priest Rapids Dam (0.000015 ± 0.0000094 pCi/L) but was below the 1-pCi/L surface-water quality criteria level (see Appendix C, Table C.2).

Uranium was sampled in riverbank springs in the 100-H Area, 100-F Area, Old Hanford Townsite, and 300 Area in 1998. The highest activity was found for the 300 Area spring (58 ± 6.1 pCi/L), which is downgradient from the retired 300 Area process trenches. The 300 Area spring had elevated gross alpha activity, which paralleled that of uranium.

Samples from riverbank springs were analyzed for strontium-90 in the 100-B, 100-D, 100-F, 100-H, 100-K, and 100-N Areas. However, the 100-H and 100-N Area samples (samples from both locations were above the ambient surface-water quality criteria level in 1997) were destroyed during processing for strontium-90 at the analytical laboratory and it was not possible to collect additional samples in 1998. The gross beta activities at 100-H and 100-N Area springs, which should parallel the strontium-90 activity, were similar to previous results; thus, strontium-90 in 1998 was likely similar to that seen in previous years. The ambient surface-water quality criteria level of 8 pCi/L for strontium-90 was not exceeded at any other riverbank springs location, and the results were consistent with those found in previous years.

Historically, riverbank seepage in the 100-N Area has been monitored for contaminants by sampling from either well 199-N-8T, which is located close to the river; well 199-N-46 (caisson), which is slightly inland from well 199-N-8T (PNNL-11795, Figure 3.2.4); or riverbank springs. Since 1993, 100-N Area seepage samples have been collected from riverbank springs. For 1993 to 1996 and 1998, there was no visible riverbank springs directly adjacent to wells 199-N-8T or 199-N-46 during the sampling period. The 100-N Area riverbank springs samples were, instead, collected from the nearest visible downstream riverbank spring. In 1998, the samples were also collected from the downstream riverbank spring sampled in previous years (i.e., downriver from well 199-N-8T). Contaminant activities measured in the water from the two riverbank springs locations sampled in previous years were distinctly different (Table 4.2.3). Historically, the activities of strontium-90 and gross beta were considerably higher in the spring directly adjacent to well 199-N-8T than for the downstream spring. Tritium activities in riverbank springs water are typically elevated at both locations, and 1998 tritium results were similar to those found in previous years (see Table 3.2.5). Tritium was the only contaminant detected at the 100-N Area riverbank spring in 1998; however, the 1998 100-N Area riverbank spring sample submitted for strontium-90 analysis was destroyed during processing at the analytical laboratory. The maximum tritium activity

Table 4.2.3. Selected Radionuclide Activities in 100-N Area Riverbank Springs Water, 1993 Through 1998

	Concentration, pCi/L[a]		
Year	Tritium	Gross Beta	Strontium-90
1993[b]			
Min	28,000 ± 2,200	2.4 ± 3.2	-0.010 ± 0.22
Max	29,000 ± 2,300	4.5 ± 3.3	0.020 ± 0.26
1994[b]	31,000 ± 2,400	8.8 ± 2.3	0.13 ± 0.11
1995[b]	12,000 ± 970	1.5 ± 1.5	0.079 ± 0.10
1996[b]	17,000 ± 1,300	4.5 ± 1.8	0.053 ± 0.048
1997[b]	19,000 ± 1,500	3.5 ± 1.6	0.59 ± 0.13
1997[c]	14,000 ± 1,100	16,000 ± 1,400	9,900 ± 1,800
1998[b]	24,000 ± 1,900	2.3 ± 2.1	[d]

(a) Concentrations are ±2 total propagated analytical uncertainty.
(b) Sample collected from riverbank spring downstream of well 199-N-8T.
(c) Samples collected from spring below well 199-N-8T (100-N Area spring 8-13, see PNNL-11795, Figure 3.2.4).
(d) Sample was lost during processing at the analytical laboratory.

was 1.2 times the ambient surface-water quality criteria level (see Appendix C, Table C.2). The tritium results for the 100-N Area riverbank springs samples are of the same magnitude as those reported in Section 3.2, "Near-Facility Environmental Monitoring," Table 3.2.7.

Activities of selected radionuclides in riverbank springs water near the Old Hanford Townsite from 1993 through 1998 are provided in Figure 4.2.14. Gross beta activities in 1998 were similar to those observed since 1994. The 1998 tritium and technetium-99 activities were slightly higher than in recent years but below values reported for 1993. Annual fluctuations in these values may reflect the influence of bank storage during the sampling period. Tritium and technetium-99 detected in Old Hanford Townsite riverbank springs water in 1998 were 600% and 11% of their respective ambient surface-water quality criteria levels (see Appendix C, Table C.2). The iodine-129 measured in the Old Hanford Townsite riverbank springs water for 1998 was 22% of the ambient surface-water quality criteria level (see Appendix C, Table C.2).

Figure 4.2.15 depicts the activities of selected radionuclides in the 300 Area riverbank springs from 1993 through 1998. Results in 1998 were similar to those observed previously. The elevated tritium activities measured in the 300 Area riverbank springs are indicators of the contaminated groundwater plume emanating from the 200 Areas (Section 5.9 in PNL-10698). Technetium-99 and iodine-129 are also contained in the 200 Areas' contaminated groundwater plume. Tritium, technetium-99, and iodine-129 activities in 300 Area riverbank springs water in 1998 were 48%, 1.4%, and 0.47% of their respective ambient surface-water quality criteria levels (see Appendix C, Table C.2). The highest total uranium in riverbank springs water from 1993 through 1998 was found in the 300 Area riverbank springs, with the 1998 value more than four times higher than the proposed site-specific EPA drinking water standard (13.4 pCi/L [EPA 822-R-96-001]; see Appendix C, Table C.2). Elevated uranium activities exist in the unconfined aquifer beneath the 300 Area in the vicinity of uranium fuel fabrication facilities and inactive waste sites. Gross alpha and gross beta activities in the 300 Area riverbank springs water from 1993 through 1998 parallel uranium and are likely associated with its presence.

4.2.3.4 Nonradiological Results for Riverbank Springs Water Samples

The range of concentrations of selected chemicals measured in riverbank springs water in 1993 through 1998 are presented in Table 4.2.4. For most locations, the 1998 nonradiological sample results were similar to those reported previously. Nitrate concentrations were highest in the 100-F and 100-H Area springs. Chromium concentrations are typically highest in the 100-D, 100-H, and 100-K Areas' riverbank springs. Hanford groundwater monitoring results for 1998 indicated similar nonradiological contaminants in shoreline areas (see Section 6.1, "Hanford Groundwater Monitoring Project").

The ambient surface-water quality criteria for cadmium, copper, lead, nickel, silver, and zinc are total-hardness dependent (WAC 173-201A; see Appendix C, Table C.3). For comparison purposes, springs water criteria were calculated using the same 48-mg $CaCO_3$/L hardness given in Appendix C, Table C.3. Metal concentrations measured in riverbank springs from the Hanford Site shoreline in 1998 were below ambient surface-water acute toxicity levels (WAC 173-201A), except for chromium concentrations in 100-B, 100-K, 100-D, and 100-H Areas riverbank springs (see Appendix C, Table C.3). Arsenic concentrations in riverbank springs water were well below ambient surface water chronic toxicity levels, but all samples (including upriver Columbia River water samples) exceeded the federal limit (40 CFR 141, see Appendix C, Table C.3). Nitrate concentrations at all spring water locations were below the drinking water standards were below the drinking water standard (see Appendix C, Table C.2).

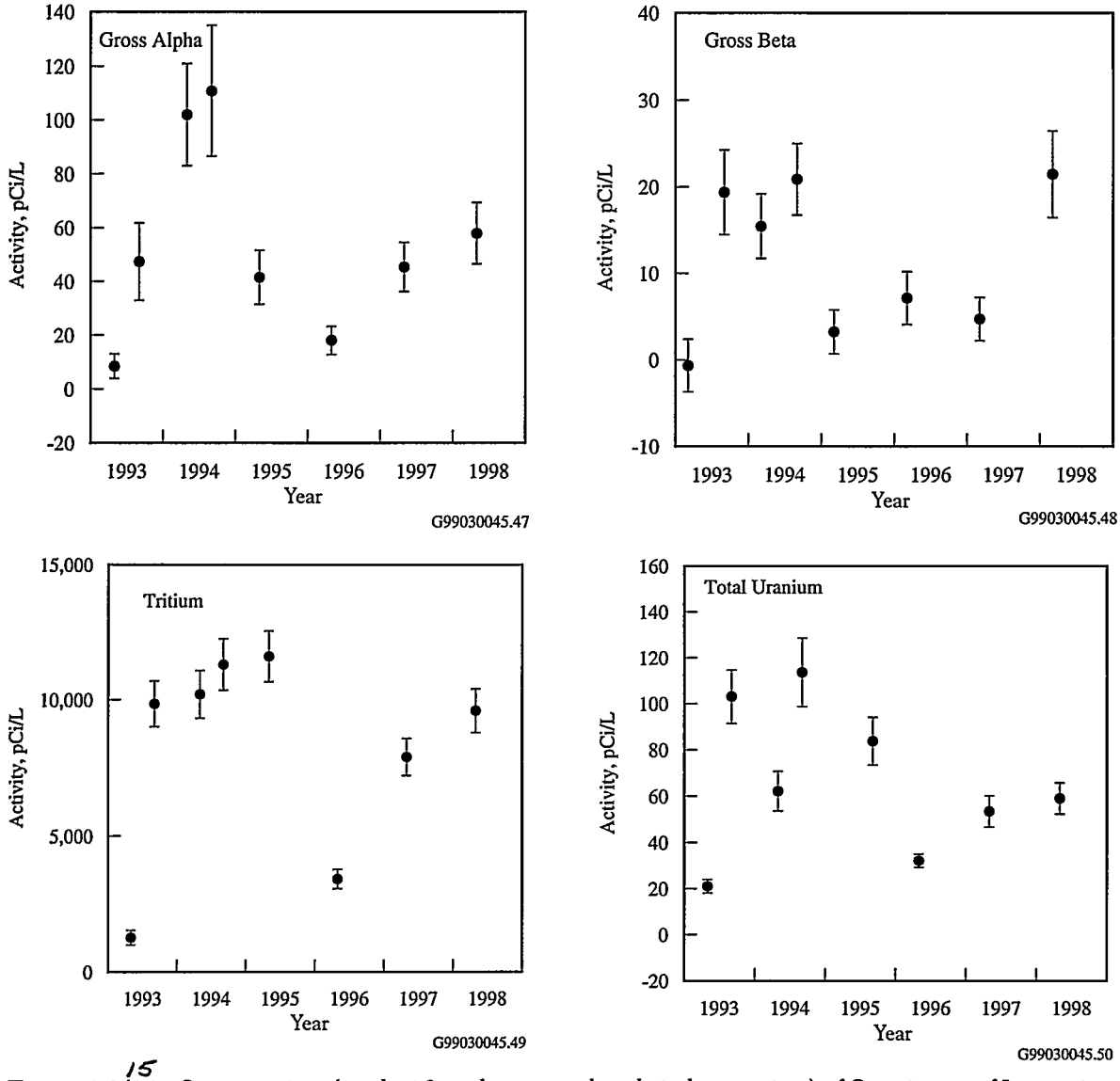


Figure 4.2.~~14~~15. Concentrations (results ±2 total propagated analytical uncertainty) of Constituents of Interest in Riverbank Springs Water Near the Old Hanford Townsite, 1993 Through 1998.

4.2.4 Onsite Pond Water

Two onsite ponds (see Figure 4.2.1), located near operational areas, were sampled periodically during 1998. Although the ponds are inaccessible to the public and did not constitute a direct offsite environmental impact during 1998, they were accessible to migratory waterfowl, creating a potential biological pathway for the dispersion of contaminants (PNL-10174). Periodic sampling of the ponds also provided an independent check on effluent control and monitoring systems. Fast Flux Test Facility pond samples are collected from a pond that is a disposal site for process water (primarily cooling tower water).

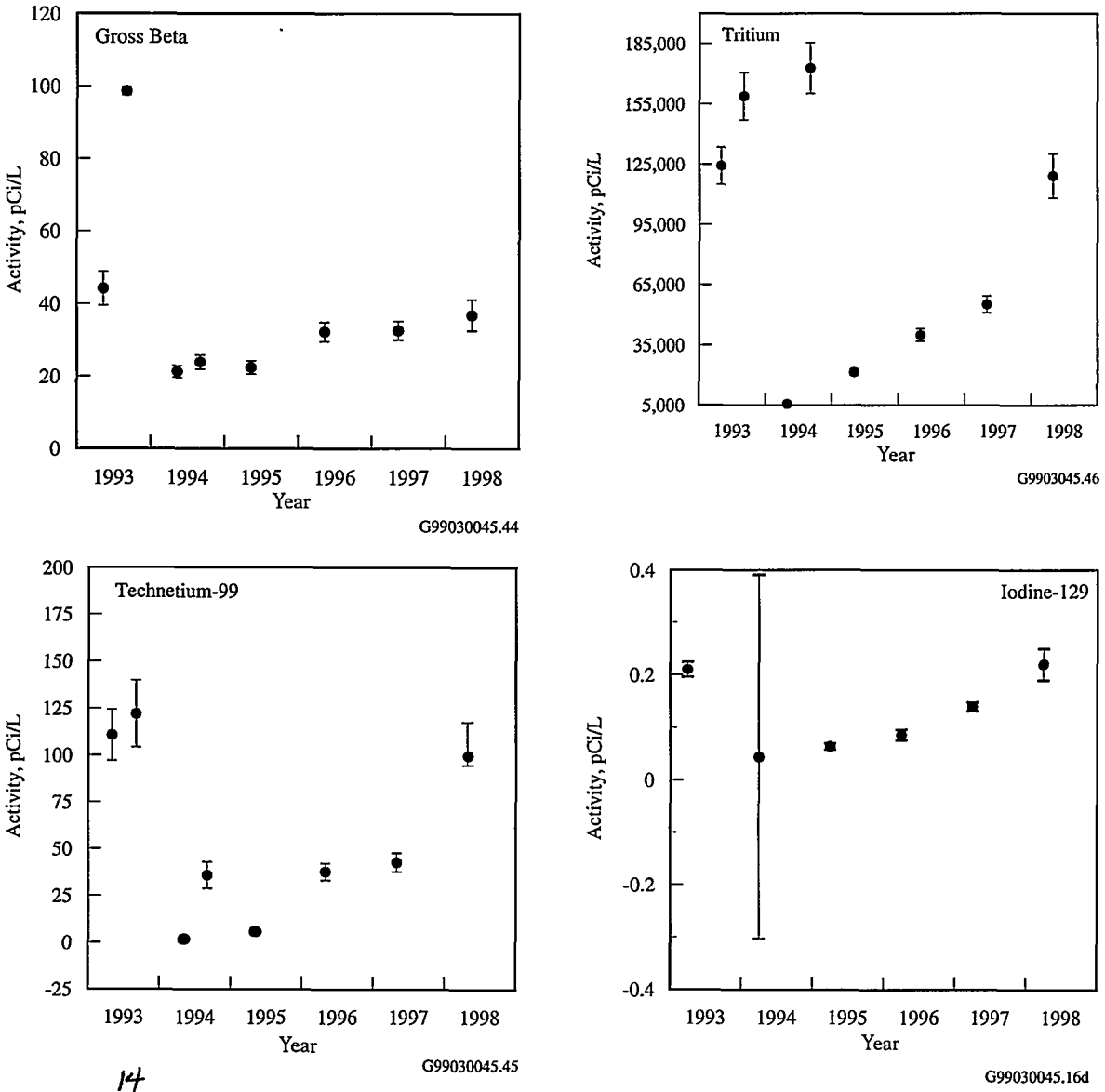


Figure 4.2.~~15~~14. Concentrations (results ±2 total propagated analytical uncertainty) of Constituents of Interest in 300 Area Riverbank Springs Water, 1993 Through 1998. As a result of figure scale, some uncertainties (error bars) are concealed by the point symbol.

West Lake, the only naturally occurring pond on the site, is located north of the 200-East Area (ARH-CD-775). West Lake has not received direct effluent discharges from site facilities but is influenced by changing water table elevation.

4.2.4.1 Collection of Pond Water Samples and Analytes of Interest

In 1998, grab samples were collected quarterly from the Fast Flux Test Facility Pond and from West Lake. Unfiltered aliquots of all samples were analyzed for gross alpha and gross beta activities,

Table 4.2.4. Activity Ranges of Selected Nonradiological Chemicals in Riverbank Springs, 1993 Through 1998

	Ambient Surface-Water Quality Criteria Level, µg/L	Concentration, µg/L							
		100-B Area	100-K Area	100-N Area[a]	100-D Area	100-H Area	100-F Area	Old Hanford Townsite	300 Area
No. of Samples		6	3	5	7	5	5	6	5
Metals									
Antimony[b]		0.064 - 0.24	0.17 - 0.42	0.16 - 0.24	0.12 - 0.36	0.20 - 0.31	0.15 - 0.17	0.098 - 0.42	0.14 - 0.28
Arsenic[b]	190	1.1 - 1.3	1.2 - 1.4	2.5 - 3.2	1.0 - 1.4	0.90 - 1.6	2.0 - 2.2	3.2 - 4.5	1.1 - 1.3
Cadmium	[c]	ND[d] - 0.72	ND - 2.0	ND - 0.072	ND - 0.088	ND - 0.087	0.032 - 4.8	ND - 0.01[e]	0.01[e] - 0.055
Chromium	[c]	13 - 25	1.7 - 66	ND - 45	ND - 400	18 - 124	6.0 - 99	ND - 5.3	ND - 6.4
Copper	[c]	ND - 0.61	0.33 - 37	ND - 30	ND - 6.4	ND - 4.7	ND - 85	ND - 5.4	ND - 14
Lead[b]	[c]	0.33 - 0.90	0.056 - 2.5	0.28 - 0.35	0.41 - 0.77	0.37 - 0.43	0.53 - 1.9	0.18 - 0.22	0.25 - 0.95
Mercury[f]	0.012	0.00066	NA[g]	NA	0.0026	0.0015	0.0015	0.00056	0.0014
Nickel	[c]	ND - 8.1	ND - 0.90	ND - 25	ND - 26	ND - 2.1	ND - 31	ND - 22	ND - 1.3
Selenium[b]	5	1.3 - 2.9	ND - 0.89	ND - 0.58	1.0 - 2.3	0.55[e] - 0.96	ND - 3.0	1.8 - 1.9	1.8 - 2.8
Silver[f]	--	0.008[e]	0.008[e]	0.012	0.008[e]	0.008[e]	0.008[e]	0.008[e]	0.008[e]
Thallium[b]	[c]	0.004[e] - 0.0088	0.021 - 0.047	0.016 - 0.023	0.072 - 0.098	0.044 - 0.055	0.011 - 0.025	0.012 - 0.035	0.014 - 0.045
Zinc	[c]	ND - 45	3.0 - 410	1.2 - 460	1.3 - 18	1.7 - 15	4.1 - 910	0.66 - 110	4.0 - 100
Anions									
Nitrate	--	3,700 - 11,000	320 - 15,000	3,100 - 15,000	1,000 - 46,000	5,800 - 47,000	8,800 - 33,000	1,800 - 40,000	4,000 - 23,000

(a) Sample collected from riverbank spring downstream of well 199-N-8T (see Table 4.2.3).
(b) Two samples.
(c) Ambient surface-water quality criteria level is hardness-dependent (WAC 173-201A-040; see Appendix C, Table C.3).
(d) ND = result was less than the minimum detection level.
(e) Result was less than the minimum detection limit; minimum detection level is given.
(f) 1998 values only; one sample.
(g) NA = sample was not analyzed for this chemical.

gamma-emitting radionuclides, and tritium. West Lake samples were also analyzed for strontium-90, technetium-99, and uranium-234, -235, and -238. Constituents were chosen for analysis based on their known presence in local groundwater or in effluents discharged to the pond and their potential to contribute to the overall radiation dose to the public.

4.2.4.2 Radiological Results for Pond Water Samples

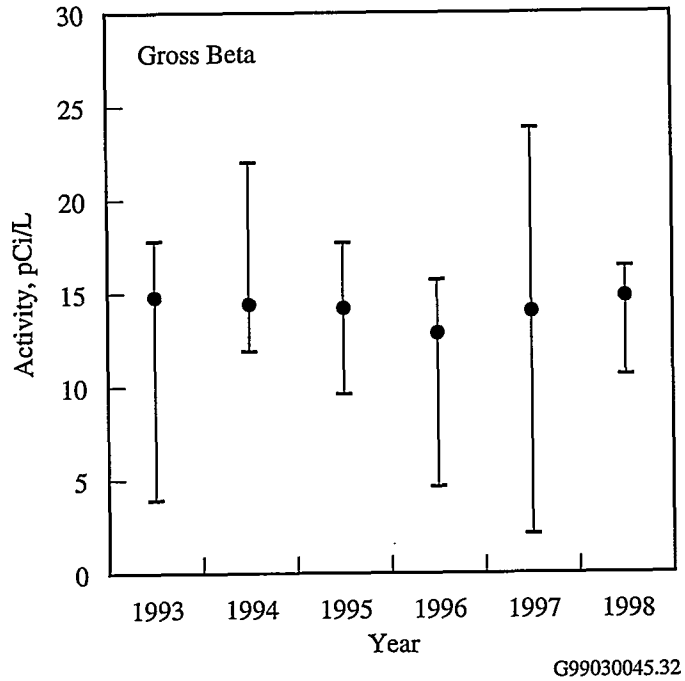
Analytical results from pond water samples collected during 1998 are reported in PNNL-12088, APP. 1. With the exceptions of uranium-234 and uranium-238 in the July and October samples from West Lake, radionuclide activities in onsite pond water were less than the DOE derived concentration guides (DOE Order 5400.5; see Appendix C, Table C.5). The median gross alpha, gross beta, and total uranium exceeded their ambient surface-water quality criteria in West Lake. The medians of all other radionuclides were below ambient surface-water quality criteria levels (WAC 173-201A, 40 CFR 141; see Appendix C, Table C.2).

Figure 4.2.16 shows the annual gross beta and tritium activities in Fast Flux Test Facility Pond water from 1993 through 1998. Median activities of both constituents have remained stable in recent years. However, tritium activities in the July 1995 sample was 16,400 pCi/L, which was much higher than that observed previously. During this time, dire emergency water supply well 499-S0-7 was in use. Tritium levels in well 499-S0-7 are typically >20,000 pCi/L, reflective of those observed in a portion of the local unconfined aquifer. The use of well 499-S0-7 is most likely responsible for the high levels of tritium observed in July 1995. Median gross beta and tritium activities in Fast Flux Test Facility Pond water during 1998 were 30% and 23% of their respective ambient surface-water quality criteria. The concentrations of all other measured contaminants in this pond water were below detection limits.

The annual activities of selected radionuclides from 1993 through 1998 in West Lake water are shown in Figure 4.2.17. Median radionuclide activities in West Lake during 1998 were similar to those observed in the past. The gross alpha and gross beta activities in West Lake water are believed to result from high levels of naturally occurring uranium in the surrounding soils (BNWL-1979, PNL-7662). Annual median total uranium activities have remained stable over the last 6 yr, but the range is large. The highest activities measured in 1998 were in summer and fall, when the water level in the pond was low. It is thought that the relatively large concentration of suspended sediment in the samples is causing the elevated results. Similar total uranium activities were reported in PNNL-7662 for West Lake samples that contained high concentrations of suspended sediment. Declines in groundwater levels beneath the 200 Areas have been recorded since the decommissioning of the 216-U-10 Pond in 1984 and the shutdown of production facilities (see Section 6.1, "Hanford Groundwater Monitoring Project"). As a result, the water level in West Lake has dropped. Median activities of tritium, strontium-90, and technetium-99 in West Lake in 1998 were 0.70%, 14%, and 2.6%, respectively, of the ambient surface-water quality criteria levels and reflected local groundwater concentrations. The activities of all other measured radionuclides were rarely above detection limits, except for naturally occurring potassium-40.

4.2.5 Offsite Water

During 1998, water samples were collected from an irrigation canal across the Columbia River and downstream from the Hanford Site that receives water pumped from the Columbia River. As a result of public concern about the potential for Hanford-associated contaminants in offsite water, sampling



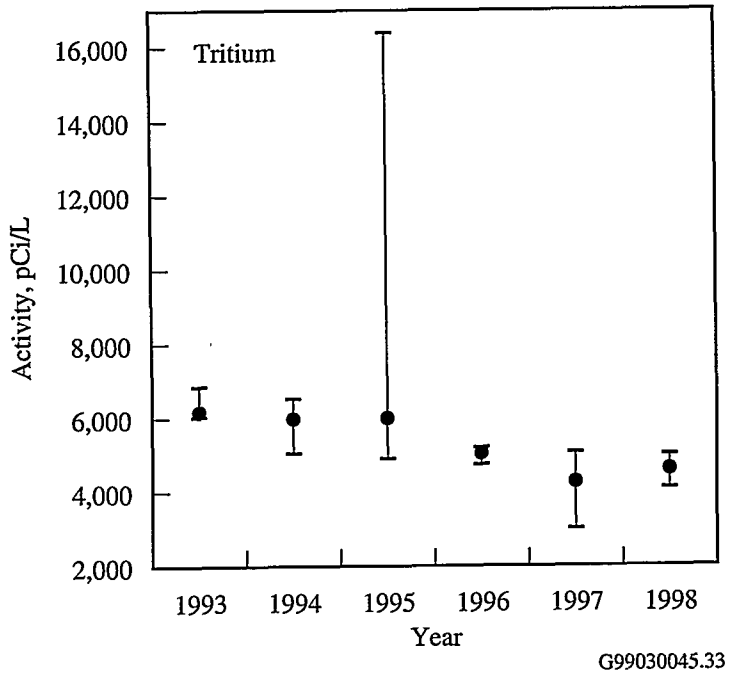


Figure 4.2.16. Median, Maximum, and Minimum Gross Beta and Tritium Activities in Fast Flux Test Facility Pond Water Samples, 1993 Through 1998

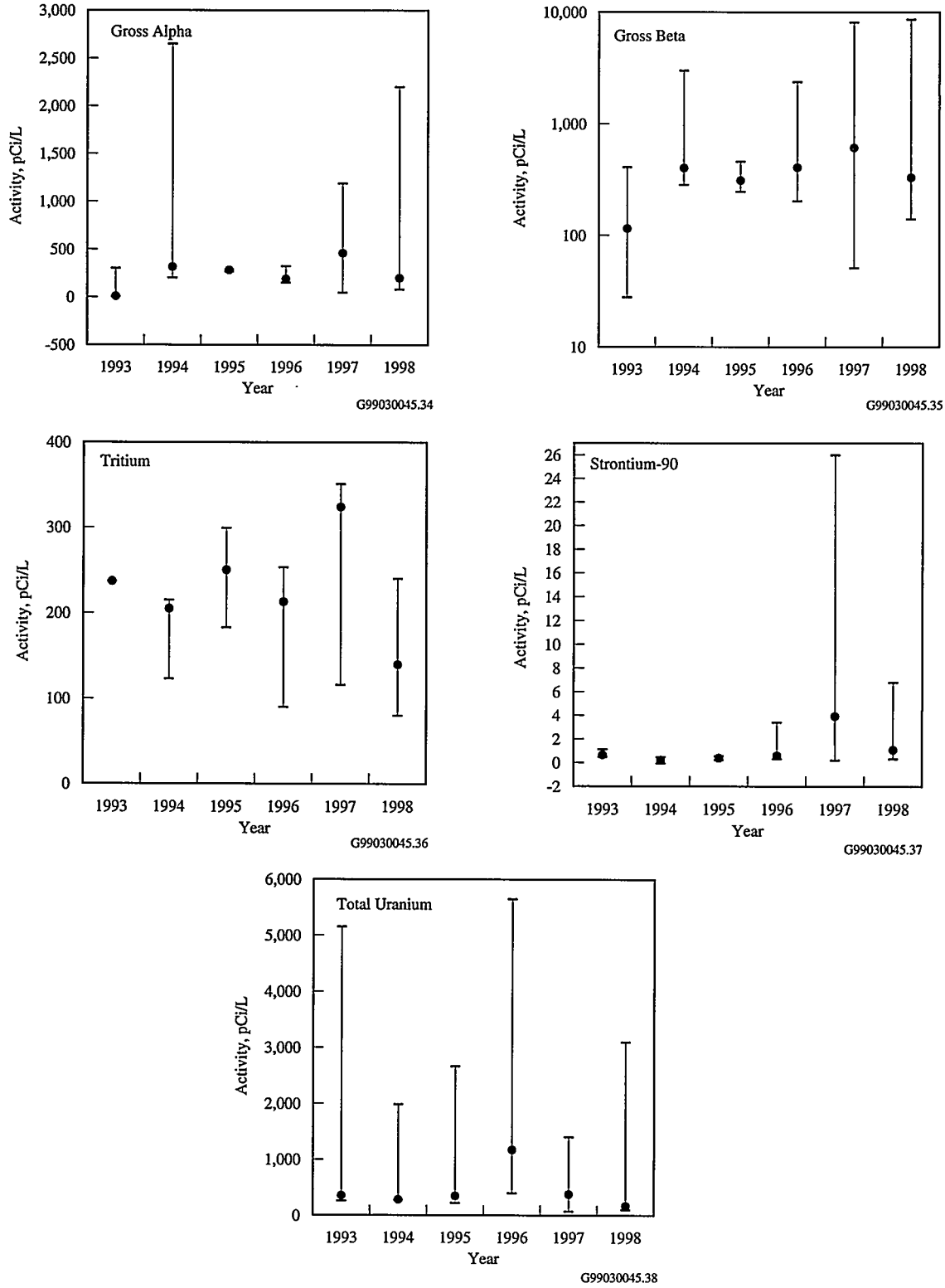


Figure 4.2.17. Median, Maximum, and Minimum Activities of Selected Radionuclides in West Lake Water Samples, 1993 Through 1998

was conducted to document the levels of radionuclides in water used by the public. Consumption of vegetation irrigated with Columbia River water downstream of the site has been identified as one of the primary pathways contributing to the potential dose to the hypothetical maximally exposed individual and any other member of the public (see Section 5.0, "Potential Radiological Doses from 1998 Hanford Operations").

4.2.5.1 Collection, Analysis, and Results for Irrigation Canal Water

Water in the Riverview irrigation canal was sampled three times in 1998 during the irrigation season. Unfiltered samples of the canal water were analyzed for gross alpha, gross beta, gamma emitters, tritium, strontium-90, and uranium-234, -235, and -238. Results are presented in PNNL-12088, APP. 1. In 1998, radionuclide activities measured in this canal's water were at the same levels observed in the Columbia River. All radionuclide activities were below the DOE derived concentration guides and ambient surface-water quality criteria levels (DOE Order 5400.5, WAC 173-201A, 40 CFR 141). The strontium-90 activities in the irrigation water during 1998 ranged from 0.063 ± 0.032 to 0.10 ± 0.044 pCi/L and were similar to those reported for the Columbia River at Priest Rapids Dam and the Richland Pumphouse (see Section 4.2.1, "Columbia River Water").

4.3 Hanford Site Drinking Water Surveillance

R. W. Hanf, L. M. Kelly, and R. G. Gant

The primary purpose of Hanford Site drinking water surveillance is to verify the quality of the site's drinking water. This is achieved by the routine collection and analysis of drinking water samples and the comparison of the resulting data with established drinking water standards and guidelines (WAC 246-290, 40 CFR 141, EPA-570/9-76-003, EPA 822-R-96-001, DOE Order 5400.5; see Appendix C, Tables C.2 and C.5). From January through September 1998, most radiological surveillance of DOE-owned drinking water systems on the site was conducted by Pacific Northwest National Laboratory for DynCorp Tri-Cities Services, Inc. DE&S Hanford, Inc. collected radiological data for a single system in the 100-K Area (Table 4.3.1). In October 1998, Pacific Northwest National Laboratory assumed responsibility for radiological surveillance of the 100-K Area system. Chemical and microbiological monitoring of all onsite, DOE-owned, drinking water systems was conducted by DynCorp Tri-Cities Services, Inc.

The national primary drinking water regulations of the Safe Drinking Water Act of 1974 apply to the drinking water supplies at the Hanford Site. These regulations are enforced by the Washington State Department of Health. WAC 246-290 requires that all drinking water analytical results be reported routinely to the Washington State Department of Health. In recent years, summary and individual radiological results have been reported to the state through this annual Hanford Site environmental report and through a supplemental data compilation (PNNL-12088, APP. 1). Nonradiological data have been reported to the state by DynCorp Tri-Cities Services, Inc. and have not been published.

4.3.1 Radiological Monitoring of Hanford Site Drinking Water Systems

Drinking water was supplied to DOE facilities on the site by 12 DOE-owned, contractor-operated, water treatment systems (see Table 4.3.1) and one system owned and operated by the city of Richland. Ten of these systems (including Richland's system) used water from the Columbia River. Three systems used groundwater from beneath the site. Most of the systems were operated by DynCorp Tri-Cities Services, Inc.; however, DE&S Hanford, Inc., Bechtel Hanford, Inc., and B&W Hanford Company also each operated one system, though water for the Bechtel Hanford, Inc. system was supplied by a pumping station operated by DynCorp Tri-Cities Services, Inc. The city of Richland provided drinking water to the 700 Area, 1100 Area (now owned by the Port of Benton), and Richland North Area and served as a backup supplier for the 300 Area. Water from the city of Richland's system was not monitored through the site drinking water surveillance project; however, personnel from Pacific Northwest National Laboratory's Surface Environmental Surveillance Project routinely collected water samples from the Columbia River at the Richland Pumphouse, which is the city of Richland's drinking water intake. The analytical results (radiological) for these samples of untreated river water can be found in Appendix A (Table A.2).

Table 4.3.1. DOE-Owned Drinking Water Systems on the Hanford Site, 1998

Location/Number	Source of Supply	Notes
100-D/001761	Columbia River via 181-B or D raw water export	Filtered and chlorinated at 183-D Pumphouse. Operated by DynCorp Tri-Cities Services, Inc.
100-B/04480U	Columbia River via 181-B or D raw water export	Filtered and chlorinated at 182-B Reservoir Pumphouse. Operated by DynCorp Tri-Cities Services, Inc.
100-K/00177J	Columbia River via 181-K Pumphouse	Filtered and chlorinated at 183-KE Water Treatment Plant. Operated by DE&S Hanford, Inc.
100-N/418532	Columbia River via 181-B or D raw water export	Filtered and chlorinated at 183-N Water Treatment Plant. Operated by Bechtel Hanford, Inc.
200-E/41866V	Columbia River via 181-B or D raw water export	Filtered and chlorinated at 283-E Water Treatment Plant. Operated by DynCorp Tri-Cities Services, Inc.
200-W/001004	Columbia River via 181-B or D raw water export	Filtered and chlorinated at 283-W Water Treatment Plan. Operated by DynCorp Tri-Cities Services, Inc.
251 Building/001782 (electrical switching)	Columbia River via 181-B or D raw water export	Filtered and chlorinated at 251 Building. Operated by DynCorp Tri-Cities Services, Inc.
609 Building/001806 (100 Areas Fire Station)	Columbia River via 181-B or D raw water export	Filtered and chlorinated at 609 Building. Operated by DynCorp Tri-Cities Services, Inc.
Yakima Barricade/ 001848	Well 699-49-100C	No treatment provided. Operated by DynCorp Tri-Cities Services, Inc.
Patrol Training Academy/00183Q	Well 699-S28-E0	Chlorination only. Operated by DynCorp Tri-Cities Services, Inc.
400 Area/419470	Wells 499-S1-8J, 499-S0-7, and 499-S0-8	Supplied from well 499-S1-8J (P-16); well 499-S0-8 (P-14) is the emergency supply, well 499-S0-7 (P-15) is the dire emergency supply. Chlorination only. Operated by B&W Hanford Company.
300 Area/418408	Columbia River via 312 Pumphouse or city of Richland	Filtered and chlorinated at 315 Building. Operated by DynCorp Tri-Cities Services, Inc.

In 1998, radionuclide activities in onsite drinking water were monitored at the seven facilities shown in Figure 4.3.1, which represent the principal water supply facilities for the site's DOE-owned drinking water treatment systems. The 100-B Area pumphouse continued to serve as the primary Columbia River pumping station for many areas on the site (100-N Area, 200-East and 200-West Areas, 251 Building, and 100 Areas Fire Station), with the 100-D Area pumphouse available as an emergency backup. Water for the 100-K Area was supplied by the 181-KE Pumphouse. The 300 Area obtained its water via the 312 Pumphouse or the city of Richland. The Yakima Barricade, Patrol Training Academy, and 400 Area (Fast Flux Test Facility) obtained water from groundwater wells.

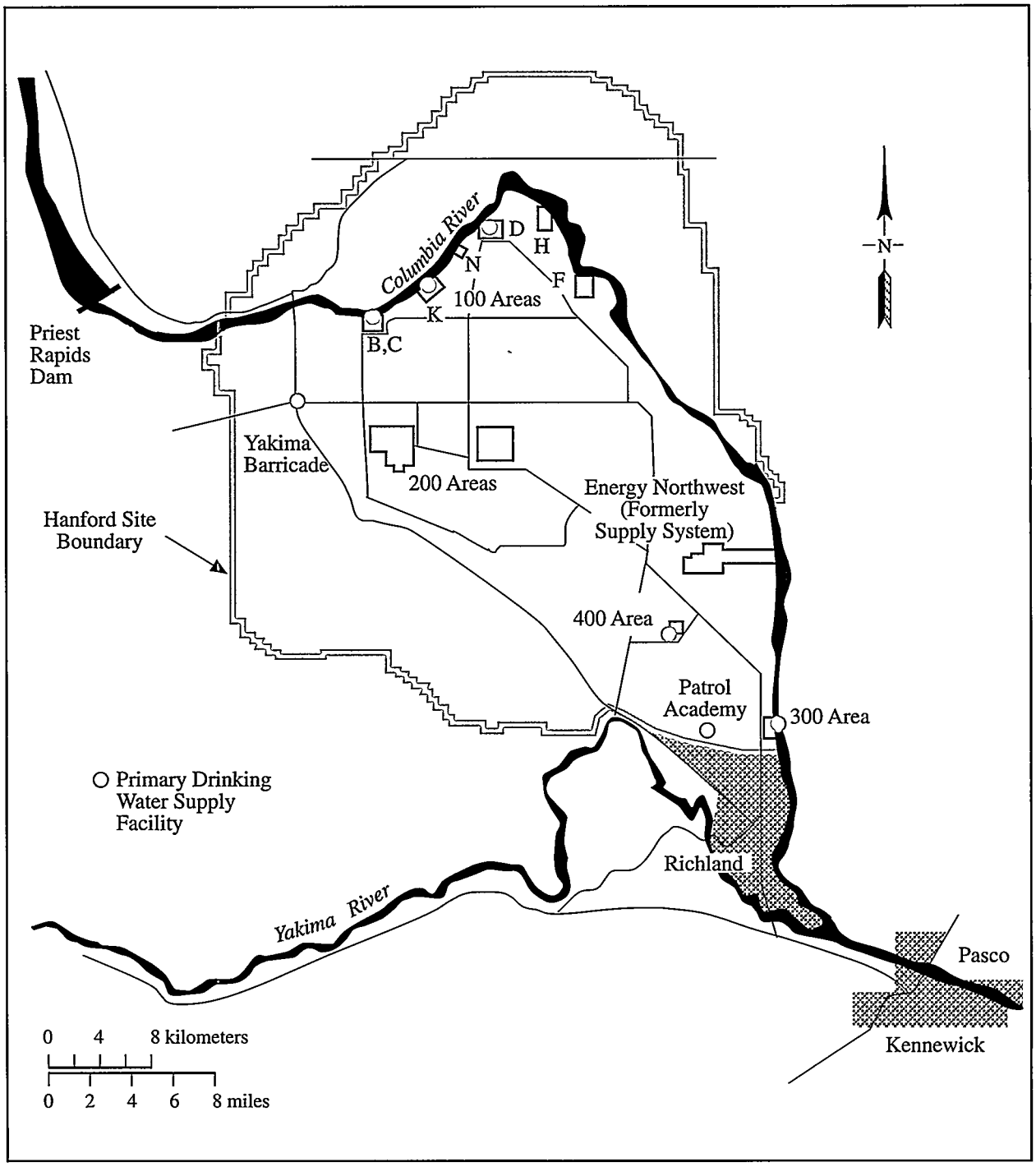
The 400 Area continued to use well 499-S1-8J (P-16) for drinking water, with well 499-S0-8 (P-14) serving as the emergency supply. Well 499-S0-8 supplied drinking water for a total of 959 h during 1998 (251.1 h in May, 293.4 h in June, 202.4 h in July, 165.8 h in August, 46.4 h in December) when well 499-S1-8J was offline for rebuild and maintenance. Well 499-SO-7 (P-15) continued to function as the dire emergency supply and furnished drinking water for approximately 11 h in July when well 499-SO-8 could not keep up with the demand. In addition to supplying drinking water, these three wells are also important for maintaining fire suppression capabilities within the 400 Area.

4.3.2 Collection of Drinking Water Samples and Analytes of Interest

Drinking water samples were collected according to a schedule established at the beginning of the calendar year (PNNL-11803). A majority of the samples were collected and analyzed quarterly. The 300 Area samples were collected monthly and composited for quarterly analysis. The Yakima Barricade and Patrol Training Academy samples were collected quarterly and composited for annual analysis. Samples from most locations were grab samples of untreated water. The 400 Area and Patrol Academy samples were treated water. Samples of untreated well water were also collected from the 400 Area drinking water wells by the Hanford Groundwater Monitoring Project. These samples were analyzed monthly. Drinking water samples obtained from the 100-B Area pumphouse and the 400 Area in April were cosampled with the Washington State Department of Health. The analytical results from the state's samples help to verify the quality of the drinking water data reported herein and in PNNL-12088, APP. 1.

All 1998 drinking water samples were analyzed for gross alpha, gross beta, tritium, and strontium-90. Additionally, samples from the 300 Area were analyzed for uranium and technetium, and plutonium and americium activities were monitored in water from the 100-K Area. The 100-K Area and 300 Area samples were also analyzed by gamma spectroscopy.

Gross alpha and gross beta measurements provided a general indication of radioactive contamination. Gamma spectroscopy was used to detect numerous specific radionuclides (see Appendix E). Radiochemical analyses were used to determine the activities of other specific radionuclides.



G99030045.98

Figure 4.3.1. Hanford Site Primary Drinking Water Supply Facilities, 1998

4.3.3 Radiological Results for Hanford Site Drinking Water

Results for radiological monitoring of Hanford Site drinking water during 1998 are summarized in Table 4.3.2. Gross alpha, gross beta, tritium, strontium-90, and total uranium activities are included in the table to demonstrate compliance with drinking water standards. The maximum amount of beta-gamma radiation from man-made radionuclides allowed in drinking water by Washington State and the EPA is an annual average activity that will not produce an annual dose equivalent to the whole body or any internal organ greater than 4 mrem/yr. If both tritium and strontium-90 are present, the sum of their annual dose equivalent to bone marrow must not exceed 4 mrem. Compliance with this standard may be assumed if the annual average activity for each of gross alpha, gross beta,

Table 4.3.2. Selected Radiological Constituents in Hanford Site Drinking Water, 1998 Annual Average Activities (pCi/L)[a]

System	No. of Samples	Gross Alpha	Gross Beta	Tritium	Strontium-90	Total Uranium
100-B Area	4[b,c]	0.52 ± 0.19	0.47 ± 0.46	119 ± 45	0.93 ± 0.02	NM[d]
100-D Area	4[b,c]	1.80 ± 2.56	2.19 ± 1.57	37.4 ± 19.3	0.11 ± 0.02	NM
100-K Area	4[b,c]	0.51 ± 0.52	1.39 ± 0.36	52.3 ± 15.2	0.42 ± 0.26[e]	NM
300 Area	4[c,f]	1.65 ± 0.76	1.68 ± 0.90	277 ± 174	0.07 ± 0.03	1.74 ± 0.88
400 Area (FFTF)[g]	4[b]	0.97 ± 1.20	6.36 ± 0.80	4,912 ± 328	0.01 ± 0.02	NM
Patrol Academy	1[h,i]	4.55 ± 2.3	4.65 ± 1.8	62.6 ± 130	ND[j]	NM
Yakima Barricade	1[c,h,i]	0.73 ± 1.6	8.49 ± 2.1	8.4 ± 130	0.01 ± 0.03	NM
Standards		15[k,l]	50[l,m]	20,000[l,n]	8[k,l]	13.4[o]

(a) Average value ±2 standard error of the calculated mean.
(b) Grab samples collected and analyzed quarterly.
(c) Untreated raw water.
(d) NM = Not measured.
(e) Three samples only.
(f) Cumulative sample; collected monthly and composited for quarterly analysis.
(g) FFTF = Fast Flux Test Facility.
(h) Grab sample; collected quarterly and composited for annual analysis.
(i) Result ± total analytical error.
(j) ND = No data; laboratory unable to analyze sample.
(k) WAC 246-290.
(l) 40 CFR 141.
(m) Equivalent to 4 mrem/yr standard.
(n) Activity assumed to yield an annual dose of 4 mrem/yr.
(o) Based on an EPA drinking water standard of 20 µg/L and calculated using the specific activities (percent by weight) of naturally occurring uranium-234, -235, and -238.

tritium, and strontium-90 are <50, 15, 20,000, and 8 pCi/L, respectively (40 CFR 141 and WAC 246-290). All DOE-owned drinking water systems on the Hanford Site were in compliance with Washington State and EPA annual average radiological drinking water standards in 1998, and results were similar to those observed in recent years (see Section 4.3 in PNNL-11472 and PNNL-11795).

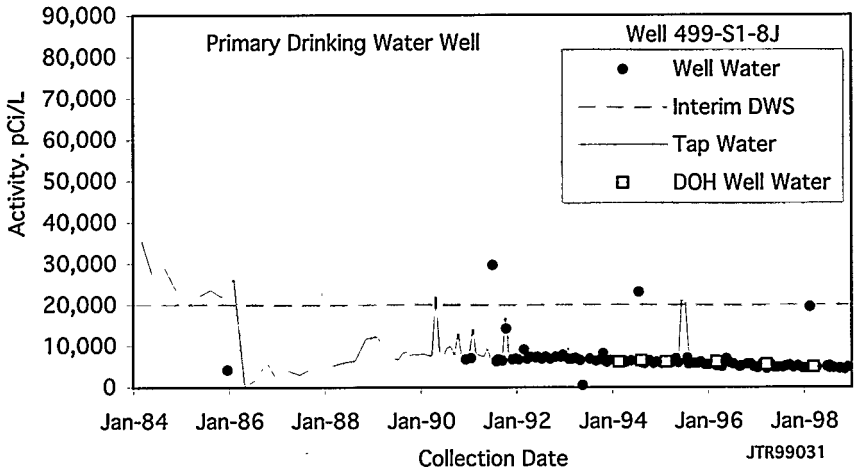
Activities of uranium, plutonium, americium, and radionuclides measured by gamma spectroscopy at selected locations (see PNNL-12088, APP. 1) were all below drinking water standards.

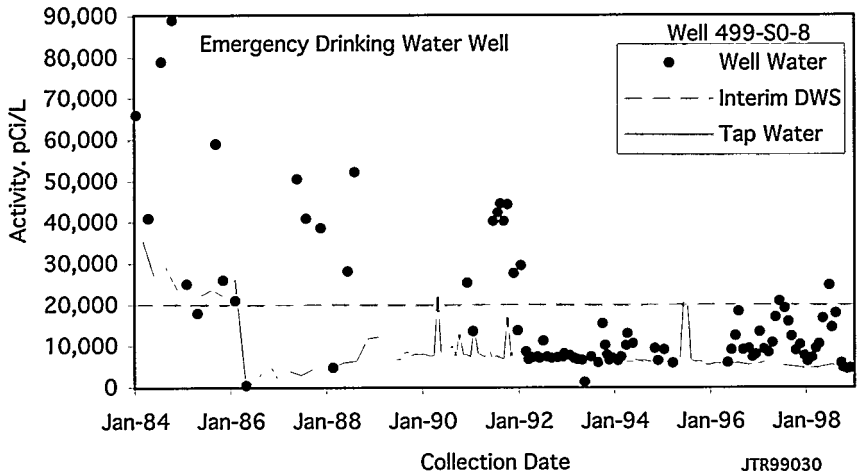
Raw water samples from all three 400 Area drinking water wells were collected and analyzed monthly by the Hanford Groundwater Monitoring Project. Results from these samples show that tritium levels continued to be lowest in well 499-S0-8J and highest in well 499-S0-7. Tritium levels also increased (>14,000 pCi/L) in well 499-S0-8 from May through August when this well was operated in place of well 499-S1-8J (Table 4.3.3, Figure 4.3.2).

Table 4.3.3. Tritium Activities (pCi/L) in 400 Area Drinking Water Wells, 1998[a]

Sampling Date	Primary Drinking Water Well 499-S1-8J (P-16)	Emergency Drinking Water Well 499-S0-8 (P-14)	Dire Emergency Drinking Water Well 499-S0-7 (P-15)
January 12, 1998	4,680 ± 540	6,350 ± 661	22,100 ± 1,800
February 13, 1998[b]	19,500 ± 1,600	7,240 ± 707	4,880 ± 536
March 16, 1998	4,610 ± 529[c]	9,400 ± 859	18,200 ± 1,500
April 10, 1998	4,900 ± 553	10,500 ± 960	19,500 ± 1,610
May 8, 1998	NS[d]	16,700 ± 1,400	19,200 ± 1,580
June 25, 1998	4,950 ± 545	24,700 ± 1,980	31,500 ± 2,470
July 15, 1998	5,200 ± 563	14,500 ± 1,240	26,000 ± 2,070
	4,730 ± 529[e]		
August 14, 1998	4,650 ± 531	18,000 ± 1,500	22,600 ± 1,830
September 25, 1998	4,470 ± 512	5,800 ± 608	21,500 ± 1,740
October 9, 1998	4,600 ± 524	4,730 ± 533	19,300 ± 1,590
November 9, 1998	4,300 ± 494	4,440 ± 505	17,900 ± 1,480
December 4, 1998	4,770 ± 520	4,660 ± 513	19,700 ± 1,610

(a) Reported concentration ±2 total propagated analytical error.
(b) Samples from wells 499-S1-8J and 499-S0-7 may have been switched and mislabeled.
(c) Sample collected on March 17, 1998.
(d) NS = Not sampled.
(e) An additional sample was collected as a quality control duplicate.





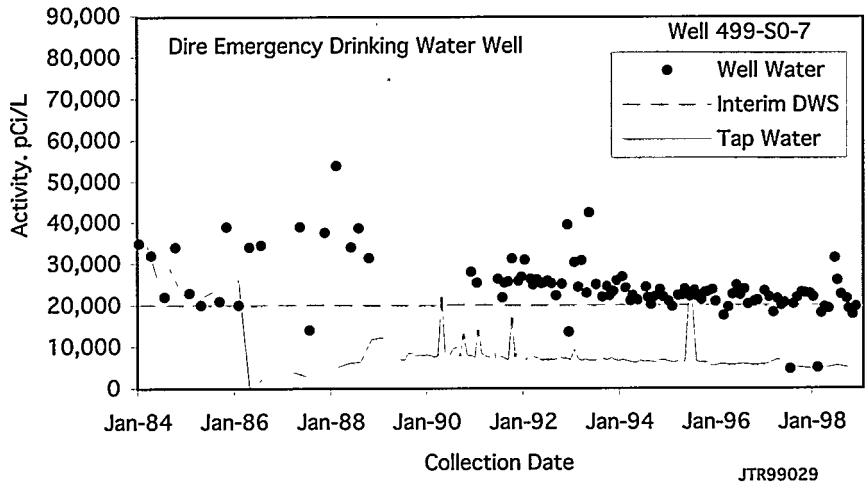


Figure 4.3.2. Tritium Activities in Drinking Water from Three Wells in the 400 Area, 1984 Through 1998 (DOH = Washington State Department of Health, DWS = drinking water standard)

4.4 Food and Farm Product Surveillance

T. M. Poston

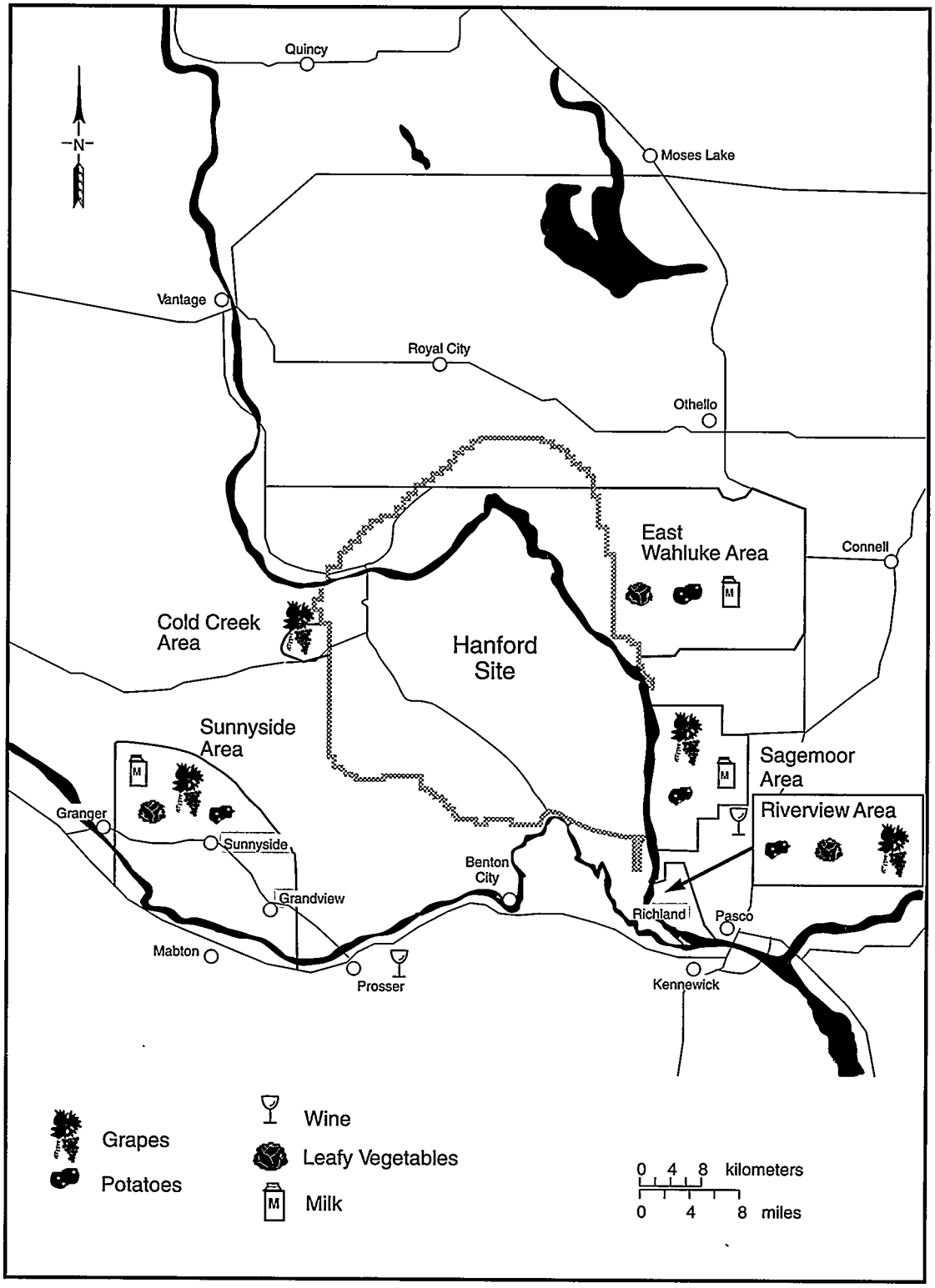
Foodstuffs, including milk, vegetables, fruits, and wine, were collected in 1998 at several locations surrounding the Hanford Site (Figure 4.4.1). Samples were collected primarily from locations in the prevailing downwind directions (south and east of the site) where deposition of airborne effluents or fugitive dust from the Hanford Site could be expected. Samples were also collected in generally upwind directions and at locations somewhat distant from the site to provide information on background radioactivity.

The food and farm product sampling design addresses the potential influence of Hanford Site releases in two ways: 1) by comparing results from several downwind locations to those from generally upwind or distant locations and 2) by comparing results from locations irrigated with Columbia River water withdrawn downstream from the Hanford Site to results from locations irrigated with water from other sources. In 1996, the food and farm product sampling schedule was modified by establishing a 2- or 3-year rotation for certain farm products. Additionally, analyses for specific radionuclides that historically have not been detected in a food or farm product were discontinued. These changes were adopted because of the emphasis on cleanup of the site. Specific details of the 1998 food and farm product sampling design, including sampling locations and radionuclides analyzed, are reported in DOE/RL-91-50, Rev. 2 and PNNL-11803 and are summarized in Table 4.4.1.

Gamma scans (cobalt-60, cesium-137, and other radionuclides; see Appendix E) and strontium-90 analyses were performed routinely for nearly all products. Additionally, milk was analyzed for iodine-129 and tritium, and wine was analyzed for tritium. Results for fruits and vegetables are reported in picocuries per gram wet weight. Results for tritium are reported in picocuries per liter of liquid distilled from milk and wine. Most tritium is found as water, and very little tritium is organically bound to other constituents present in food products.

Tritium and iodine-129 from site facilities are released to the atmosphere and to the Columbia River via riverbank springs. Strontium-90 from Hanford is released to the Columbia River through riverbank springs. Cesium-137 is present in atmospheric fallout from weapons testing and is found in site radiological waste.

For many radionuclides, activities are below levels that can be detected by the analytical laboratory. When this occurs for an entire group of samples, a nominal detection limit is determined by using two times the total propagated analytical uncertainty (2 sigma). This value from a group of samples is used as an estimate of the lower level of detection for that analyte and particular food product. The total propagated analytical uncertainty includes all sources of analytical error associated with the analysis (e.g., counting errors and errors associated with weight and volumetric measurements). Theoretically, reanalysis of the sample should yield a result that falls within the range of the uncertainty 95% of the time. Results and uncertainties not given in this report may be found in PNNL-12088, APP. 1.



G99030045.3

Figure 4.4.1. Food and Farm Product Sampling Locations, 1998

Table 4.4.1. Locations, Sampling Frequencies, and Analyses Performed for Routinely Sampled Food and Farm Products, 1998[a]

	Number of Locations			Number of Locations Analyzed			
Product	Upwind	Downwind	Sampling Frequency[b]	^{3}H	Gamma	^{90}Sr	^{129}I
Milk	1	2	Q or SA	3	3	3	3
Vegetables	1	2	A	0	4	4	0
Fruit	2	2	A	0	4	4	0
Wine	2	2	A	4[c]	4	0	0

(a) Products may include multiple varieties for each category.
(b) Q = quarterly, SA = semiannually, A = annually.
(c) Samples lost during analyses; results provided by Washington State Department of Health on cosamples.

4.4.1 Milk Samples and Analytes of Interest

Composite samples of raw, whole milk were collected in 1998 from three East Wahluke Area and two Sagemoor Area dairy farms. These sampling areas are located near the site perimeter in the prevailingly downwind direction (see Figure 4.4.1). Milk samples were also collected from a Sunnyside Area dairy to indicate background radionuclide activities at a generally upwind location.

Milk was analyzed for tritium, strontium-90, iodine-129, and gamma emitters such as cesium-137 because these radionuclides have the potential to move through the air-pasture-cow milk or water-pasture-cow milk food chains to humans. Gamma scans and strontium-90 analyses were conducted quarterly, and iodine-129 analyses were conducted on two semiannual composite samples. Tritium analyses were discontinued in 1995 because tritium activities had dropped below the detection level of standard liquid scintillation counting methods. In 1998, an electrolytic enrichment technique (DOE/RL-91-50, Rev. 2) for measuring tritium in milk samples was instituted. The electrolytic enrichment technique has a detection limit of approximately 10 pCi/L of water distilled from milk.

One factor influencing activities of radionuclides in milk is the source of food for the dairy cows. Dairy cows may be fed food grown outside of the sampling area in which the dairy farm is located. Generally, levels of fallout radioactivity in environmental media correlate positively with the amount of precipitation that an area receives. The agricultural areas around the site are arid and historically have received less rain, and, therefore, less weapons-testing atmospheric fallout than some distant locations. Consequently, levels of radioactivity in hay or alfalfa grown in some distant, rainy locations and purchased by local dairies may contribute more radioactivity to milk than contaminant levels in feed grown locally. Alternatively, it is possible that alfalfa fed to dairy cows in the Sunnyside Area could have been grown in areas downwind of Hanford (e.g., Sagemoor Area). Fallout radionuclides in feed may be a significant source of radioactivity in milk products; however, measured levels of radionuclides in milk are usually near levels considered to be background.

Strontium-90 was measured in 6 of 12 (50%) milk samples analyzed in 1998, with no apparent differences between upwind and downwind locations.

Strontium-90 activities remain near the nominal detection limit (0.7 pCi/L) and have been relatively constant over the past 6 yr (Figure 4.4.2). The maximum observed strontium-90 activity in milk in 1998 was 0.95 ± 0.38 pCi/L in a Sunnyside Area sample. Strontium-90 in milk collected from the Sagemoor Area was essentially below detection (<0.5 pCi/L) in all samples. While there is no strontium-90 standard for milk, the drinking water standard (based on a 2-L/d consumption) is 8 pCi/L (40 CFR 141). The maximum milk consumption rate for estimating dose is approximately 0.75 L/d (see Appendix D, Table D.2).

Iodine-129 was identified by high-resolution mass spectrometry in six milk samples. In recent years, the levels of iodine-129 in milk collected from generally downwind dairies in the Sagemoor and East Wahluke Areas have persisted at levels two to four times greater than levels measured upwind in Sunnyside (Figure 4.4.3). Iodine-129 activities have been declining with the end of nuclear production activities on the site and contribute <1% of the dose to the maximally exposed individual through the

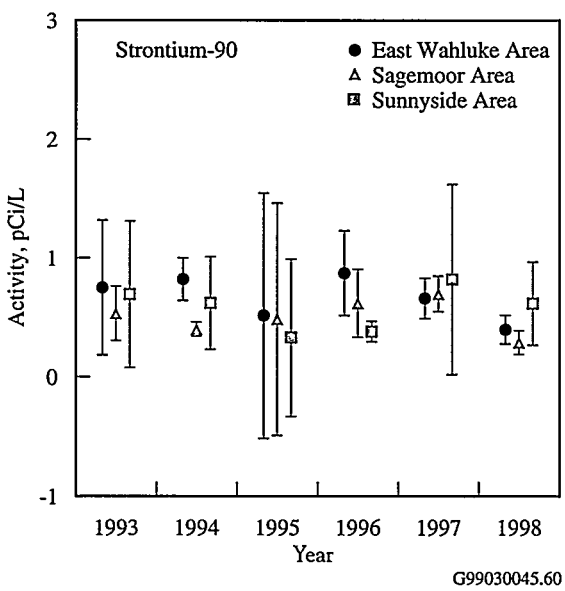


Figure 4.4.2. Median, Maximum, and Minimum Strontium-90 Activities in Milk, 1993 Through 1998

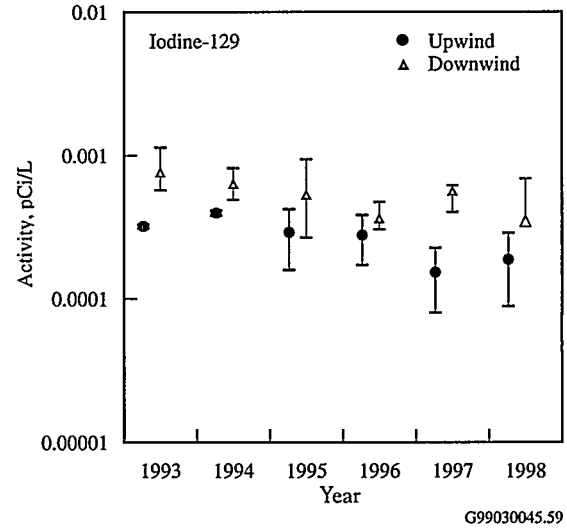


Figure 4.4.3. Median, Maximum, and Minimum Iodine-129 Activities in Milk, 1993 Through 1998

consumption of dairy products (see Section 5.0, "Potential Radiological Doses from 1998 Hanford Operations"). The maximum observed iodine-129 in milk in 1998 was 0.0007 ± 0.0001 pCi/L in a sample collected from the Sagemoor Area. While there is no iodine-129 standard for milk, the drinking water standard is 1 pCi/L (EPA-570/9-76-003).

None of the 12 milk samples collected and analyzed in 1998 contained detectable cesium-137 activities (<3.3 pCi/L). Because there is no cesium-137 standard for milk, the drinking water standard is 200 pCi/L (EPA-570/9-76-003). Additionally, no other man-made gamma emitters were detectable in milk (PNNL-12088, APP. 1).

Tritium was analyzed by the electrolytic enrichment method in quarterly composite milk samples from the Wahluke and Sagemoor Areas and the single sample from the Sunnyside Area for the first three quarters of 1998. For the first two quarters, tritium activities in milk were similar at each dairy. The apparent increase in the third quarter for each dairy may be attributed to elevated counts in the laboratory blank (laboratory background sample). The most interesting observation is the consistent

relative differences between the three sampling areas. A plausible explanation for these differences may be the drinking water provided to cows at the participating dairies. The dairies in all three areas use well water. The aquifers in Franklin County for the dairies in the Sagemoor and Wahluke Areas have historically been recharged by Columbia River water brought into the areas by the Columbia Basin Irrigation Project. Background tritium activities in Columbia River water in the 1960s ranged from 800 to 5,540 pCi/L that resulted from fallout from nuclear weapons detonated above the ground (Wyerman et al. 1970). Irrigation water from the Columbia River containing these comparatively high tritium activities entered the groundwater aquifers in Franklin County as a result of overapplication and leaking canals. This water remains in the aquifers that provide water for the dairies. Over the past 30 yr, tritium activities have slowly decreased as a result of radiological decay and possible dilution caused by subsequent recharge with less-contaminated irrigation water. Based on a 12.3-yr half-life, if we assume an aquifer having an activity of 1,000 pCi/L in 1963 (assumes some dilution with natural groundwater), the estimated level after three half-lives in 1998 would be 125 pCi/L.

Sampling and analysis of dairy water and milk from each participating dairy were initiated in the fall of 1998, but analytical problems with electrolytic enrichment of milk and wine samples have delayed this study. Data collected in 1999 are expected to demonstrate the direct relationship of tritium in well water and milk at each dairy. Information is being gathered on past irrigation practices in the Columbia Basin and the lower Yakima Valley. While the relationships between tritium in milk and groundwater used by the dairies are interesting, the actual levels of tritium in milk make a minor contribution to the dose of those who consume milk (see Section 5.0, "Potential Radiological Doses from 1998 Hanford Operations").

4.4.2 Vegetable Samples and Analytes of Interest

Samples of leafy vegetables (i.e., cabbage, rhubarb, beet tops) and potatoes were obtained during the summer from gardens and farms located within selected sampling areas (see Figure 4.4.1). Leafy vegetables were sampled to monitor for the potential deposition of airborne contaminants. The Riverview Area was sampled because of its exposure to potentially contaminated irrigation water withdrawn from the Columbia River downstream of the Hanford Site. All vegetable samples were analyzed for gamma-emitting radionuclides and strontium-90.

Measurements of gamma emitters in potatoes and leafy vegetable samples were all less than their respective detection limit (0.02 pCi/g) and are consistent with results in recent years (PNNL-11796). Strontium-90 was detected in two leafy vegetable samples. The Riverview Area sample (0.021 ± 0.008 pCi/g wet wt.) had approximately five times the level of the East Wahluke Area sample (0.004 ± 0.001 pCi/g wet wt.).

4.4.3 Fruit Samples and Analytes of Interest

Grapes were collected during harvest from the areas shown in Figure 4.4.1. All grape samples were analyzed for gamma-emitting radionuclides and strontium-90.

Measurable levels of cesium-137 and other man-made gamma-emitting radionuclides were not detected in grapes in 1998. These results are consistent with measurements in grapes, apples, and melons over recent years (PNL-9824, PNL-10575, PNNL-11140, PNNL-11473, PNNL-11796). The nominal level of detection for cesium-137 was 0.01 pCi/g wet wt. Strontium-90 was detected in the grape sample collected in the Riverview Area (0.005 ± 0.004 pCi/g wet wt.); however, levels in grape samples from the other locations were below detection (<0.004 pCi/g wet wt.).

4.4.4 Wine Samples and Analytes of Interest

Locally produced red and white wines (1998 vintage grapes) were analyzed for gamma-emitting radionuclides and tritium. The wines were made from grapes grown at individual vineyards downwind of the site and at an upwind location in the lower Yakima Valley. Two samples each of red and white wines were obtained from each location and analyzed. The electrolytic enrichment method was used for tritium analysis in water distilled from the wine; however, there were difficulties with the analytical equipment and the samples were lost during analysis. Wine samples were cosampled with the Washington State Department of Health in 1998. Tritium activities based on scintillation detection of water distilled from the wine were provided to the Pacific Northwest National Laboratory by the Washington State Department of Health. The lower limit of detection of the Washington State Department of Health 1998 cosamples was 50 pCi/L.

Gamma spectroscopy did not indicate the presence of cesium-137 or any other man-made gamma emitters in any of the 1998 wine samples. The nominal detection limit for cesium-137 in wine is approximately 3 pCi/L.

Based on results provided by the Washington State Department of Health, tritium activities in 1998 wine samples were slightly higher in the Columbia Basin wines when compared to the Yakima Valley wines (Figure 4.4.4). The Yakima Valley wines were below the detection limit of 50 pCi/L. While there is no tritium standard for wine, the drinking water standard (40 CFR 141) is 20,000 pCi/L. This standard is based on the daily consumption of 2 L of water.

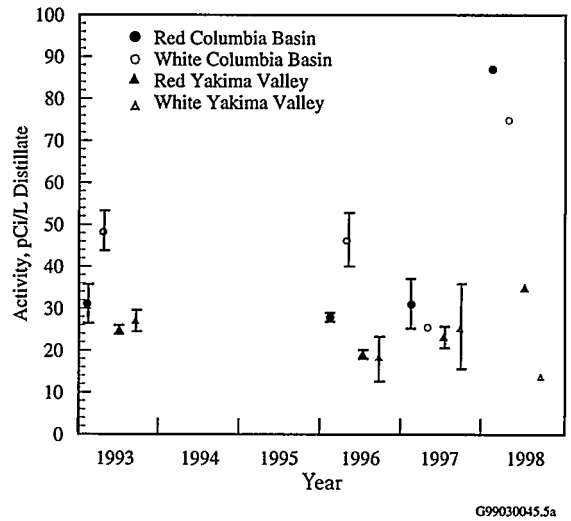


Figure 4.4.4. Median, Maximum, and Minimum Tritium Activities in Wine Samples Collected in 1993 Through 1998 (1998 results from Washington State Department of Health)

4.5 Fish and Wildlife Surveillance

B. L. Tiller and T. M. Poston

Contaminants in fish and wildlife that inhabit the Columbia River and Hanford Site are monitored for several reasons. Wildlife have access to areas of the site containing radioactive or chemical contamination, and fish can be exposed to contamination entering the river along the shoreline. Fish and some wildlife species exposed to Hanford contaminants might be harvested for food and may potentially contribute to offsite public exposure. In addition, detection of contaminants in wildlife may indicate that wildlife are entering contaminated areas (e.g., burrowing in waste burial grounds) or that materials are moving out of contaminated areas (e.g., through blowing dust or food-chain transport). Consequently, fish and wildlife samples are collected at selected locations annually (Figure 4.5.1). More-detailed rationale for the selection of specific species sampled in 1998 can be found in DOE/RL-91-50, Rev. 2.

Routine background sampling is conducted approximately every 5 yr at locations believed to be unaffected by Hanford releases. Additional background data also may be collected during special studies.

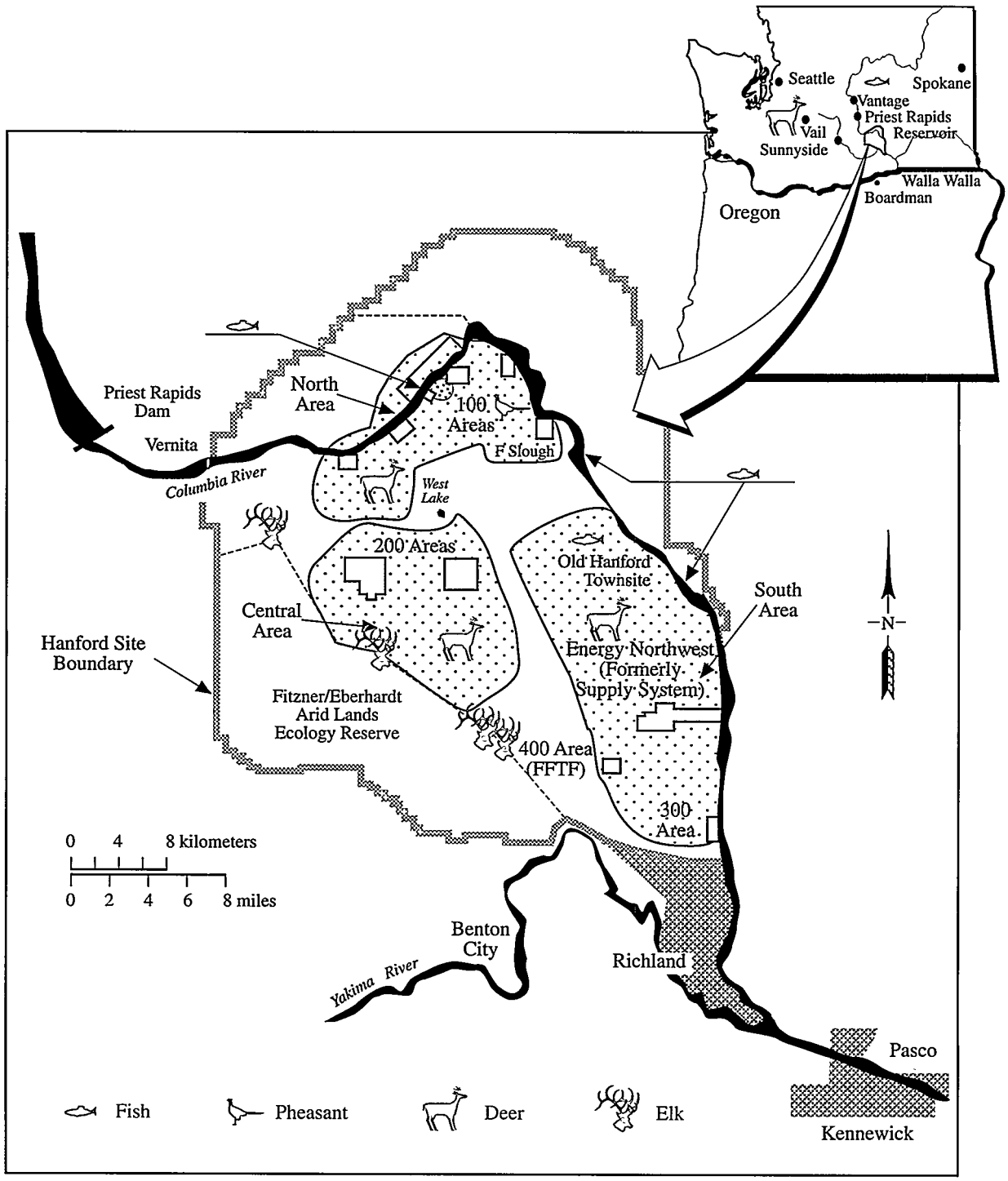
As a result of changing site operations, fish and wildlife sampling frequencies were modified significantly in 1995. Species that had been collected annually were placed on a rotating schedule so that surveillance of all key species would be accomplished over a 3-yr period. Factors supporting these changes included the elimination of many onsite radiological source terms and a decrease in environmental concentrations of radionuclides of interest. Additionally, several radionuclides that were monitored in the past had not been detected in recent wildlife samples because they were no longer present in the environment in sufficient amounts to accumulate in wildlife or they did not accumulate in fish or wildlife tissues of interest.

For each species of fish or wildlife, radionuclides are selected for analysis based on the potential for the contaminant to be found at the sampling site and to accumulate in the organism (Table 4.5.1). At the Hanford Site, strontium-90 and cesium-137 have been historically the most frequently measured radionuclides in fish and wildlife.

Strontium-90 is chemically similar to calcium; consequently, it accumulates in hard tissues rich in calcium such as bone, antlers, and eggshells. Strontium-90 has a biological half-life in hard tissue of 14 to 600 d. Hard-tissue concentrations may profile an organism's lifetime exposure to strontium-90. However, strontium-90 generally does not contribute much to human dose because it does not accumulate in edible portions of fish and wildlife. Springs water in the 100-N Area is the primary source of strontium-90 from Hanford to the Columbia River; however, the current contribution relative to historical fallout from atmospheric weapons testing is small (<2%) (PNL-8817).

Cesium-137 is particularly important because it is chemically similar to potassium and is found in the muscle tissue of fish and wildlife. Having a relatively short biological half-life (<200 d in muscle; <20 d in the gastrointestinal tract), cesium-137 is an indicator of more-recent exposure to radioactive materials and is also a major constituent of historical fallout.

Fish and wildlife samples were analyzed by gamma spectrometry to detect a number of gamma emitters (see Appendix E). However, gamma spectrometry



G99030045.92

Figure 4.5.1. Fish and Wildlife Sampling Locations, 1998

Table 4.5.1. Locations, Species, and Contaminants Sampled for Fish and Wildlife, 1998

Medium	No. of Offsite Locations	No. of Onsite Locations	No. of Analyses Gamma	No. of Analyses Strontium-90
Fish (suckers, carp)	1[a]	2[b]	8	8
Pheasant	0	1[c]	1	1
Mule deer	0	3[d]	7	7
Elk	0	4[e]	4	4

(a) Background samples collected from the Columbia River near Vantage, Washington.
(b) Samples collected from 100-N to 100-D and 300 Areas.
(c) Samples collected from 100-D to 100-H Area.
(d) Samples collected from the north, south, and central area populations (see Figure 4.5.1).
(e) Samples collected along Highways 240 and 24.

results for most radionuclides are not discussed here because activities were too low to measure or measured activities were considered artifacts of low-background counts. Low-background counts occur at random intervals during sample counting and can produce occasional spurious false-positive results.

For many radionuclides, activities are below levels that can be detected by the analytical laboratory. When this occurs for an entire group of samples, two times the total propagated analytical uncertainty is used as an estimate of the nominal detection level for that analyte and particular medium. Results and propagated uncertainties for all results may be found in PNNL-12088, APP. 1.

4.5.1 Fish Samples and Analytes of Interest

In 1998, carp and large-scale suckers were collected from the Columbia River. Carp were electrofished from the 100-N to 100-D sampling area by the U.S. Geological Service, Biological Resource Division, and donated to the Pacific Northwest National Laboratory. Carp samples were collected from the 300 Area and suckers were collected from the background sampling area near Vantage, Washington by Pacific Northwest National Laboratory staff using beach seines. Results for carp collected in 1998 are compared to background fishes collected from the Columbia River approximately 80 km (50 mi) upstream of the Hanford Site (Vantage). Fillets and the eviscerated remains (carcass) of fish were analyzed for radiological contaminants. All analytical data for 1998 samples are given in PNNL-12088, APP. 1.

In 1998, fillet (muscle) samples were analyzed with gamma spectrometry for cesium-137 and other gamma-emitting radionuclides (PNNL-12088, APP. 1). Cesium-137 was not detected in any of the five carp fillet samples collected in 1998. The number of cesium-137 analyses that were reported below the analytical detection limits was greater in 1998 (5 of 5) compared to the number reported (26 of 41)

over the preceding 8 yr (Table 4.5.2). An increase in the number of results below the detection limit was also apparent in samples collected from the background location in 1998 (3 of 3) when these samples were compared to background samples collected in 1992 (14 of 25).

Strontium-90 was found in three of five carp carcass samples collected and analyzed in 1998. The number of detectable strontium-90 levels were lower in 1998 (3 of 5), compared to the preceding 8 yr (28 of 28). Mean levels of strontium-90 in carcass tissues collected from the Hanford Reach in 1998 were not significantly different from those observed in Hanford Reach samples collected over the preceding 8 yr, as well as levels observed in background suckers collected from the Columbia River near Vantage in 1998. Average strontium-90 activities in background suckers collected in 1998 (0.02 ± 0.01 pCi/g) were lower than average levels found in carp collected from the same background location in 1992 (0.07 ± 0.01 pCi/g).

Overall, radionuclide activities in Hanford Reach carp were similar to the levels observed in background carp and suckers. The associated dose from the hypothetical consumption of fish is found in Section 5.0, "Potential Radiological Doses from 1998 Hanford Operations."

Table 4.5.2. Cesium-137 and Strontium-90 Activities (pCi/g) in Columbia River Carp and Suckers, 1998 Compared to Previous 8 Years

	1998			1990-1997		
Location	Maximum[a]	Mean[b]	No. Less Than Detection[c]	Maximum[a]	Mean[b]	No. Less Than Detection[c]
Cesium-137 in Muscle						
100-N to 100-D Areas	0.01 ± 0.02	-0.001 ± 0.01	4 of 4	0.06 ± 0.03	0.01 ± 0.008	13 of 21
300 Area	0.04 ± 0.02[d]	NA[e]	1 of 1	0.02 ± 0.01	0.001 ± 0.003	13 of 20
Background[f]	-0.003 ± 0.03	-0.01 ± 0.01	3 of 3	0.02 ± 0.01[g]	0.007 ± 0.002[g]	14 of 25
Strontium-90 in Carcass						
100-N to 100-D Areas	0.07 ± 0.02	0.03 ± 0.03	2 of 4	0.06 ± 0.02	0.04 ± 0.009	0 of 8
300 Area	0.03 ± 0.02	NA	0 of 1	0.2 ± 0.04	0.03 ± 0.01	0 of 20
Background[f]	0.03 ± 0.02	0.02 ± 0.01	2 of 3	0.1 ± 0.02[g]	0.07 ± 0.01[g]	0 of 25

(a) Maximum is ± total propagated uncertainty (2 sigma).
(b) Result is ±2 standard error of the mean.
(c) Number of samples with values less than the detection limit out of number of samples analyzed.
(d) Not detected; best estimated activity.
(e) NA = Not applicable; only one sample.
(f) 1998 background samples were suckers collected from the Columbia River near Vantage, Washington.
(g) Background samples were carp collected from the Columbia River near Vantage, Washington in 1992.

4.5.2 Wildlife Sampling

Wildlife sampled and analyzed in 1998 for radioactive constituents included elk, deer, and pheasants. Radiological constituents analyzed for in 1998 wildlife samples included gamma emitters and strontium-90.

4.5.2.1 Deer and Elk Samples and Analytes of Interest

Studies of mule deer populations residing on the Hanford Site indicate their division into three distinct groups (PNL-10711): 1) the population that inhabits land around the retired reactors in the 100 Areas is designated the north area population; 2) the population that resides from the Old Hanford Townsite south to the 300 Area is designated the south area population; and 3) by default, deer collected around the 200 Areas, away from the river is designated the central area population (see Figure 4.5.1).

Radionuclide levels in deer collected onsite in 1998 were compared to levels in deer collected distant from the site from 1991 through 1995 near Boardman, Oregon and in Stevens County, Washington. Additionally, onsite levels were compared to levels in a white-tailed deer that was cosampled with the Washington State Department of Health in 1996 at Vail, Washington. These comparisons with samples from distant locations are useful in evaluating Hanford's impact to deer. The deer collected in Stevens County and Vail inhabited mountain regions that received more rainfall than Hanford; therefore, background levels of radionuclides are usually higher there (PNL-10174). The climate and precipitation surrounding the Boardman region is similar to Hanford.

Until recently, elk have not inhabited areas on the Hanford Site where the potential for uptake of radionuclide contaminants exists (see Section 7.2, "Ecosystem Monitoring [Plants and Wildlife]"). There are very little data available about contaminant concentrations in elk residing on or near the Hanford Site.

Radiological Results for Deer Samples. Cesium-137 was not detected in the seven deer muscle samples collected from the Hanford Site and analyzed in 1998 (Table 4.5.3). These results are consistent with those obtained over the preceding 8 yr and with the trends observed in a Hanford wildlife summary report (PNL-10174). As shown in Table 4.5.3, the number of results reported at or below the analytical detection limit is higher (7 of 7) in 1998 when compared to the previous 8 yr (35 of 55). PNL-10174 summarized wildlife radionuclide data collected from 1983 through 1992 and also indicated a decline in cesium-137 levels in all wildlife examined. In addition, the levels of cesium-137 in >60 Hanford deer muscle samples collected during the 1990s were less than the background levels measured in deer samples collected from 1991 through 1995 from Stevens County and, in 1996, from Vail.

The risk associated with radionuclide contamination found in deer muscle during the 1990s can be quantified by the expected dose resulting from consumption of deer meat. A 50-yr effective dose equivalent resulting from the consumption of 41 kg (90 lb) of meat/year collected from a Hanford Site deer in 1992, containing the highest cesium-137 activity, was determined to be 0.041 mrem. An individual would need to ingest approximately 100,000 kg (220,000 lb) of deer meat to approach the 100-mrem maximum annual dose allowed by DOE Order 5400.5 and the National Council on Radiation Protection and Measurements (1993). To put this dose estimate in perspective, natural background doses in the United States average approximately 300 mrem.

Strontium-90 was detected in six of seven deer bone samples analyzed in 1998 (see Table 4.5.3).

Table 4.5.3. Activities of Selected Radionuclides (pCi/g) in Deer and Elk, 1998 Compared to Previous 8 Years

Location	1998 Maximum[a]	1998 Mean[b]	1998 No. Less Than Detection[c]	1990-1997 Maximum[a]	1990-1997 Mean[b]	1990-1997 No. Less Than Detection[c]
Cesium-137 in Muscle						
Deer						
Central	0.003 ± 0.007	0.003 ± 0.003	2 of 2	0.37 ± 0.05	0.05 ± 0.08	5 of 9
North	0.005 ± 0.005	0.004 ± 0.004	2 of 2	0.03 ± 0.01	0.006 ± 0.003	18 of 24
South	0.0004 ± 0.004	0.0004 ± 0.004	3 of 3	0.01 ± 0.007	0.002 ± 0.002	12 of 22
Stevens Co., WA[d]	NS[e]	NS		0.5 ± 0.06	0.31 ± 0.26	0 of 3
Boardman, OR[d]	NS	NS		0.03 ± 0.03	0.01 ± 0.01	3 of 4
Vail, WA[f]	NS	NS		0.12 ± 0.03	NA[g]	0 of 1
Elk						
ALE[h]	0.003 ± 0.005	0.0006 ± 0.002	4 of 4	NS	NS	
Strontium-90 in Bone						
Deer						
Central	0.19 ± 0.05	0.19 ± 0.008	0 of 2	3.3 ± 0.6	0.74 ± 1.0	1 of 6
North	0.39 ± 0.08	0.37 ± 0.12	0 of 2	58.3 ± 11.3	5.4 ± 6.2	0 of 20
South	0.19 ± 0.05	0.12 ± 0.13	1 of 3	0.42 ± 0.1	4.0 ± 4.6	1 of 7
Stevens Co., WA	NS	NS		2.1 ± 0.41	1.1 ± 1.0	0 of 3
Boardman, OR	NS	NS		0.13 ± 0.041	0.11 ± 0.015	0 of 4
Vail, WA	NS	NS		0.94 ± 0.20	NA	0 of 1
Elk						
ALE	1.41 ± 0.03	0.44 ± 0.52	1 of 4	NS	NS	

(a) Maximum is ± total propagated uncertainty (2 sigma).
(b) Result is ±2 standard error of the mean.
(c) Number of samples with values less than the detection limit out of number of samples analyzed.
(d) Background samples collected between 1991 and 1995.
(e) NS = No sample.
(f) Background samples collected in 1996.
(g) NA = Not applicable; only one sample.
(h) ALE = Fitzner-Eberhardt Arid Lands Ecology Reserve; samples refer to elk samples collected along Highways 24, 240, and 241.

Two of the seven animals sampled came from the north (retired reactor) population and contained 0.39 ± 0.08 and 0.27 ± 0.06 pCi/g strontium-90, respectively. Three of the seven animals sampled were from the south area population, and results ranged from below detection to 0.19 ± 0.05 pCi/g. Two deer samples were collected from the central area population (near the 200 Areas), and the results were 0.19 ± 0.05 and 0.18 ± 0.06 pCi/g, respectively. The lower values found in deer bone from the south area and central area populations are consistent with strontium-90 levels found in deer antlers summarized in PNL-10711. Strontium-90 levels found in deer bone in 1998 were similar to the levels found in the previous 7 yr, and no unusually high values were found in samples collected during 1998. Deer bone samples from Boardman had a maximum strontium-90 activity of 0.13 ± 0.04 pCi/g, which was lower than the maximum values in the deer bone samples from Vail and Stevens County but comparable to results

from Hanford deer samples analyzed over the past several years (see Table 4.5.3). The apparently higher strontium-90 activities in onsite deer bone from the north area may indicate some prior exposure to localized, low-level contamination on the site.

Radiological Results for Elk Samples. Radionuclide levels were monitored in tissue collected from four road-killed elk along Highways 240 and 24 in 1998 (see Table 4.5.3). With the exception of strontium-90, all other radionuclides were reported as below analytical detection limits. Strontium-90 was detected in bone tissue from three of the four animals; 0.32 ± 0.07, 0.46 ± 0.13, and 1.41 ± 0.3 pCi/g, respectively. These levels are similar to north area deer levels; however, elk inhabit the higher elevations on the Hanford Site and reflect levels of strontium-90 that are expected from atmospheric fallout from worldwide weapons testing in the 1950s and 1960s. Strontium-90 is sequestered in the calcium-rich tissues like bone. As such, strontium-90 is unlikely to be transferred to humans because bone is not the edible portion of the animal.

4.5.2.2 Pheasant Samples and Analytes of Interest

Six pheasants were collected from the 100-D to 100-F Areas in the fall of 1998 (see Figure 4.5.1). Attempts were made to collect upland game from near the 100-N Area but upland game habitat there was limited. Radionuclide levels found in the 100-D to 100-F samples were compared to levels in samples collected onsite during the previous 7 yr and were also compared to levels found in samples collected from a background location in the lower Yakima Valley near Sunnyside in 1994.

Cesium-137 was not detected in the six pheasant muscle samples collected in 1998 (Table 4.5.4). The number of results reported at or below the analytical detection limit was higher in 1998 (6 of 6),

Table 4.5.4. Activities of Selected Radionuclides (pCi/g) in Upland Game, 1998 Compared to Previous 8 Years

	1998			1990-1997		
Location	Maximum[a]	Mean[b]	No. Less Than Detection[c]	Maximum[a]	Mean[b]	No. Less Than Detection[c]
Cesium-137 in Muscle						
100-N Area	NS[d]	NS		-0.014 ± 0.02	-0.018 ± 0.008	2 of 2
100-D to 100-F Area	0.018 ± 0.019	0.005 ± 0.008	6 of 6	0.17 ± 0.03	0.017 ± 0.012	15 of 28
Background[e]	NS	NS		0.16 ± 0.14	0.011 ± 0.017	19 of 20
Strontium-90 in Bone						
100-N Area	NS	NS		0.08 ± 0.05	0.07 ± 0.02	0 of 2
100-D to 100-F Area	0.07 ± 0.09	0.04 ± 0.006	6 of 6	0.2 ± 0.1	0.07 ± 0.02	4 of 28
Background[e]	NS	NS		0.1 ± 0.06	0.04 ± 0.01	8 of 20

(a) Maximum is ± total propagated analytical uncertainty (2 sigma).
(b) Result is ±2 standard error of the mean.
(c) Number of samples with values at or less than the detection limit out of number of samples analyzed.
(d) NS = No sample.
(e) Background samples collected from Yakima Valley near Sunnyside, Washington.

compared to the previous 8 yr (17 of 30). The 1998 levels were consistent with those reported in PNL-10174. The levels found in upland game collected on the Hanford Site during the 1990s were not elevated, compared to levels found in upland game from the Yakima Valley in 1994. Of the samples from the Yakima Valley, 95% (19 of 20) were found to be at or below the analytical detection limit.

Strontium-90 levels were not found above the analytical detection limit in any of the six bone samples collected during 1998. Only 14% (4 of 28) of the upland game samples collected from the 100-D to 100-F Areas during the past 8 yr were found to be at or below analytical detection limits.

Levels of strontium-90 found in upland game bone samples during the 1990s were consistently lower ($P \leq 0.005$) than levels found in deer bone collected from the same vicinity (see Tables 4.5.3 and 4.5.4). The diet of upland game primarily includes insects and dry-land grass seeds; whereas deer generally consume riparian and woody plants. Deep-rooted riparian plants can contain higher contaminant levels if their roots are deep enough to reach contaminated groundwater.

4.6 Soil and Vegetation Surveillance

T. M. Poston

Soil surveillance provides information on long-term contamination trends and baseline environmental radionuclide activities at undisturbed locations (DOE/RL-91-50, Rev. 2). Surveillance of perennial vegetation provides information on atmospheric deposition of radioactive materials in uncultivated areas and at onsite locations adjacent to potential sources of man-made radioactivity. Accordingly, radionuclide activities in soil and perennial vegetation provide a baseline against which unplanned releases can be compared.

Soil and perennial vegetation samples have been collected on and around the Hanford Site for >50 yr. Consequently, a large database exists that thoroughly documents onsite and offsite activities of man-made radionuclides in soil and natural vegetation at specific locations. Because the current site mission includes environmental restoration and cleanup and because routine plutonium production operations at the site have ceased, the need for annual soil and perennial vegetation surveillance has diminished. There are several additional reasons for the reduced need for soil and perennial vegetation sampling. Man-made radionuclides with short half-lives have decayed to stable isotopes and are no longer present. Moreover, radionuclide releases from the Hanford Site in recent years have been small, and, therefore, baseline radionuclide activities have not changed appreciably for a number of years. Because only radionuclides with relatively long half-lives presently are found in soil and vegetation, sitewide environmental surveillance sampling of soil and vegetation can be less frequent. Radiological surveillance of soil and vegetation was last conducted in 1994 (Section 4.6 in PNNL-10574). In 1998, routine sampling of soil and perennial vegetation was conducted at 15 locations on site and 5 locations off site (Figure 4.6.1). Additionally, special sampling of Columbia River shoreline mulberry trees at the 100-N Area was conducted in October 1998 to verify the results of samples collected and analyzed by an external stakeholder group. Fruit and leaves from trees located near the 100-F Area and the Old Hanford Townsite were also sampled and analyzed.

Other soil and vegetation sampling by Fluor Daniel Hanford, Inc. was conducted near active facility release points and waste sites. Results are discussed in Section 3.2, "Near-Facility Environmental Monitoring."

4.6.1 Soil Sampling

Soil samples were collected at 20 locations on and around the Hanford Site in 1998 (see Figure 4.6.1). Soil samples were organized into three distinct groups: 1) onsite, 2) offsite (combined perimeter and one distant upwind location at Sunnyside), and 3) the Fitzner-Eberhardt Arid Lands Ecology Reserve site (formerly grouped with perimeter locations). Onsite sample locations are selected in areas around industrial development on the site. The offsite perimeter locations sampled in 1998 were Ringold, Byers Landing, Sagemoor, and Riverview. These four locations lie in a generally downwind location east and southeast of the site. Soil was collected from two sites on the Fitzner-Eberhardt Arid Lands Ecology Reserve.

Soil samples consisted of five plugs, 2.54 cm (1 in.) deep and 10.2 cm (4 in.) in diameter, that were

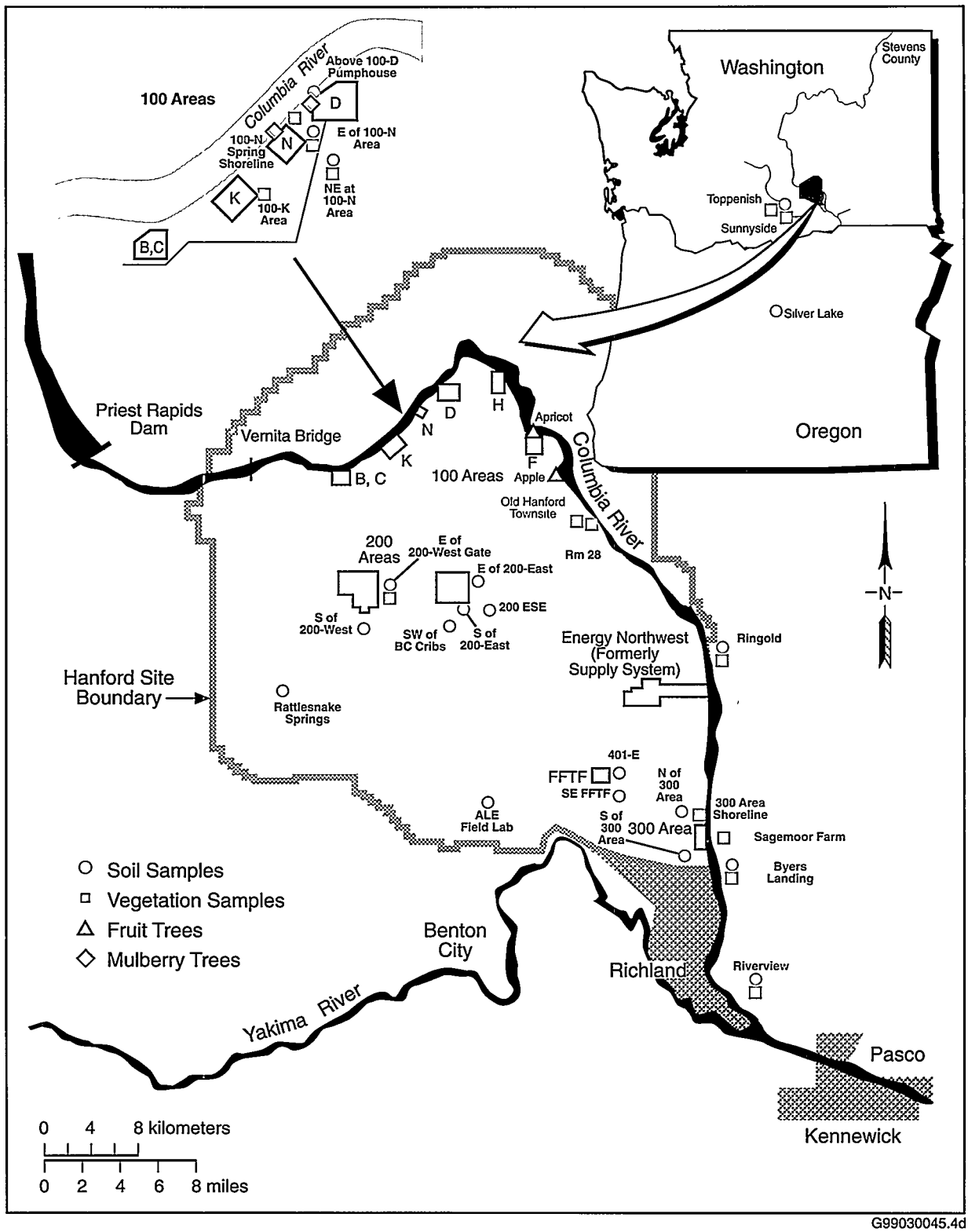


Figure 4.6.1. Soil and Vegetation Sampling Locations, 1998

collected within 10 m (33 ft) of one another and combined into one bulk sample. Soil samples were dried to remove residual moisture and sieved at the laboratory prior to analysis to remove rocks and plant debris.

In 1998, soil samples were analyzed for gamma-emitting radionuclides, strontium-90, uranium-234, -235, -238, plutonium-238, plutonium-239,240, and, in selected samples, americium-241 (Table 4.6.1). The 1998 results were compared to those from 1992 through 1997 (see Appendix A, Table A.8) and from soil samples collected from mountainous regions as part of special studies (Table 4.6.2). In 1996, results of an assessment of Hanford background radionuclide activities in soils were published (DOE/RL-96-12). These assessment results provide comparison values (median and 95th percentile[a] activities) for radionuclides that are routinely monitored on the Hanford Site.

In 1998, observed strontium-90 and cesium-137 activities in all soil samples were near detection limits. Median activities of strontium-90, cesium-137, and plutonium-239,240 collected from onsite locations were no different than those found at perimeter locations in 1998 and the preceding sampling years (1992 through 1994) (Figure 4.6.2). Maximum activities of strontium-90, cesium-137, and plutonium-239,240 in samples collected on the site were higher than the maximums measured at offsite locations because some of the locations on the site were selected to monitor specifically for past industrial releases. The East of 200-West Gate soil

Table 4.6.1. Routine Soil and Vegetation Samples Collected and Analyzed, 1998

Location	No. of Samples	Frequency	Analytes
Soil			
Onsite[a]	13	Annual to once every 5 yr	Gamma, ^{90}Sr, U_{iso}[b], Pu,[c] ^{241}Am
Distant	1	Annual to once every 5 yr	Gamma, ^{90}Sr, U_{iso}, Pu, ^{241}Am
Downwind perimeter[a]	4	Annual to once every 5 yr	Gamma, ^{90}Sr, U_{iso}, Pu, ^{241}Am
ALE[d]	2	Annual to once every 5 yr	Gamma, ^{90}Sr, U_{iso}, Pu, ^{241}Am
Vegetation			
Onsite	5	Annual to once every 5 yr	Gamma, ^{90}Sr, U_{iso}, Pu
Distant	2	Annual to once every 5 yr	Gamma, ^{90}Sr, U_{iso}, Pu
Perimeter	4	Annual to once every 5 yr	Gamma, ^{90}Sr, U_{iso}, Pu
Shoreline	3	Annual to once every 5 yr	Gamma, ^{90}Sr, U_{iso}, Pu

(a) Not all analytes are analyzed for at each location.
(b) U_{iso} is a method of analyzing for uranium by detecting alpha particles.
(c) Plutonium-238 and plutonium-239,240.
(d) Fitzner-Eberhardt Arid Lands Ecology Reserve.

(a) The percentile is a statistical grouping of values, 95% of all values fall below the 95th percentile; hence, the 95th percentile is used as an estimate of the upper bounds of uranium activities in soil.

Table 4.6.2. Comparison of Strontium-90, Cesium-137, and Plutonium-239,240 Activities (pCi/g dry wt.) in Soils at Remote Locations with Site Background Observed Onsite and Offsite Concentrations

Location[a]	Year	Radionuclide	Minimum[b]	Median (50th Percentile)	Maximum[b] (95th Percentile)	Number
Silver Lake lowland	1994	Strontium-90	0.14 ± 0.03	0.18 ± 0.04	0.23 ± 0.04	3
		Cesium-137	0.29 ± 0.05	0.33 ± 0.05	0.43 ± 0.07	
Silver Lake mountain	1994	Strontium-90	0.54 ± 0.10	0.67 ± 0.13	0.69 ± 0.13	3
		Cesium-137	1.67 ± 0.21	1.70 ± 0.20	1.72 ± 0.20	
Stevens County	1994	Strontium-90	NR[c]	NR	0.39 ± 0.07	1
		Cesium-137	NR	NR	0.82 ± 0.09	
Hanford Site background[d]	1985 to 1992	Strontium-90	NR	0.06	0.21	73
		Cesium-137	NR	0.31	1.08	149
		Plutonium-239,240	NR	0.0077	0.026	128
Hanford Site perimeter	1998	Strontium-90	0.043 ± 0.010	0.054 ± 0.008[e]	0.060 ± 0.012	4
		Cesium-137	0.16 ± 0.02	0.20 ± 0.03	0.32 ± 0.04	
		Plutonium-239,240	0.0066 ± 0.0010	0.0088 ± 0.0015	0.012 ± 0.0015	
On the Hanford Site	1998	Strontium-90	0.014 ± 0.004	0.065 ± 0.015	0.38 ± 0.069	13
		Cesium-137	0.005 ± 0.009	0.14 ± 0.021	1.8 ± 0.18	
		Plutonium-239,240	0.0004 ± 0.0002	0.0052 ± 0.0009	0.53 ± 0.058	

(a) See Figure 4.6.1 for locations.
(b) ±2 sigma total analytical error.
(c) NR = Not reported.
(d) Estimated values based on samples collected on and around the Hanford Site (see Table 3-5 in DOE/RL-95-55).
(e) 2-sigma error of highest activity used to calculate the median.

sampling location (see Figure 4.6.1) has consistently had the highest activities of these radionuclides.

In the past, soil sites on the Fitzner-Eberhardt Arid Lands Ecology Reserve were included in the perimeter grouping. Because of the transfer of management of this reserve to the U.S. Fish and Wildlife Service in 1997, results from the Rattlesnake Springs and Arid Lands Ecology Field Laboratory stations are reported separately. Results for these locations for 1998 were similar to 1993 (see Appendix A, Table A.9) and fall within the range of activities observed at other onsite or offsite locations (see Figure 4.6.2).

Uranium is a natural radionuclide that is present in all soils. Uranium activities in soil on and near the Hanford Site were analyzed in 1998 by acid leaching and alpha spectrometry of the extracted residue. In prior years, soil samples were analyzed by both alpha spectrometry and low-energy photon spectrometry.

The median background activity and the 95th percentile background activity of uranium-238 near and on the Hanford Site have been reported as 0.76 and 1.18 pCi/g, respectively (DOE/RL-95-55). These background activities are based primarily on low-energy photon spectrometry. Low-energy photon spectrometry results for uranium-238 are generally lower than alpha spectrometry results; however, the degree of difference varies, depending on the soil type and particle-size distribution. Maximum uranium-238 activities measured in soils on and around the

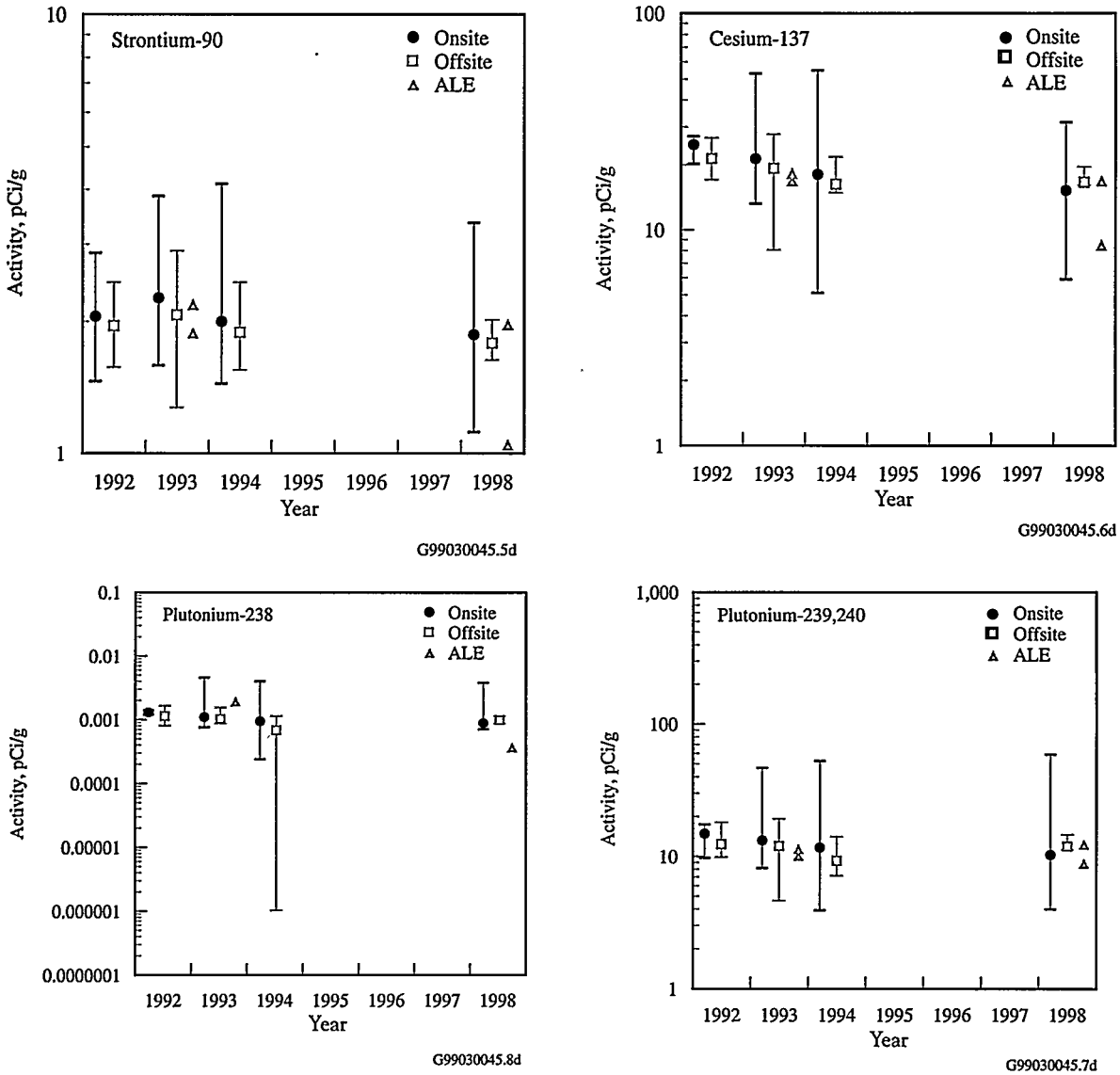


Figure 4.6.2. Median, Maximum, and Minimum Radionuclide Activities of Strontium-90, Cesium-137, Plutonium-238, and Plutonium-239,240 in Soil (pCi/g dry wt), 1992 Through 1998 (ALE = Fitzner-Eberhardt Arid Lands Ecology Reserve)

Hanford Site in 1998 by alpha spectrometry were below the reported median background.

Onsite and offsite soil radionuclide activities from 1998 were also compared with the background values on and near the site (DOE/RL-95-55) and with the results from distant and remote sampling sites in Stevens County, Washington, and the two locations at Silver Lake, Oregon (Table 4.6.2). The remote samples provide some indication of the concentrations of fallout radionuclides that are found in other parts of the Pacific Northwest. Background fallout radionuclide activities generally increase with increased annual precipitation and altitude.

4.6.2 Vegetation Sampling

Vegetation samples were collected at 14 locations on and around the Hanford Site in 1998 (see Figure 4.6.1). Vegetation samples collected in 1998 were organized into four distinct groups: 1) onsite, 2) perimeter, 3) distant upwind locations, and 4) Columbia River shoreline samples (see Table 4.6.1). Onsite sample locations were generally selected in areas around industrial development on the site. The downwind perimeter locations were Ringold, Byers Landing, Sagemoor, and Riverview. These four locations lie generally downwind, east and southeast, of the site. They are expected to be in areas of highest offsite accumulation of contaminants from stack emissions. Special shoreline samples were collected at the Hanford Slough (in conjunction with apple tree sampling), at Hanford River mile marker 28, and at the 300 Area.

Perennial vegetation samples consist of the current year's growth of leaves, stems and new branches collected from sagebrush and rabbitbrush. Sample vegetation is dried before analyses, and analytical results are reported on a dry weight basis. Shoreline vegetation samples usually are taken from a predominant species at the sample location site. Samples of leaves and fruit collected from abandoned fruit trees were also analyzed for trace metals by inductively coupled plasma-mass spectrometry and by cold vapor atomic adsorption spectrometry (specifically for mercury). Metals results were reported on a dry weight basis.

Surveillance of perennial vegetation samples for radionuclides in 1998 generally confirmed observations of past sampling efforts. Activities of cesium-137, uranium-238, plutonium-238, and technetium-99 (in two samples of shoreline vegetation) were all below nominal detection limits (see Appendix A, Table A.10). Nominal detection limits for these radionuclides were 0.02, 0.02, 0.0002, and 0.4 pCi/g, respectively. Plutonium-239,240 was measured in one perennial vegetation sample (0.004 ± 0.001 pCi/g) collected at the East of the 200-West Gate sampling location (see Figure 4.6.1). All other plutonium-239,240 activities were below detection (0.0003 pCi/g).

Strontium-90 was found in 12 of 14 vegetation samples collected in 1998. There was no appreciable difference between the range of strontium-90 activities measured from 1992 through 1998 or between onsite, perimeter, and distant locations (Figure 4.6.3).

Special sampling involved the collection of leaves from willows along the Columbia River shoreline at the 300 Area and rough bugleweed along the river shoreline at Hanford River mile marker 28, near the Old Hanford Townsite. Samples collected near the river shoreline at the 100-N Area consisted of rabbitbrush. The rabbitbrush samples were not collected at the river shoreline. Instead, they were collected as near to the shoreline as possible because the shoreline area was covered with basalt. Consequently, the 100-N Area shoreline results were grouped and

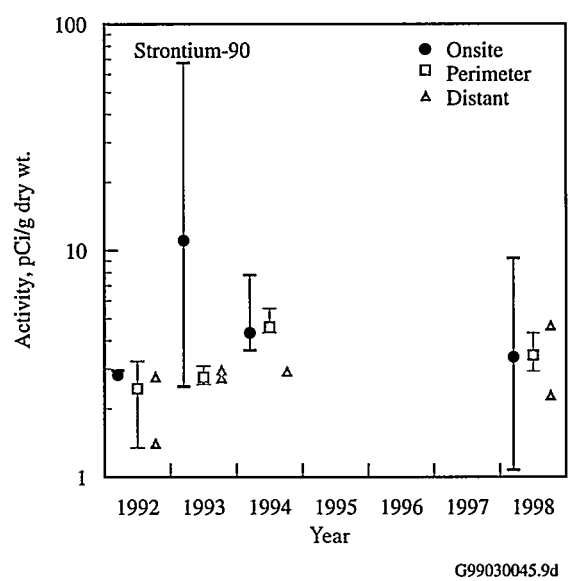


Figure 4.6.3. Median, Maximum, and Minimum Radionuclide Activities of Strontium-90 in Natural Vegetation, 1992 Through 1998

reported with other onsite (nonshoreline) perennial vegetation samples. Mulberry trees were sampled in October at two locations at the 100-N Area shoreline and approximately 1,600 m (1 mi) downstream of the radiological control area at the 100-N Area shoreline.

Results of shoreline vegetation samples are summarized in Table 4.6.3 and are compared to a comprehensive survey of shoreline vegetation conducted from 1990 through 1992 (PNL-8797). Generally, strontium-90 activities were comparable to results from the 1990 to 1992 study, with the exception of the 100-N Area mulberry tree samples. The maximum strontium-90 measured in the 1998 mulberry leaf sample was >10 times lower than the maximum observed in 1990. While uranium-238 was approximately 10 times higher in 1998 bugleweed samples than in onions sampled from 1990 to 1992, the activities in the bugleweed were no different than the uranium-238 observed in historical perennial vegetation and shoreline plants (PNL-8797, PNL-10728).

4.6.3 Tree Sampling

Fruit trees growing on the site were sampled in 1998 to complement samples collected in 1997 (PNNL-11795). Fruit and leaves were collected from an apple tree at the Old Hanford Townsite and an apricot tree at the 100-F Area. Samples were analyzed for radiological constituents and trace metals. These trees are located on the Hanford Site and are not generally accessible to the public.

Concentrations of 13 trace metals were measured in leaf samples in 1997 and 1998. The metals were grouped into four distinct classifications based on the relationship of the concentrations in the samples to values from the literature that define natural background metal concentrations and concentrations of metals in vegetation associated with elevated and potentially toxic environmental

Table 4.6.3. Radionuclide Activities (pCi/g dry wt.) in Shoreline Vegetation, 1998 Compared to 1990-1992 (PNL-8797)

				Historic Maximum		
Species (1998)	Location	Radionuclide	1998 Activity[a]	Species	Activity[a]	Year
Willow	300 Area	Strontium-90	0.26 ± 0.05	Mulberry	0.17 ± 0.04	1990
		Cesium-137	0.07 ± 0.02	Mulberry	0.02 ± 0.01	1990
Bugleweed	HRM 28[b] (Old Hanford Townsite)	Technetium-99	0.66 ± 0.42	Mulberry	17 ± 2.3	1992
		Cesium-137	0.25 ± 0.03	Onion	0.15 ± 0.08	1992
		Uranium-238	0.64 ± 0.07	Onion	0.085 ± 0.012	1992
		Plutonium-239,240	0.006 ± 0.001	Asparagus	0.0006 ± 0.0004	1992
Mulberry tree	100-N Area Shoreline	Strontium-90	2.0 ± 0.37	Mulberry	437 ± 85	1990
		Strontium-90	28 ± 4.9	Mulberry	437 ± 85	1990
	1,600 m (1 mi) below 100-N Area shoreline	Strontium-90	0.20 ± 0.04	Mulberry	1.1 ± 0.21	1990

(a) ±2 sigma total analytical uncertainty.
(b) HRM = Hanford river mile, as measured from the Highway 24 Vernita Bridge.

exposures to metal contamination (Coughtrey and Thorne 1983, Coughtrey et al. 1983, Kabata-Pendias and Pendias 1984). The four classifications are all measured concentrations 1) less than the analytical detection limit, 2) less than or equal to the reported background concentrations, 3) less than the reported toxic concentration range, and 4) within the nominal toxic range of metal concentrations. The last classification may indicate that trees have been exposed to elevated concentrations of metals in their immediate habitat.

Based on this classification, all trace metal constituents measured in Hanford Site tree samples were below or within the concentration ranges associated with uncontaminated (i.e., background) habitat (Table 4.6.4). Chromium was measured in apricot leaves collected in 1997 from trees growing near the 100-D Reactor, within the bounds of known chromium groundwater plumes. Chromium was not detected in the tree samples collected at the Old Hanford Townsite or 100-F Area in either 1997 or 1998. The levels in the 100-D Area apricot leaf samples were well within the range of background vegetation concentrations and were below concentrations that are potentially harmful to vegetation. Metals concentrations in leaves are summarized in Appendix A, Table A.11.

Table 4.6.4. Classification of Trace Metal Concentrations (µg/g dry wt.) in Onsite Fruit Tree Samples Collected in 1997 and 1998 Compared to Nominal Background and Nominal Toxic Reference Concentrations[a]

Classification of Metals	Metal (Detection Limit)	Measured Concentration Range	Reference Concentrations[a]: Nominal Background Concentration Range	Reference Concentrations[a]: Nominal Toxic Range
All measured concentrations <detection level	Antimony (0.02)	<0.02	7.0 to 50	≥150
	Beryllium (0.1)	<0.1	0.001 to 0.4	10 to 50
	Selenium (2.0)	<2.0	0.03 to 5.0	5.0 to 30
	Silver (0.45)	<0.45	0.07 to 1.4	5.0 to 10
	Thallium (0.01)	<0.01	0.008 to 0.125	≥20
Measured concentration ≤nominal background concentratiozn range	Arsenic (0.15)	<0.15 to 0.39	0.02 to 1.5	5.0 to 20
	Lead (0.01)	<0.01 to 0.25	1.0 to 15	30 to 300
	Zinc (1.0)	2.0 to 16.7	27 to 141	100 to 400
Measured concentration <nominal toxic range	Cadmium (0.04)	<0.04 to 0.2	0.05 to 0.2	5 to 30
	Chromium (1.0)	<1.0 to 0.31[b]	0.1 to 0.5	5 to 30
	Copper (0.8)	0.34 to 14.1	6.3 to 29	20 to 100
	Mercury (0.0016)	<0.0016 to 0.022	0.003 to 0.011	1 to 3
	Nickel (0.15)	0.15 to 1.1	0.1 to 5.0	10 to 100
Measured concentration = nominal toxic range	None	None	None	None

(a) Nominal concentrations were taken from Coughtrey and Thorne (1983), Coughtrey et al. (1983), and Kabata-Pendias and Pendias (1984).
(b) Detection limit for 1998 samples was <1.0 µg/g dry wt.; detection limit for 1997 samples was 0.2 µg/g dry wt.

Analyses of leaves and fruit from the apricot and apple trees were also performed for tritium, gamma emitters, and strontium-90. No man-made gamma emitters were detected in any fruit tree samples collected in 1997 or 1998. Tritium (as distillate from plant material) was found in fruit tree leaves and fruit in 1998 at activities slightly higher than levels found in fruit tree samples collected at the 100-F Area and Old Hanford Townsite in 1997 (Table 4.6.5). The tritium activities in 1998 samples were approximately a factor of 10 lower than those found in 100-D Area apricot tree samples in 1997.

Strontium-90 was not found in apricot or apple fruit samples collected on the site in 1998; however, strontium-90 was found in leaf samples from the apple and apricot trees (Table 4.6.6). Strontium-90 activities in leaf samples were comparable to those observed in perennial vegetation samples routinely collected on the site in 1998.

Table 4.6.5. Tritium (pCi/L of sample distillate) in Fruit Tree Samples Collected from the Hanford Site, 1997 and 1998

Sample	Location	Activity[a]
1997		
Quince leaves	Old Hanford Townsite	15.2 ± 7.40
Apricot leaves	100-D Area	618 ± 57.2
Apricot leaves	100-D Area	503 ± 47.4
Apricot leaves	100-F Area	12.1 ± 7.20
1998		
Apricot leaves	100-F Area	62.7 ± 15.1
Apricot fruit	100-F Area	39.0 ± 9.56
Apple leaves	Old Hanford Townsite	60.5 ± 15.2
Apple fruit	Old Hanford Townsite	67.4 ± 16.3

(a) ±2 sigma total analytical error.

Table 4.6.6. Strontium-90 Activities (pCi/g dry wt.) in Fruit Tree Samples Collected from the Hanford Site, 1997 and 1998

Sample	Location	Activity[a]
1997		
Apricot leaves	100-D Area	0.015 ± 0.005
Apricot leaves	100-D Area	0.011 ± 0.004
Apricot leaves	100-F Area	0.16 ± 0.013
Quince fruit	Old Hanford Townsite	0.004 ± 0.005
Quince leaves	Old Hanford Townsite	0.094 ± 0.017
1998		
Apricot fruit	100-F Area	0.018 ± 0.013
Apricot leaves	100-F Area	0.13 ± 0.026
Apple fruit	Old Hanford Townsite	0.008 ± 0.007
Apple leaves	Old Hanford Townsite	0.036 ± 0.024

(a) ±2 sigma total analytical error.

4.7 External Radiation Surveillance

E. J. Antonio

External radiation is defined as radiation originating from a source external to the body. External radiation fields consist of a natural component and an anthropogenic, or man-made, component. The natural component can be divided into 1) cosmic radiation; 2) primordial radionuclides, primarily potassium-40, thorium-232, and uranium-238; and 3) an airborne component, primarily radon and its progeny. The man-made component consists of radionuclides generated for or from nuclear medicine, power, research, waste management, and consumer products containing nuclear materials. Environmental radiation fields may be influenced by the presence of radionuclides deposited as fallout from atmospheric testing of nuclear weapons or those produced and released to the environment during the production or use of nuclear fuel. During any year, external radiation levels can vary from 15% to 25% at any location because of changes in soil moisture and snow cover (National Council on Radiation Protection and Measurements 1987).

The interaction of radiation with matter results in energy being deposited in that matter. This is why your hand feels warm when exposed to a light source (e.g., sunlight, flame). Ionizing radiation energy deposited in a mass of material is called radiation absorbed dose. A special unit of measurement, called the rad, was introduced for this concept in the early 1950s. The International System of Units introduced the gray (Gy) and is defined as follows: 1 Gy is equivalent to 100 rad (American Society for Testing and Materials 1993).

One device for measuring radiation absorbed dose is the thermoluminescent dosimeter that absorbs and stores energy of ionizing radiation within the dosimeter's crystal lattice. By heating the material under controlled laboratory conditions, the stored energy is released in the form of light, which is measured and related to the amount of ionizing radiation energy stored in the material. Thermoluminescence, or light output exhibited by dosimeters, is proportional to the amount of radiation exposure (X), which is measured in units of roentgen (R). The exposure is multiplied by a factor of 0.98 to convert to a dose (D) in rad to soft tissue (Shleien 1992). This conversion factor relating R to rad is, however, assumed to be unity (1) throughout this report for consistency with past reports. This dose is further modified by a quality factor, Q = 1, for beta and gamma radiation and the product of all other modifying factors (N). N is assumed to be one to obtain dose equivalence (H) measured in rem. The sievert (Sv) is the equivalent of the rem.

$$D\ (\text{rad}) = X\ (R) * 1.0$$

$$H\ (\text{rem}) = D * N * Q$$

To convert to units of gray and sievert, divide rad and rem by 100, respectively.

In 1998, environmental external radiation exposure rates were measured at locations on and off the Hanford Site using thermoluminescent dosimeters and pressurized ionization chambers. External radiation and surface contamination surveys at specified locations were performed with portable radiation survey instruments.

4.7.1 External Radiation Measurements

In 1995, the Harshaw 8800-series system replaced the former Hanford Standard environmental dosimeter system. The Harshaw environmental dosimeter consists of two TLD-700 chips and two TLD-200 chips and also provides both shallow and deep dose measurement capabilities. Thermoluminescent dosimeters are positioned approximately 1 m (3 ft) above the ground at 26 onsite locations (Figure 4.7.1). Figure 4.7.2 shows the locations around the site perimeter, in nearby communities, and distant locations. Figure 4.7.3 gives the locations along the Columbia River shoreline. The number of thermoluminescent dosimeter measurement locations changed in 1998, with the addition of two onsite and five perimeter locations and the discontinuation of four Columbia River shoreline locations. All thermoluminescent dosimeters are collected and read quarterly. The two TLD-700 chips at each location are used to determine the average total environmental dose at that location. The average dose rate is computed by dividing the average total environmental dose by the length of time the dosimeter was in the field. Quarterly dose equivalent rates (millirem per day) at each location were converted to annual dose equivalent rates (millirem per year) by averaging the quarterly dose rates and multiplying by 365 d/yr. The two TLD-200 chips are included only to determine doses in the event of a radiological emergency.

To determine the maximum dose rate at each location, the quarterly doses were summed and divided by the total number of days a dosimeter was in the field at the specific location. The error uncertainties associated with the maximum dose rates were calculated as two times the square root of the summed quarterly variances divided by the total number of days the dosimeters were in the field. This method of determining the location with the maximum dose rate is slightly different, but statistically more accurate than simply determining the maximum dose rate based on quarterly dose rates, as calculated in previous years.

All community and most of the onsite and perimeter thermoluminescent dosimeter locations are collocated with air monitoring stations. The onsite and perimeter locations were selected based on determinations of the highest potentials for public exposures (i.e., access areas, downwind population centers) from past and current Hanford Site operations. The two background stations in Yakima and Toppenish were chosen because they are generally upwind and distant from the site.

The shoreline of the Hanford Reach of the Columbia River is monitored by a series of 24 thermoluminescent dosimeters located in the area from upstream of the 100-B Reactor shoreline to downstream of Bateman Island at the mouth of the Yakima River. Ground contamination surveys are also conducted quarterly at 13 shoreline locations. These measurements are made to estimate radiation exposure levels attributed to sources on the Hanford Site, to estimate background levels along the shoreline, and to help assess exposures to onsite personnel and offsite populations. Ground contamination surveys are conducted using Geiger-Müeller meters (Geiger counters) and Bicron® Microrem meters. Results are reported in counts per minute and microrem per hour, respectively. Geiger counter measurements are made within 2.54 cm (1 in.) of the ground and cover a 1-m^2 (10-ft^2) area. The Bicron® measurements are taken 1 m (3 ft) above the ground surface and at least 10 m (33 ft) away from devices or structures, which may contribute to the ambient radiation levels.

Pressurized ionization chambers are situated at four community-operated monitoring stations (see Section 7.4, "Community-Operated Environmental Surveillance Program"). These instruments provide a means of measuring ambient exposure rates near and downwind of the site and at locations distant and upwind of the site. Real-time exposure rate data are displayed at each station to provide information to

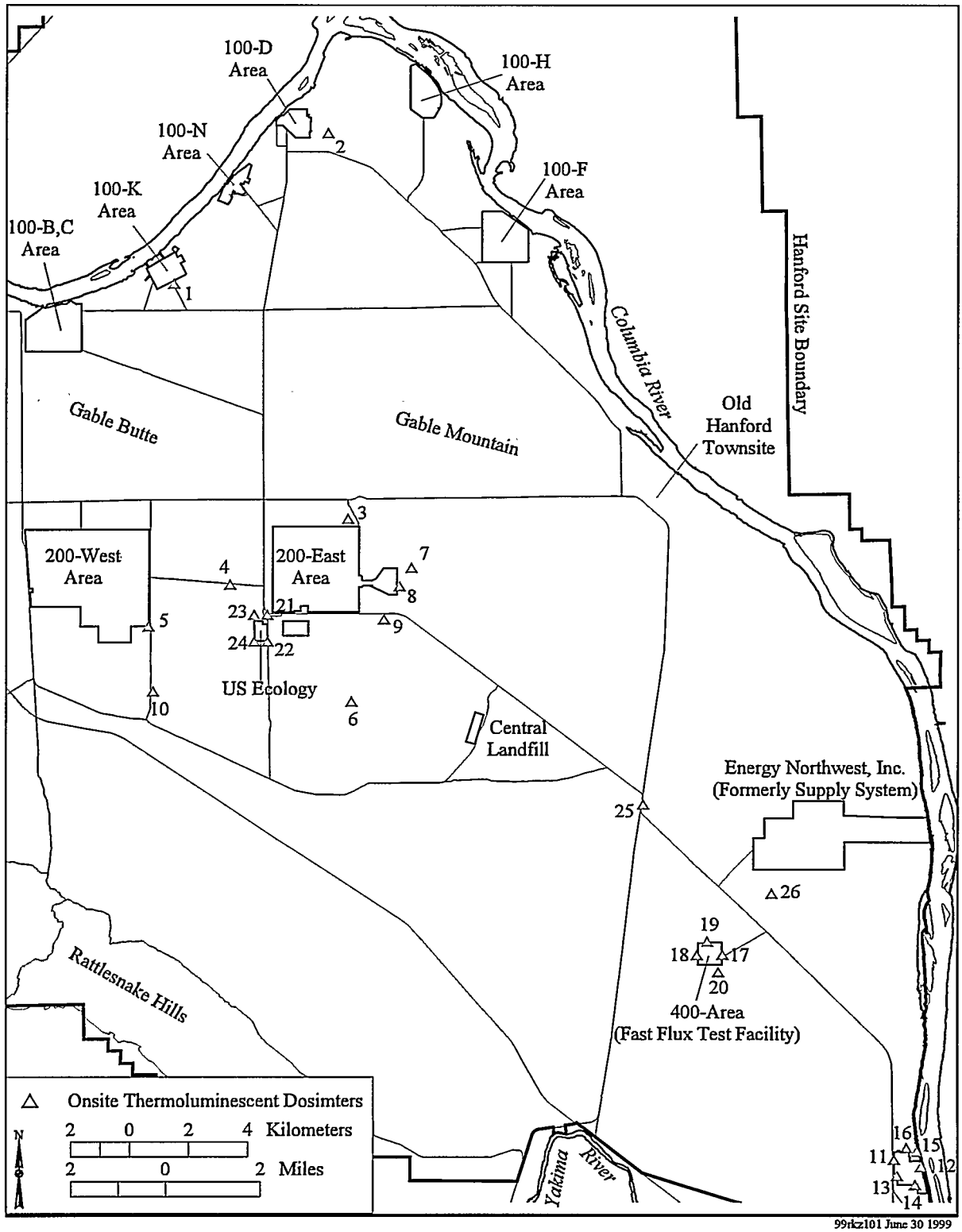


Figure 4.7.1. Thermoluminescent Dosimeter Locations and Station Numbers on the Hanford Site, 1998

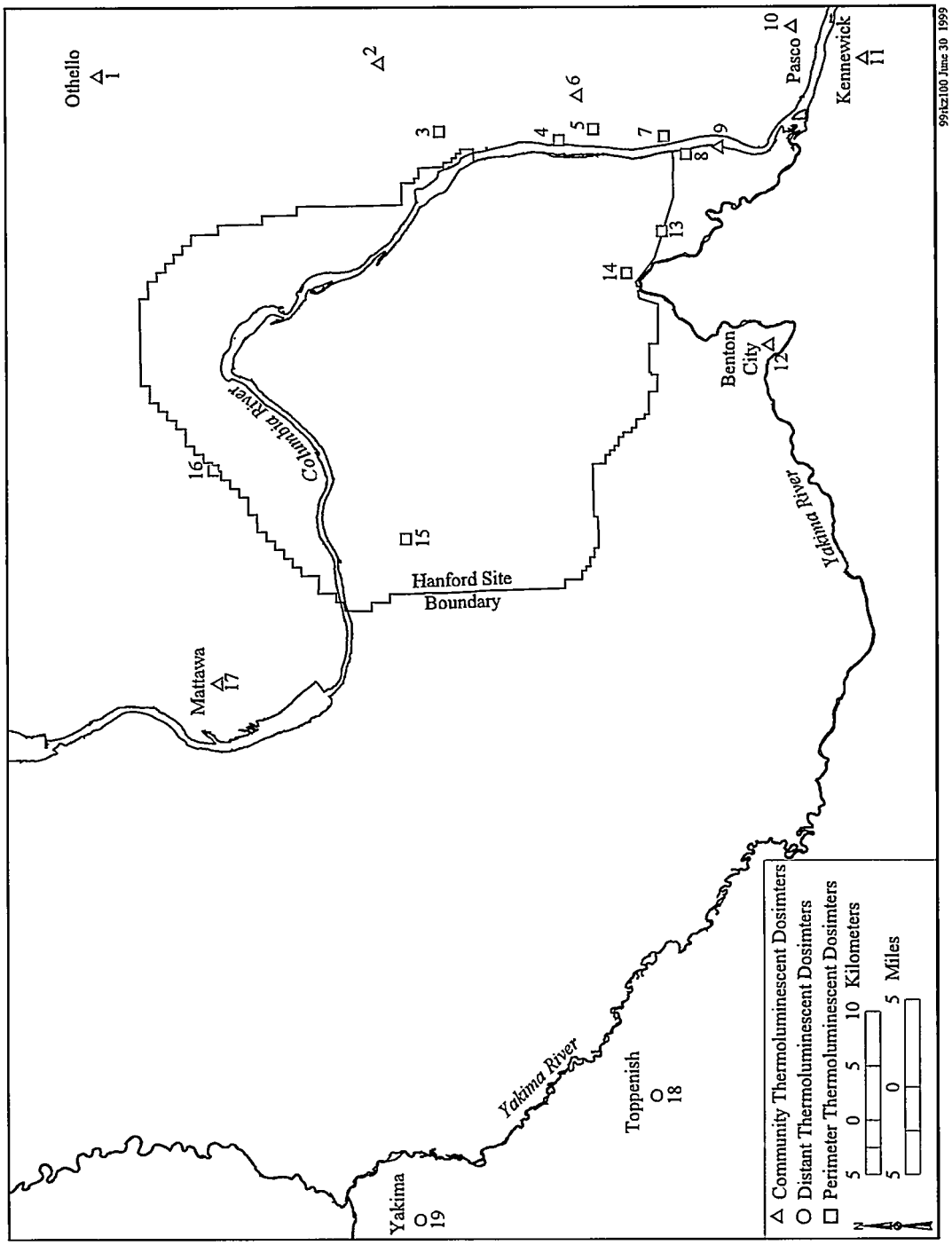


Figure 4.7.2. Thermoluminescent Dosimeter Locations and Station Numbers for Community, Distant, and Perimeter Sites, 1998

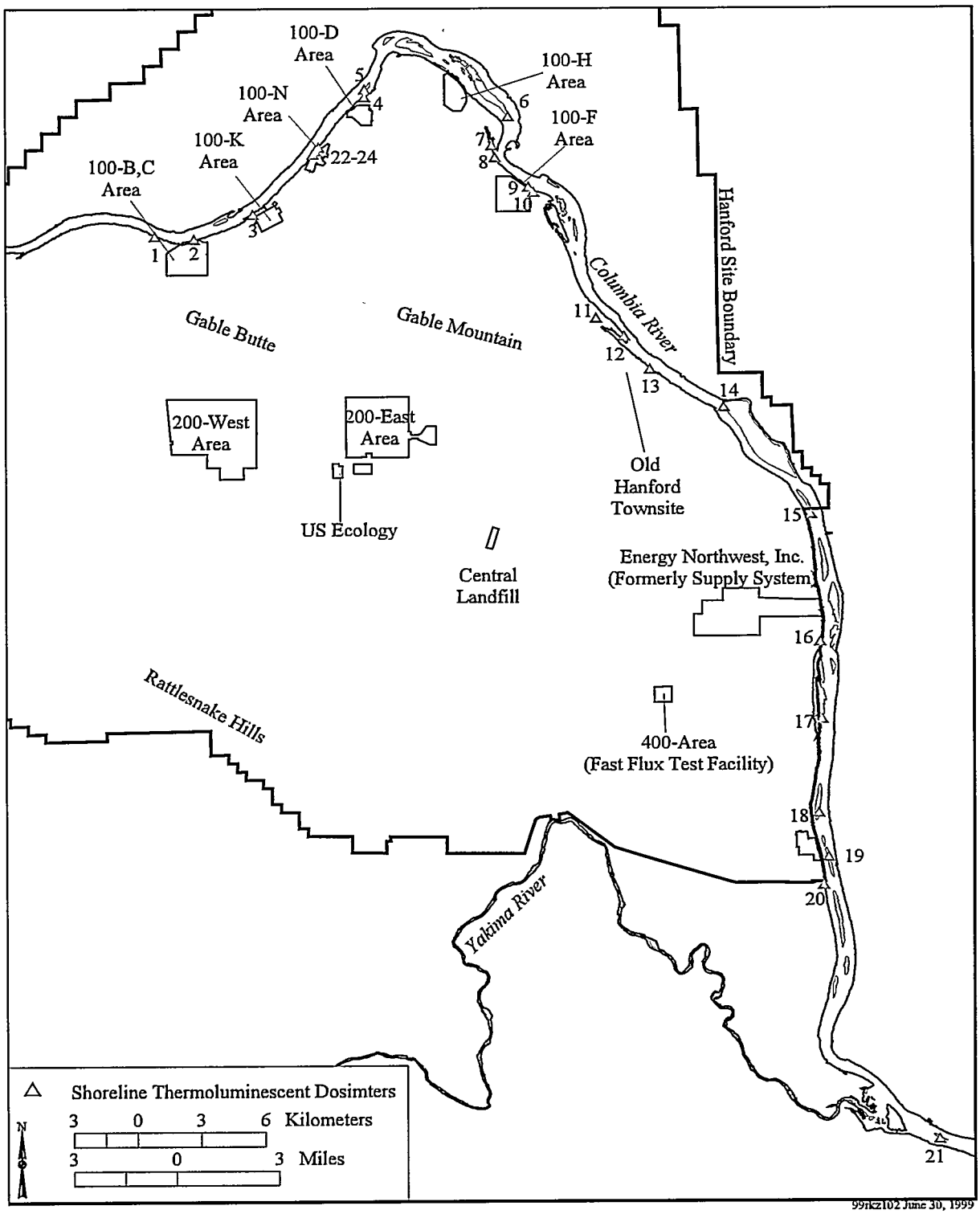


Figure 4.7.3. Thermoluminescent Dosimeter Locations and Station Numbers on the Columbia River, 1998

the public and to serve as an educational tool for the teachers who manage the stations.

4.7.1.1 External Radiation Results

Thermoluminescent dosimeter readings have been converted to annual dose equivalent rates by the process described above. Table 4.7.1 shows the maximum and mean dose rates for perimeter and offsite locations measured in 1998 and the previous 5 yr. External dose rates reported in Tables 4.7.1 through 4.7.3 include the maximum annual dose rate (±2 standard deviations) for all locations within a given surveillance zone and the mean dose rate (±2 standard error of the mean) for each distance class. Locations were classified (or grouped) based on their proximity to the site.

The annual dose rates measured in 1998 are given in Table 4.7.1. The mean perimeter dose rate was 89 ± 5 mrem/yr; in 1997, the mean was 89 ± 10 mrem/yr and the 5-year perimeter mean dose rate was 94 ± 6 mrem/yr. The mean background dose rate (measured at distant communities) in 1998, was 71 ± 1 mrem/yr, compared to the previous year's mean of 67 ± 1 mrem/yr and the current 5-year average of 78 ± 7 mrem/yr. The variation in dose rates may be partially attributed to changes in natural background radiation that can occur as a result of changes in annual cosmic radiation (up to 10%) and terrestrial radiation (15% to 25%) (National Council on Radiation Protection and Measurements 1987). Other factors possibly affecting the annual dose rates reported here have been described in PNL-7124 and include variations in the sensitivity of individual thermoluminescent dosimeter zero-dose readings, fading, random errors in the readout equipment, and changes in station locations, to name a few. Figure 4.7.4 displays a comparison of dose rates between onsite, perimeter, and distant thermoluminescent dosimeter locations from 1993 through 1998.

Table 4.7.2 provides the measured dose rates for thermoluminescent dosimeters positioned along the Columbia River shoreline. Dose rates were highest along the shoreline near the 100-N Area and were approximately 1.5 times the typical shoreline dose rates. The higher dose rates measured along the 100-N Area shoreline have been attributed to past waste management practices in that area (PNL-3127). The 1998 maximum annual shoreline dose rate was 152 ± 2 mrem/yr, which is not significantly different

Table 4.7.1. Dose Rates (mrem/yr[a]) Measured by Thermoluminescent Dosimeters at Perimeter and Offsite Locations, 1998 Compared to Previous 5 Years

		1998		1993-1997		
Location	Map Location[b]	Maximum[c]	Mean[d]	No. of Samples	Maximum[c]	Mean[d]
Perimeter	1 - 9	95 ± 2	89 ± 5	23	120 ± 11	94 ± 6
Community	10 - 17	90 ± 3	78 ± 4	38	107 ± 16	84 ± 3
Distant	18 - 19	72 ± 1	71 ± 1	11	101 ± 14	78 ± 7

(a) ±2 standard error of the mean.
(b) All station locations are shown on Figure 4.7.2.
(c) Maximum annual average dose rate for all locations within a given distance classification.
(d) Means computed by averaging annual means for each location within each distance classification.

Table 4.7.2. Dose Rates (mrem/yr[a]) Measured by Thermoluminescent Dosimeters Along the Hanford Reach of the Columbia River, 1998 Compared to Previous 5 Years

		1998		1993-1997		
Location	Map Location[b]	Maximum[c]	Mean[d]	No. of Samples	Maximum[c]	Mean[d]
Typical shoreline	1 - 21	102 ± 1	88 ± 3	120	141 ± 26	96 ± 3
100-N shoreline	22 - 24	152 ± 2	128 ± 27	19	257 ± 16	164 ± 21
All shoreline	1 - 24	152 ± 2	93 ± 7	139	257 ± 16	105 ± 5

(a) ±2 standard error of the mean.
(b) All locations are shown on Figure 4.7.3.
(c) Maximum annual average dose rate for all locations within a given distance classification.
(d) Means computed by averaging annual means for each location within each distance classification.

Table 4.7.3. Dose Rates (mrem/yr[a]) Measured by Thermoluminescent Dosimeters on the Hanford Site, 1998 Compared to Previous 5 Years

		1998		1993-1997		
Location	Map Location[b]	Maximum[c]	Mean[d]	No. of Samples	Maximum[c]	Mean[d]
100 Areas	1 - 2	89 ± 2	81 ± 15	11	108 ± 10	88 ± 8
200 Areas	3 - 10	94 ± 1	88 ± 4	35	121 ± 10	94 ± 4
300 Area	11 - 16	85 ± 2	83 ± 2	30	110 ± 12	88 ± 4
400 Area	17 - 20	86 ± 3	83 ± 3	20	111 ± 16	91 ± 9
600 Area	21 - 26	126 ± 2	92 ± 13	28	165 ± 14	103 ± 9
Combined onsite	1 - 26	126 ± 2	86 ± 4	124	165 ± 14	94 ± 3

(a) ±2 standard error of the mean.
(b) All locations shown on Figure 4.7.1.
(c) Maximum annual average dose rate for all locations within a given area classification.
(d) Means computed by averaging the annual means for each location within each distance classification.

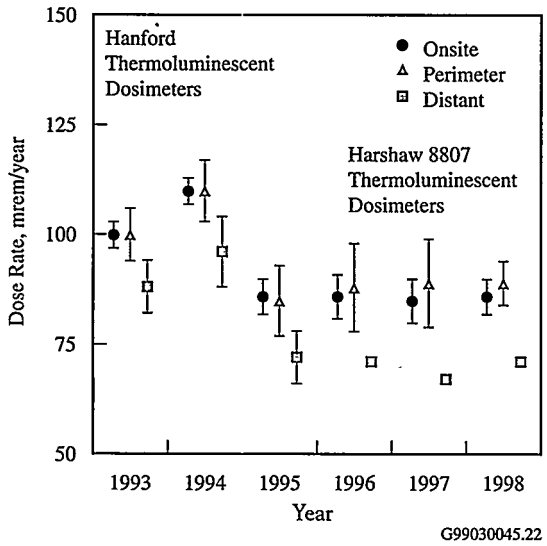


Figure 4.7.4. Annual Average Dose Rates (±2 standard error of the mean), 1993 Through 1998

from the maximum of 153 ± 31 mrem/yr measured in 1997, but is significantly different than the 5-year maximum of 257 mrem/yr. The 5-year maximum was measured in 1993 using the old Hanford standard dosimeter. The general public does not have legal access to the 100-N Area shoreline but does have access to the adjacent Columbia River. The dose implications associated with this access are discussed in Section 5.0, "Potential Radiological Doses from 1998 Hanford Operations."

Table 4.7.3 summarizes the results of 1998 onsite measurements, which are grouped by operational area. The average dose rates in all operational areas were higher than average dose rates measured at distant locations. The highest average dose rate on the site (126 ± 2 mrem/yr) was seen in the 600 Area and was due to waste disposal activities at US Ecology, Inc., a non-DOE facility. The 5-yr maximum onsite dose rate was 165 ± 14 mrem/yr.

4.7.2 Radiological Survey Results

In 1998, Geiger counters and Bicron® Microrem meters were used to perform radiological surveys at selected Columbia River shoreline locations. These surveys provide a coarse screening for elevated radiation fields. The surveys showed that radiation levels at the selected locations were comparable to levels observed at the same locations in previous years. The highest dose rate measured with the Bicron® Microrem meter (20 µRem/h) was measured in winter along the 100-N Area shoreline; the lowest dose rate measured was 4 µRem/h and was recorded at other locations in the spring and autumn. The highest reported count rate measured with the Geiger counter in ground level surveys was 100 cpm. The lowest ground level count rate (<50 cpm) was recorded at the same location and on the same day that the lowest Bicron® reading was recorded.

Survey data are not included in the 1998 surveillance data (PNNL-12088, APP. 1) but are maintained in the Surface Environmental Surveillance Project files at Pacific Northwest National Laboratory and can be obtained on written request.

Gamma radiation levels in air were continuously monitored in 1998 at four community-operated air monitoring stations (Section 7.4, "Community-Operated Environmental Surveillance Program"). These stations were located in Leslie Groves Park in Richland, at Edwin Markham Elementary School in north Franklin County, at Basin City Elementary School in Basin City, and at Heritage College in Toppenish (see Figure 4.1.1) Measurements were collected to determine ambient gamma radiation levels near and downwind of the site and upwind and distant from the site, to display real-time exposure rate information to the public living near the station, and to be an educational aid for the teachers who manage the stations.

Measurements at the Basin City and Edwin Markham Schools were obtained using Reuter-Stokes

Model S 1001-EM19 pressurized ionization chambers connected to Reuter-Stokes RSS-112 Radiation Monitoring Systems. Data were collected every 5 s; an average reading was calculated and recorded on an electronic data card every 30 s. Data cards were exchanged monthly. Readings at the Leslie Groves Park and Heritage College stations were collected every 10 s with a Reuter-Stokes Model RSS-121 pressurized ionization chamber, and an average reading was recorded every hour by a flat panel computer system located at the station. Data were obtained monthly from the computer via modem. Data were not collected at every station every month because of problems with the instrument batteries and electrical power. The data collected at each station each month are summarized in Table 4.7.4.

The measurements recorded at Basin City, Edwin Markham, and Leslie Groves Park during the year were similar and at background levels. The readings at Heritage College were also within normal levels, but were, on average, slightly lower than those measured near the Hanford Site.

Generally, monthly exposure rates ranged from a maximum of 13.7 mR/h at Edwin Markham in October to a minimum of 4.9 mR/h at Leslie Groves Park in November (see Table 4.7.4). The data collected in February at Basin City ranged from 0.1 to 177 μR/h. Several abnormally high and low readings were recorded during the first week of the month at Basin City and were related to a weak battery in the detector. Median readings at the stations near Hanford were consistently between 8.1 and 8.8 mR/h, and readings at the distant station (Heritage College) ranged between 7.7 and 8.2 mR/h. These dose rates were consistent with those measured by thermoluminescent dosimeters at these locations (Table 4.7.5).

Table 4.7.4. Average Exposure Rates Measured by Pressurized Ionization Chambers at Four Offsite Locations[a], 1998

Month		Exposure Rate, μR/h (number of readings)[b]							
		Leslie Groves Park[c]		Basin City[d]		Edwin Markham[d]		Toppenish[c]	
January	Median	8.6	(744)	ND		8.8	(695)	7.8	(744)
	Maximum	10.4		ND[e]		10.7		10	
	Minimum	5.0		ND		8.1		6.9	
February	Median	8.5	(672)	8.3	(433)	8.8	(1,503)	7.9	(672)
	Maximum	9.8		177		11.1		10.9	
	Minimum	5.0		0.1		8.4		7.5	
March	Median	8.5	(744)	ND		8.7	(294)	7.8	(737)
	Maximum	9.2		ND		9.4		8.8	
	Minimum	5.4		ND		8.5		7.6	
April	Median	8.4	(720)	8.3	(1,428)	8.7	(1,463)	7.8	(720)
	Maximum	9.5		9.9		11.7		8.6	
	Minimum	5.5		7.8		8.3		7.5	
May	Median	8.3	(744)	ND		8.6	(1,225)	7.8	(725)
	Maximum	9.9		ND		9.3		10.6	
	Minimum	6.3		ND		8.3		7.4	
June	Median	8.2	(720)	8.2	(1,471)	8.5	(294)	7.7	(696)
	Maximum	8.6		9.2		8.8		9.9	
	Minimum	7.1		7.9		8.3		7.4	
July	Median	8.2	(363)	ND		8.3	(822)	7.7	(225)
	Maximum	10.5		ND		11.7		10.4	
	Minimum	6.1		ND		7.5		7.5	
August	Median	8.7	(744)	8.1	(1,446)	8.4	(1,398)	ND	
	Maximum	8.7		8.7		8.8		ND	
	Minimum	7.8		7.8		7.5		ND	
September	Median	8.4	(658)	ND		8.6	(1,424)	8.0	(132)
	Maximum	9.9		ND		9.1		8.5	
	Minimum	6.6		ND		8.2		7.6	
October	Median	8.4	(716)	8.2	(1,524)	8.7	(1,347)	8.2	(744)
	Maximum	9.4		9.3		13.7		9.2	
	Minimum	5.8		7.9		8.2		7.7	
November	Median	8.5	(720)	ND		8.8	(1,321)	8.1	(722)
	Maximum	9.4		ND		11.4		12.6	
	Minimum	4.9		ND		8.4		7.7	
December	Median	8.5	(744)	8.1	(552)	ND		7.9	(746)
	Maximum	9.4		9.1		ND		8.6	
	Minimum	5.1		7.8		ND		7.4	

(a) Sampling locations are illustrated in Figure 4.1.1.
(b) Number of 30- or 60-min averages used to compute monthly average.
(c) Readings are stored every 60 min. Each 60-min reading is an average of 360 individual measurements.
(d) Readings are stored every 30 min. Each 30-min reading is an average of 360 individual measurements.
(e) ND = No data collected; equipment or power problems.

Table 4.7.5. Quarterly Average Exposure Rates (μR/h[a]) Measured by Thermoluminescent Dosimeters at Four Offsite Locations,[b] 1998

Quarter Ending	Leslie Groves Park	Basin City	Edwin Markham	Toppenish
March	8.958 ± 0.167	8.833 ± 0.167	8.500 ± 0.208	7.833 ± 0.000
June	NS[c]	NS	8.625 ± 0.167	8.167 ± 0.417
September	7.417 ± 0.500	NS	8.292 ± 0.208	7.708 ± 0.417
December	7.917 ± 0.125	8.833 ± 0.125	9.125 ± 0.375	8.542 ± 0.208

(a) ±2 standard deviation of the exposure rate.
(b) Sampling locations shown on Figure 4.1.1.
(c) NS = No sample; thermoluminescent dosimeter missing.

4.8 References

40 CFR 141. U.S. Environmental Protection Agency. "National Primary Drinking Water Regulations; Radionuclides; Proposed Rule." *Code of Federal Regulations.*

American Society for Testing and Materials. 1993. "E 380-93 Standard Practice for Use of the International System of Units (SI) (the Modernized Metric System)." In *Annual Book of ASTM Standards.* Philadelphia, Pennsylvania.

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

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

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

BNWL-2305. 1977. *Association of Hanford Origin Radionuclides with Columbia River Sediment.* D. E. Robertson and J. J. Fix, Pacific Northwest Laboratory, Richland, Washington.

Clean Water Act. 1997. Public Law 95-217, as amended, 91 Stat. 1566 and Public Law 96-148 as amended.

Coughtrey, P. J., and M. C. Thorne. 1983. *Radionuclide Distribution and Transport in Terrestrial and Aquatic Ecosystems. A Critical Review of Data.* Vol. Two, A. A. Balkema, Rotterdam, The Netherlands.

Coughtrey, P. J., D. Jackson, and M. C. Thorne. 1983. *Radionuclide Distribution and Transport in Terrestrial and Aquatic Ecosystems. A Critical Review of Data.* Vol. Three, A. A. Balkema, Rotterdam, The Netherlands.

DeWitt, T. H., R. C. Swartz, D. J. Hansen, D. McGovern, and W. J. Berry. 1996. "Bioavailability and Chronic Toxicity of Cadmium in Sediment to the Estuarine Amphipod *Leptocheirus plumulosus.*" *Environmental Toxicology and Chemistry* 15(12):2095-2101.

DOE/EH-0173T. 1991. *Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance.* U.S. Department of Energy, Washington, D.C.

DOE Order 5400.1. "General Environmental Protection Program."

DOE Order 5400.5. "Radiation Protection of the Public and the Environment."

DOE/RL-91-50, Rev. 2. 1997. *Environmental Monitoring Plan, United States Department of Energy Richland Operations Office.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-92-12. 1992. *Sampling and Analysis of 100 Area Springs.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-92-67. 1992. *Final Remedial Investigation/Feasibility Study - Environmental Assessment Report for the 1100-EM-1 Operable Unit, Hanford.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-93-94, Rev. 1. 1994. *Plan and Schedule for Disposition and Regulatory Compliance for Miscellaneous Streams.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-95-55. 1995. *Hanford Site Background: Evaluation of Existing Soil Radionuclide Data.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-96-12. 1996. *Hanford Site Background: Part 2, Soil Background for Radionuclides*. U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Eisenbud, M. 1987. *Environmental Radioactivity from Natural, Industrial, and Military Sources*. Third Edition, Chapter 5, Academic Press, Inc., New York.

EPA-570/9-76-003. 1976. *National Interim Primary Drinking Water Regulations*. U.S. Environmental Protection Agency, Office of Water Supply, Washington, D.C.

EPA 822-R-96-001. 1996. *Drinking Water Regulations and Health Advisories*. U.S. Environmental Protection Agency, Office of Water, Washington, D.C.

Gibbs, R. J. 1973. "Mechanisms of Trace Metal Transport in Rivers." *Science* 180:71-73.

Hansen, D. J., W. J. Berry, J. D. Mahony, W. S. Boothman, D. M. Di Toro, D. L. Robson, G. T. Ankley, D. Ma, Q. Yan, and C. E. Pesch. 1996. "Predicting the Toxicity of Metal-Contaminated Field Sediments Using Interstitial Concentration of Metals and Acid-Volatile Sulfide Normalizations." *Environmental Toxicology and Chemistry* 15(12):2080-2094.

HW-73672. 1962. *Dispersion of 300 Area Liquid Effluent in the Columbia River*. G. E. Backman, Hanford Atomic Products Operation, General Electric Company, Richland, Washington.

Jenkins, O. P. 1922. *Underground Water Supply of the Region About White Bluffs and Hanford*. State of Washington Department of Conservation and Development, Olympia, Washington.

Kabata-Pendias, A., and H. Pendias. 1984. *Trace Elements in Soil and Plants*. CRC Press, Inc., Boca Raton, Florida.

Karickhoff, W. S., S. D. Brown, and A. T. Scott. 1978. "Sorption of Hydrophobic Pollutants on Natural Sediment." *Water Resources Bulletin* 13:231-248.

Lambert, S. M. 1967. "Functional Relationship Between Sorption in Soil and Chemical Structure." *Journal of Agricultural and Food Chemistry* 15(4):572-576.

Mudroch, A. 1983. "Distribution of Major Elements and Metals in Sediment Cores from the Western Basin of Lake Ontario." *Journal of Great Lakes Research* 9(2):125-133.

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

National Council on Radiation Protection and Measurements. 1993. *Limitation of Exposure to Ionizing Radiation*. Report No. 116, Bethesda, Maryland.

Nelson, J. L., R. W. Perkins, J. M. Nielsen, and W. L. Haushild. 1966. "Reactions of Radionuclides from the Hanford Reactors with Columbia River Sediments." In *Disposal of Radioactive Wastes into Seas, Oceans, and Surface Waters*. International Atomic Energy Agency, Vienna, Austria, pp. 139-161.

Patton, G. W., A. T. Cooper, and M. R. Tinker. 1997. "Ambient Air Sampling for Tritium - Determination of Breakthrough Volumes and Collection Efficiencies for Silica Gel Absorbent." *Health Physics* 72:397-407.

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

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

PNL-6584. 1988. *GENII - The Hanford Environmental Radiation Dosimetry Software System.* B. A. Napier, R. A. Peloquin, D. L. Strenge, and J. V. Ramsdell, Pacific Northwest Laboratory, Richland, Washington, 3 vols.

PNL-7124. 1989. *The Determination of the Penetrating Radiation Dose at Hanford.* L. A. Rathbun, Pacific Northwest Laboratory, Richland, Washington.

PNL-7500. 1990. *1988 Hanford Riverbank Springs Characterization Report.* R. L. Dirkes Pacific Northwest Laboratory, Richland, Washington.

PNL-7662. 1991. *An Evaluation of the Chemical, Radiological, and Ecological Conditions of West Lake on the Hanford Site.* T. M. Poston, K. R. Price, and D. R. Newcomer, Pacific Northwest Laboratory, Richland, Washington.

PNL-8073. 1992. *Hanford Site Ground-Water Monitoring for 1990.* J. C. Evans, R. W. Bryce, and D. J. Bates, Pacific Northwest Laboratory, Richland, Washington.

PNL-8148. 1992. *Hanford Site Environmental Report for Calendar Year 1991.* R. K. Woodruff, R. W. Hanf, and R. E. Lundgren (eds.), Pacific Northwest Laboratory, Richland, Washington.

PNL-8150. 1992. *Methods for Estimating Doses to Organisms from Radioactive Materials Released into the Aquatic Environment.* D. A. Baker and J. K. Soldat, Pacific Northwest Laboratory, Richland, Washington.

PNL-8531. 1993. *Columbia River Monitoring: Distribution of Tritium in Columbia River Water at the Richland Pumphouse.* R. L. Dirkes, Pacific Northwest Laboratory, Richland, Washington.

PNL-8580. 1993. *Water Level Measurements for Modeling Hydraulic Properties in the 300-FF-5 and 100 Aggregate Area Operable Units.* M. D. Campbell, W. J. McMahon, and K. R. Simpson, Pacific Northwest Laboratory, Richland, Washington.

PNL-8654. 1993. *Columbia River Monitoring: Summary of Chemical Monitoring Along Cross Sections at Vernita Bridge and Richland.* R. L. Dirkes, G. W. Patton, and B. L. Tiller, Pacific Northwest Laboratory, Richland, Washington.

PNL-8797. 1993. *Radiological Survey of Shoreline Vegetation from the Hanford Reach of the Columbia River, 1990-1992.* E. J. Antonio, T. M. Poston, and W. H. Rickard, Jr., Pacific Northwest Laboratory, Richland, Washington.

PNL-8817. 1993. *Contribution of Hanford Liquid Effluents to Strontium-90 Levels in Offsite Soils.* R. E. Jaquish, Pacific Northwest Laboratory, Richland, Washington.

PNL-9824. 1994. *Hanford Site Environmental Data 1993 - Surface and Columbia River.* L. E. Bisping, Pacific Northwest Laboratory, Richland, Washington.

PNL-10174. 1994. *A Qualitative Evaluation of Radionuclide Concentrations in Hanford Site Wildlife, 1983 through 1992.* T. M. Poston and A. T. Cooper, Pacific Northwest Laboratory, Richland, Washington.

PNL-10400. 1995. *Identification of Contaminants of Concern, Columbia River Comprehensive Impact Assessment—Draft.* B. A. Napier, N. C. Batishko, D. A. Heise-Craff, M. F. Jarvis, and S. F. Snyder, Pacific Northwest Laboratory, Richland, Washington.

PNL-10535. 1995. *Environmental Monitoring of Columbia River Sediments: Grain-Size Distribution and Containment Association.* M. L. Blanton, W. W. Gardiner, and R. L. Dirkes, Pacific Northwest Laboratory, Richland, Washington.

PNL-10574. 1995. *Hanford Site Environmental Report for Calendar Year 1994.* R. L. Dirkes and R. W. Hanf, Pacific Northwest Laboratory, Richland, Washington.

PNL-10575. 1995. *Hanford Site Environmental Data for Calendar Year 1994 - Surface and Columbia River.* L. E. Bisping, Pacific Northwest Laboratory, Richland, Washington.

PNL-10698. 1995. *Hanford Site Ground-Water Monitoring for 1994.* P. E. Dresel, P. D. Thorne, S. P. Luttrell, B. M. Gillespie, W. D. Webber, J. K. Merz, J. T. Rieger, M. A. Chamness, S. K. Wurstner, and B. E. Optiz, Pacific Northwest Laboratory, Richland, Washington.

PNL-10711. 1995. *Location Analysis and Strontium-90 Concentrations in Deer Antlers on the Hanford Site.* B. L. Tiller, L. E. Eberhardt, and T. M. Poston, Pacific Northwest Laboratory, Richland, Washington.

PNL-10714. 1995. *Nonradiological Chemical Pathway Analysis and Identification of Chemicals of Concern for Environmental Monitoring at the Hanford Site.* M. L. Blanton, A. T. Cooper, and K. J. Castleton, Pacific Northwest Laboratory, Richland, Washington.

PNL-10728. 1995. *Radionuclide Concentrations in Terrestrial Vegetation and Soil on and Around the Hanford Site, 1983 Through 1993.* T. M. Poston, E. J. Antonio, and A. T. Cooper, Pacific Northwest Laboratory, Richland, Washington.

PNNL-11139. 1996. *Hanford Site Environmental Report for Calendar Year 1995.* R. L. Dirkes and R. W. Hanf (eds.), Pacific Northwest National Laboratory, Richland, Washington.

PNNL-11140. 1995. *1995 Surface Environmental Surveillance Data.* L. E. Bisping, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-11472. 1997. *Hanford Site Environmental Report for Calendar Year 1996.* R. L. Dirkes and R. W. Hanf (eds.), Pacific Northwest National Laboratory, Richland, Washington.

PNNL-11473. 1997. *Hanford Site Environmental Data for Calendar Year 1996.* L. E. Bisping, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-11795. 1998. *Hanford Site Environmental Report for Calendar Year 1997.* R. L. Dirkes and R. W. Hanf (eds.), Pacific Northwest National Laboratory, Richland, Washington.

PNNL-11796. 1998. *Hanford Site Environmental Data for Calendar Year 1997.* L. E. Bisping, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-11803. 1998. *Hanford Site Environmental Surveillance Master Sampling Schedule.* L. E. Bisping, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-12088, APP. 1. 1999. *Hanford Site Environmental Surveillance Data Report for Calendar Year 1998.* L. E. Bisping, Pacific Northwest National Laboratory, Richland, Washington.

Richardson, E. M., and E. Epstein. 1971. "Retention of Three Insecticides on Different Size Soil Particles Suspended in Water." *Soil Sciences Society of America Proceedings* 35:884-887.

Safe Drinking Water Act. 1974. Public Law 93-523, as amended, 88 Stat. 1660, 42 USC 300f et seq.

Shleien, B. 1992. *The Health Physics and Radiological Health Handbook, Revised Edition.* Scinta, Inc., Silver Spring, Maryland.

Sinex, S. A., and G. R. Helz. 1981. "Regional Geochemistry of Hampton Roads Harbor and Lower Chesapeake Bay Sediments." *Environmental Geology* 3:315-323.

Skoog, D. A., and D. M. West. 1980. *Analytical Chemistry.* Third Edition, Saunders Golden Sunburst Series, Philadelphia, Pennsylvania.

Suzuki, M., T. Yamada, and T. Miyazaki. 1979. "Sorption and Accumulation of Cadmium in the Sediment of the Tama River." *Water Research* 13:57-63.

Tada, F., and S. Suzuki. 1982. "Adsorption and Desorption of Heavy Metals in Bottom Mud of Urban Rivers." *Water Research* 16:1489-1494.

U.S. Geological Survey. 1995. *Nitrate Concentrations in Ground Water of the Central Columbia Plateau.* Open File Report 95-445, U.S. Geological Survey, Tacoma, Washington.

WA-94-1. 1995. *Water Resources Data, Washington Water Year 1994.* W. D. Wiggins, G. P. Ruppert, R. R. Smith, L. L. Reed, L. E. Hubard, and M. L. Courts, U.S. Geological Survey, Tacoma, Washington.

Washington Administrative Code (WAC) 173-201A. "Water Quality Standards for Surface Waters of the State of Washington." Olympia, Washington.

Washington Administrative Code (WAC) 246-290. "Group A Public Water Supplies." Olympia, Washington.

Wells, D. 1994. *Radioactivity in Columbia River Sediments and Their Health Effects.* Washington State Department of Health, Olympia, Washington.

WHC-SD-EN-TI-006. 1992. *Hydrologic and Geologic Data Available for the Region North of Gable Mountain, Hanford Site, Washington.* R. E. Peterson, Westinghouse Hanford Company, Richland, Washington.

Wiggins, W. D., G. P. Ruppert, R. R. Smith, L. L. Reed, L. E. Hubard, and M. L. Courts. 1996. *Water Resources Data, Washington Water Year 1995.* U.S. Geological Survey, Tacoma, Washington.

Wyerman, T. A., R. K. Farnswirth, and G. L. Stewart. 1970. "Tritium in Streams in the United States, 1961-1968." *Radiological Health Data and Reports,* pp. 421-429.

5.0 Potential Radiological Doses from 1998 Hanford Operations

E. J. Antonio and K. Rhoads

During 1998, radionuclides reached the environment in gaseous and liquid effluents from Hanford Site operations. Monitored gaseous effluents were released from operating stacks and ventilation exhausts. Other potential sources include fugitive emissions from contaminated soil areas and unmonitored facilities. Liquid effluents were released from operating wastewater treatment facilities and from contaminated groundwater seeping into the Columbia River.

Potential radiological doses to the public from these releases were evaluated in detail to determine compliance with pertinent regulations and limits. Dose calculation methodology is discussed in Appendix D. The radiological impacts of 1998 Hanford operations were assessed in terms of the following:

- dose to a hypothetical, maximally exposed individual at an offsite location
- maximum dose rate from external radiation at a publicly accessible location on or within the site boundary
- dose to an avid sportsman who consumes wildlife that may have acquired contamination from radionuclides on the site
- total dose to the population residing within 80 km (50 mi) of the Hanford operating areas
- absorbed dose rate (rad/d) received by animals caused by radionuclide releases to the Columbia River.

It is generally accepted that radiological dose assessments should be based on direct measurements of radiation dose rates and radionuclide activities in the surrounding environment. However, the amounts of most radioactive materials released during 1998 from Hanford sources were generally too small to be measured directly once they were dispersed in the offsite environment. For many of the measurable radionuclides, it was difficult to identify the contributions from Hanford sources in the presence of contributions from worldwide fallout and from naturally occurring uranium and its decay products. Therefore, in nearly all instances, offsite doses were estimated using the Generation II (GENII) computer code Version 1.485 (PNL-6584) and Hanford Site-specific parameters listed in Appendix D and in PNNL-12088, APP. 1 to calculate activities of radioactive materials in the environment from effluent releases reported by the operating contractors.

As in the past, radiological doses from the water pathway were calculated based on the differences in radionuclide activities between upstream and downstream sampling points. During 1998, tritium, iodine-129, and uranium were found in the Columbia River downstream of Hanford at greater levels than predicted based on direct discharges from the 100 Areas. All other radionuclide activities were lower than those predicted from known releases. Riverbank springs water, containing these radionuclides, is known to enter the river along the portion of shoreline extending from the Old Hanford Townsite downstream to the 300 Area (see Section 4.2, "Surface Water and Sediment Surveillance" and Section 6.1, "Hanford Groundwater Monitoring Project"). No direct discharges of radioactive materials from the 300 Area to the Columbia River were reported in 1998.

The estimated dose[a] to the maximally exposed, offsite individual from Hanford operations in 1998 was 0.02 mrem (2×10^{-4} mSv) compared to 0.01 mrem

(a) Unless stated otherwise, the term "dose" in this section is the "total effective dose equivalent" (see Appendix B, "Glossary").

(1 x 10^{-4} mSv) reported for 1997. The dose to the local population of 380,000 (PNL-7803) from 1998 operations was the same as reported for 1997, 0.2 person-rem (0.002 person-Sv) (Section 5.0 in PNNL-11472). The 1998 average dose to the population was approximately 0.0005 mrem (5 x 10^{-6} mSv) per person (the same as 1997). The current U.S. Department of Energy (DOE) radiological dose limit (DOE Order 5400.5) for an individual member of the public is 100 mrem/yr (1 mSv/yr) from all pathways, which includes the U.S. Environmental Protection Agency's (EPA's) limit of 10 mrem/yr (0.1 mSv/yr) from airborne radionuclide emissions (Title 40, Code of Federal Regulations, Part 61 [40 CFR 61]). The national average radiological dose from natural sources is approximately 300 mrem/yr (3 mSv/yr) (National Council on Radiation Protection and Measurements 1987). Thus, 1998 Hanford emissions potentially contributed to the maximally exposed individual a dose equivalent to only 0.02% of the DOE dose limit, 0.2% of the EPA limit, or 0.006% of the average dose received from natural radioactivity in the environment. For the average member of the local population, these contributions were approximately 0.0005%, 0.005%, and 0.0002%, respectively.

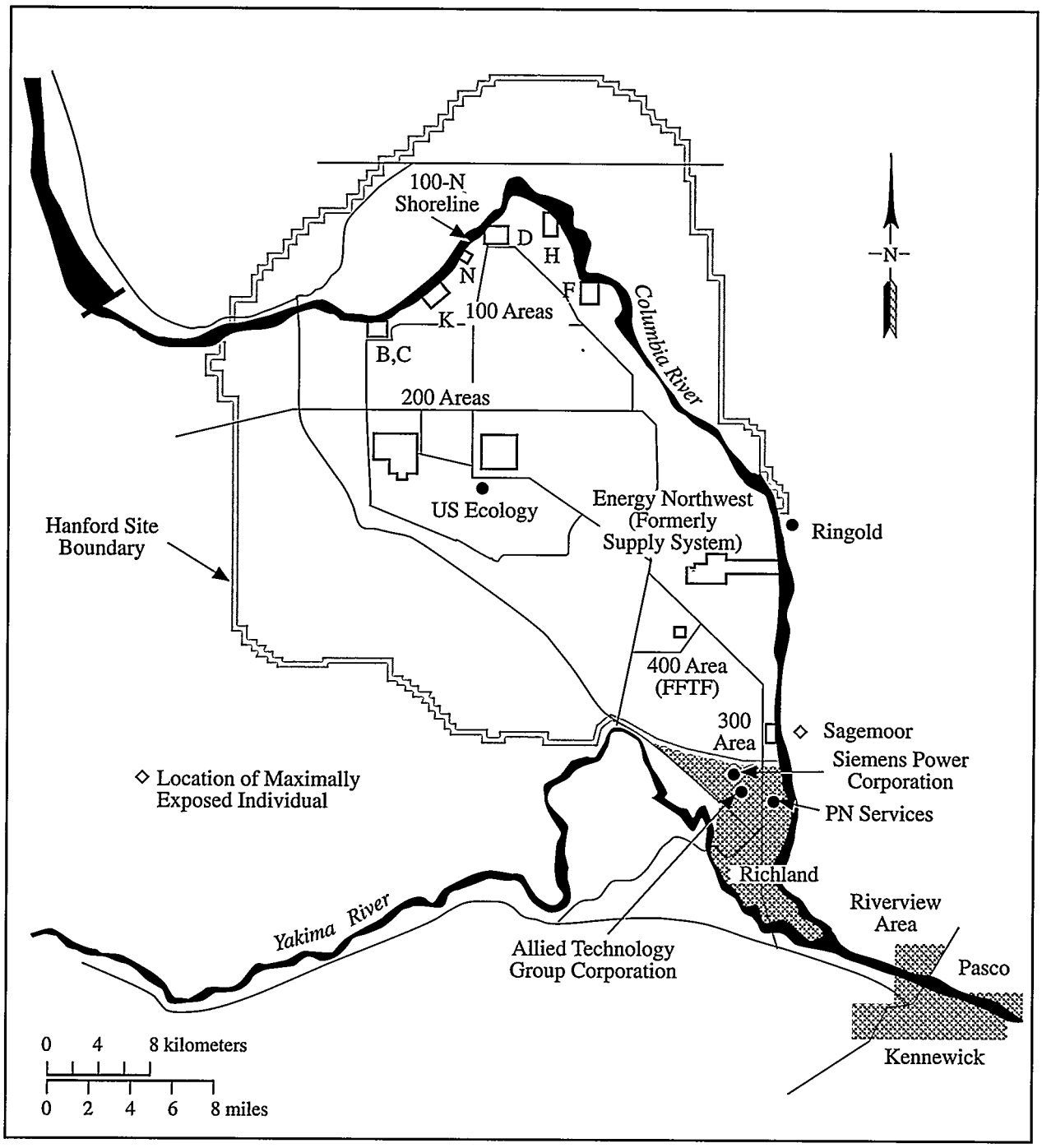
The uncertainty associated with the radiological dose calculations on which this report is based has not been quantified. However, when Hanford-specific data were not available for parameter values (e.g., vegetation uptake and consumption factors), conservative values were selected from the literature for use in environmental transport models. Thus, radiological doses calculated using environmental models should be viewed as hypothetical maximum estimates of doses resulting from Hanford operations.

5.0.1 Maximally Exposed Individual Dose

The maximally exposed individual is a hypothetical person who lives at a location and has a lifestyle such that it is unlikely that other members of the public would receive a higher radiological dose. This individual's diet, dwelling place, and other factors were chosen to maximize the combined doses from all reasonable environmental pathways of exposure to radionuclides in Hanford Site effluents. In reality, such a combination of maximized parameters is highly unlikely to apply to any single individual.

The hypothetical location of the maximally exposed individual can vary from year to year, depending on the relative contributions of the several sources of radioactive effluents released to the air and to the Columbia River from Hanford facilities. Historically, two separate locations have been used to assess the dose to the maximally exposed individual: 1) the Ringold area, 26 km (16 mi) east of separations facilities in the 200 Areas and 2) the Riverview area across the river from Richland (Figure 5.0.1). The Ringold area is closer than Riverview to Hanford facilities that historically were major contributors of airborne effluents. At Riverview, the maximally exposed individual has the highest exposure to radionuclides in the Columbia River.

Since 1993, a third location across the Columbia River from the 300 Area has been considered. Because of the shift in site operations from strategic materials production to the current mission of developing waste treatment and disposal technologies and cleaning up contamination, the significance of the air emissions from the production facilities in the 200 Areas has decreased relative to those from the 300 Area. Therefore, a receptor directly across the river from the 300 Area, at Sagemoor, would be maximally exposed to airborne radionuclides from those facilities. The applicable exposure pathways for each of these locations are described below.



G99030045.96

Figure 5.0.1. Locations Important to Dose Calculations

The Ringold area is situated to maximize air pathway exposures from emissions in the 200 Areas, including direct exposure to the plume, inhalation, external exposure to radionuclides that deposit on the ground, and ingestion of locally grown food products. In addition, it is assumed that individuals at Ringold irrigate their crops with water taken from the Columbia River downstream of where groundwater enters the river from the 100 and 200-East Areas (discussed in Section 6.1, "Hanford Groundwater Monitoring Project"). This results in additional exposures from ingestion of irrigated food products and external irradiation from radionuclides deposited on the ground by irrigation. Recreational use of the Columbia River is also considered for this individual, resulting in direct exposure from water and radionuclides deposited on the shoreline and internal dose from ingestion of locally caught fish.

The Riverview area receptor is assumed to be exposed via the same pathways as the individual at Ringold, except that irrigation water from the Columbia River may contain radionuclides that enter the river at the 300 Area, in addition to those from upstream release points. This individual is also assumed to obtain domestic water from the river via a local water treatment system. Exposure of this individual from the air pathway is typically lower than exposure at Ringold because of the greater distance from the major, onsite, air emission sources.

The individual at Sagemoor, assumed to be located 1.5 km (1 mi) directly across the Columbia River from the 300 Area, receives the maximum exposure to airborne effluents from the 300 Area, including the same pathways as the individual at Ringold. Domestic water at this location comes from a well rather than from the river, and wells in this region are not contaminated by radionuclides of Hanford origin (EPS-87-367A). Although the farms located across from the 300 Area obtain irrigation water from upstream of the Hanford Site, the conservative assumption was made that the diet of the maximally exposed individual residing 1.5 km (1 mi) east of the 300 Area consisted totally of foods purchased from the Riverview area, which could contain radionuclides present in both liquid and gaseous effluents. The added contribution of radionuclides in the Riverview irrigation water maximizes the calculated dose from the air and water pathways combined.

The 1998 hypothetical, maximally exposed individual at Sagemoor was calculated to have received a slightly higher dose (0.022 mrem/yr) than the maximally exposed individual located at either Ringold (0.009 mrem/yr) or Riverview (0.012 mrem/yr). Radiological doses to the maximally exposed individual were calculated using the effluent data in Tables 3.1.1 and 3.1.4. Quantities of radionuclides assumed to be present in the Columbia River from riverbank springs were also calculated for input to the GENII code. The estimated releases to the river from these sources were derived from the difference between the upstream and downstream activities. These radionuclides were assumed to enter the river through groundwater seeps between the Old Hanford Townsite and the 300 Area.

The calculated doses for the hypothetical, maximally exposed individual (at Sagemoor) in 1998 are summarized in Table 5.0.1. These values include the doses received from exposure to liquid and airborne effluents during 1998, as well as the future, or committed dose from radionuclides that were inhaled or ingested during 1998. As releases from facilities and the doses from these sources decrease, the contribution of diffuse sources such as wind-blown contaminated soil becomes relatively more significant. An upper estimate of the dose from diffuse sources is discussed in Section 5.0.3, "Comparison with Clean Air Act Standards." The estimated dose from diffuse sources was similar to the dose reported in Table 5.0.1 for measured emissions. Site-specific parameters for food pathways, diet, and recreational activity used for the dose calculations are contained in Appendix D (Tables D.2, D.2, and D.4, respectively).

Table 5.0.1. Dose to the Hypothetical, Maximally Exposed Individual Residing at Sagemoor from 1998 Hanford Operations

		Dose Contributions from Operating Areas, mrem				
Effluent	Pathway	100 Areas	200 Areas	300 Area	400 Area	Pathway Total
Air	External	1.2×10^{-8}	8.8×10^{-8}	2.2×10^{-8}	1.9×10^{-8}	1.4×10^{-7}
	Inhalation	6.6×10^{-6}	1.6×10^{-4}	1.4×10^{-3}	1.4×10^{-5}	1.6×10^{-3}
	Foods	2.9×10^{-7}	2.8×10^{-5}	1.3×10^{-2}	9.4×10^{-5}	1.3×10^{-2}
	Subtotal air	6.9×10^{-6}	1.9×10^{-4}	1.4×10^{-2}	1.1×10^{-4}	1.5×10^{-2}
Water	Recreation	1.7×10^{-6}	3.2×10^{-5}	0.0[a]	0.0	3.4×10^{-5}
	Foods	8.5×10^{-4}	3.7×10^{-3}	0.0	0.0	4.6×10^{-3}
	Fish	7.0×10^{-4}	2.4×10^{-3}	0.0	0.0	3.1×10^{-3}
	Drinking water	0.0	0.0	0.0	0.0	0.0
	Subtotal water	1.6×10^{-3}	6.1×10^{-3}	0.0	0.0	7.7×10^{-3}
Combined total		1.6×10^{-3}	6.3×10^{-3}	1.4×10^{-2}	1.1×10^{-4}	2.2×10^{-2}

(a) Zeros indicate no dose contribution to maximally exposed individual through water pathway.

The total radiological dose to the hypothetical, maximally exposed, offsite individual in 1998 was calculated to be 0.02 mrem (2×10^{-4} mSv) compared to 0.01 mrem (1×10^{-4} mSv) calculated for 1997. The primary pathways contributing to this dose (and the percentage of all pathways) were the following:

- consumption of foods grown downwind of the 300 Area (59%), principally tritium released from the 300 and 400 Areas
- consumption of food irrigated with Columbia River water or fish from the Columbia River (27%), principally isotopes of uranium and tritium.

The DOE radiological dose limit for any member of the public from all routine DOE operations is 100 mrem/yr (1 mSv/yr) (DOE Order 5400.5). The dose calculated for the maximally exposed individual for 1998 was 0.02% of the DOE limit. Thus, the Hanford Site was in compliance with applicable federal and state regulations.

The doses from Hanford operations for the maximally exposed individual for 1993 through 1998 are illustrated in Figure 5.0.2. During each year, the doses were estimated using methods and computer codes previously described. In 1992, the maximally exposed individual was located at Riverview. For 1993 through 1998, the hypothetical, maximally exposed individual was located across the Columbia River from the 300 Area at Sagemoor.

5.0.2 Special Case Exposure Scenarios

Exposure parameters used to calculate the dose to the maximally exposed individual are selected to define a high-exposure scenario that is unlikely to occur. Such a scenario does not necessarily result in the highest conceivable radiological dose. Low-probability exposure scenarios exist that could

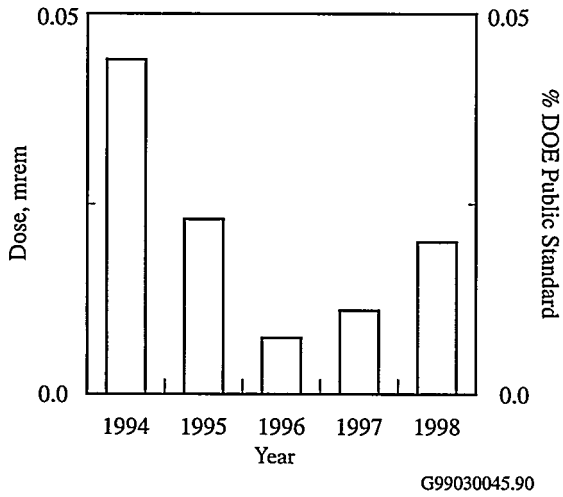


Figure 5.0.2. Calculated Dose to the Hypothetical, Maximally Exposed Individual, 1994 Through 1998

result in somewhat higher doses. Three scenarios that could potentially lead to larger doses include 1) an individual who would spend time at the site boundary location with the maximum external radiological dose rate, 2) a sportsman who might consume contaminated wildlife that migrated from the site, and 3) a consumer of drinking water at the Fast Flux Test Facility in the 400 Area.

5.0.2.1 Maximum "Boundary" Dose Rate

The boundary radiological dose rate is the external radiological dose rate measured at publicly accessible locations on or near the site. The boundary dose rate was determined from radiation exposure measurements using thermoluminescent dosimeters at locations of expected elevated dose rates on the site and at representative locations off the site. These boundary dose rates should not be used to calculate annual doses to the general public because no one can actually reside at any of these boundary locations. However, these rates can be used to determine the dose to a specific individual who might spend some time at that location.

External radiological dose rates measured in the vicinity of the 100-N, 200, 300, and 400 Areas are described in Section 4.7, "External Radiation Surveillance." Results for the 200 Areas were not used because these locations are not accessible to the public. Radiation measurements made at the 100-N Area shoreline (see Figure 5.0.1) were consistently above the background level and represent the highest measured boundary dose rates. The Columbia River provides public access to an area within approximately 100 m (330 ft) of the N Reactor and supporting facilities.

The dose rate at the location with the highest exposure rate along the 100-N Area shoreline during 1998 was 0.02 mrem/h (2×10^{-4} mSv/h), or approximately twice the average background dose rate of 0.01 mrem/h (1×10^{-4} mSv/h) normally observed at other shoreline locations. Therefore, for every hour someone spent at the 100-N Area shoreline during 1998, the external radiological dose received from Hanford operations would be approximately 0.01 mrem (1×10^{-4} mSv) above the natural background dose. If an individual spent 2 h at this location, a dose would be received that is similar to the annual dose calculated for the hypothetical, maximally exposed individual at Sagemoor. The public can approach the shoreline by boat but they are legally restricted from stepping onto the shoreline. Therefore, an individual is unlikely to remain on or near the shoreline for an extended period of time.

5.0.2.2 Sportsman Dose

Wildlife have access to areas of the site that contain radioactive materials, and some do become contaminated. Sometimes contaminated wildlife travel off the site. Sampling is conducted on the site to estimate the maximum contamination levels that might possibly exist in animals hunted off the site. Because this scenario has a relatively low probability of occurring, these doses are not included in the maximally exposed individual calculation.

Listed below are estimates of the radiological doses that could have resulted if wildlife containing the maximum levels measured in onsite wildlife in 1998 migrated off the site, were hunted, and were eaten.

- The dose from eating 1 kg (2.2 lb) of sucker or carp fillets that contains the maximum cesium-137 activity (0.04 pCi/g) measured in samples collected from the Hanford Reach of the Columbia River in 1998 is estimated to be 2×10^{-2} mrem (2×10^{-5} mSv).
- The dose from eating 1 kg (2.2 lb) of pheasant meat that contains the maximum cesium-137 activity (0.018 pCi/g) measured in samples collected on the site in 1998 is estimated to be 9×10^{-4} mrem (9×10^{-6} mSv).
- The dose from ingesting 1 kg (2.2 lb) of venison that contains the maximum cesium-137 activity (0.005 pCi/g) measured in a sample harvested on the site in 1998 is estimated to be 3×10^{-4} mrem (3×10^{-6} mSv).

These are very low doses and do not exceed the hypothetical, maximally exposed individual dose at Sagemoor. In fact, the hypothetical person who ate 1 kg (2.2 lb) of sucker or carp fillets at the maximum measured cesium-137 activity would receive the same dose as the maximally exposed individual located at Sagemoor. A person would have to consume 22 kg (48 lb) of pheasant meat or 66 kg (145 lb) of venison that contain the maximum measured cesium-137 activity to receive the same dose as the hypothetical, maximally exposed individual at Sagemoor. The methodology for determining doses from consumption of wildlife was to multiply the maximum activity measured in edible tissue by a dose conversion factor for ingestion of that flesh, which is addressed in more detail in PNL-7539.

5.0.2.3 Fast Flux Test Facility Drinking Water

During 1998, groundwater was used as drinking water by workers at the Fast Flux Test Facility in the 400 Area. Therefore, this water was sampled and analyzed throughout the year in accordance with applicable drinking water regulations (40 CFR 61). All annual average radionuclide activities measured during 1998 were well below applicable drinking water standards, but tritium was detected at levels greater than typical background values (see Section 4.3, "Hanford Site Drinking Water Surveillance," and Appendix D). Based on the measured groundwater well concentrations, the potential dose to Fast Flux Test Facility workers (an estimate derived by assuming a consumption of 1 L/d [0.26 gal/d] for 240 working days) would be approximately 0.02 mrem (0.0002 mSv). Although the hypothetical Fast Flux Test Facility worker would receive approximately the same dose as the 1998 offsite maximally exposed individual, the dose is well below the drinking water dose limit of 4 mrem for public drinking water supplies.

5.0.3 Comparison with Clean Air Act Standards

Limits for radiation dose to the public from airborne radionuclide emissions at DOE facilities are provided in 40 CFR 61, Subpart H. The regulation specifies that no member of the public shall receive a dose of >10 mrem/yr (0.1 mSv/yr) from exposure to airborne radionuclide effluents, other than radon, released at DOE facilities (EPA 520/1-89-005). The regulation also requires that each DOE facility submit an annual report that supplies information about atmospheric emissions for the preceding year and their potential offsite impacts. Washington Administrative Code (WAC) 246-247 imposes requirements similar to those in 40 CFR 61, Subpart H, except that the 10-mrem/yr dose standard includes the dose resulting from radon emissions from other than naturally occurring sources. The following summarizes information that is provided in more detail in the 1998 air emissions report (DOE/RL-99-41), which addresses both EPA and Washington State regulations.

The 1998 air emissions from monitored Hanford Site facilities resulted in a potential dose to a maximally exposed individual at Sagemoor of 0.013 mrem (1.3×10^{-4} mSv), which represents <0.13% of the 10-mrem/yr standard. The Clean Air Act of 1986 requires the use of CAP-88 (EPA-402-B-92-001) or other EPA-approved models to demonstrate compliance with the standard, and the assumptions embodied in these codes differ slightly from standard assumptions used at Hanford for reporting to DOE via this report. Nevertheless, the result of calculations performed with CAP88-PC for air emissions from Hanford facilities agrees well with doses calculated for this report using the GENII code (0.015 mrem, or 1.5×10^{-4} mSv, for air pathways).

The December 15, 1989 revisions to the Clean Air Act (40 CFR 61, Subpart H) require DOE facilities to estimate the dose to a member of the public for radionuclides released from all potential sources of airborne radionuclides. DOE, Washington State, and EPA have interpreted the regulation to include diffuse and unmonitored sources as well as monitored point sources. The EPA has not specified or approved methods for estimating emissions from diffuse sources, and standardization is difficult because of the wide variety of such sources at DOE sites. Estimates of potential diffuse source emissions at Hanford have been developed using environmental surveillance measurements of airborne radionuclides at the site perimeter.

During 1998, the estimated dose from diffuse sources to the maximally exposed individual at Sagemoor was 0.025 mrem (2.5×10^{-4} mSv), which was greater than the estimated dose at that location from stack emissions (0.013 mrem, or 1.3×10^{-4} mSv). Doses at other locations around the Hanford perimeter ranged from 0.006 to 0.04 mrem (6×10^{-5} to 4×10^{-4} mSv). Based on these results, the combined dose from stack emissions and diffuse and unmonitored sources during 1998 was well below the EPA standard.

5.0.4 Collective Dose to the Population Within 80 km (50 mi)

Exposure pathways for the general public from releases of radionuclides to the atmosphere include inhalation, air submersion, and consumption of contaminated food. Pathways of exposure for radionuclides present in the Columbia River include consumption of drinking water, fish, and irrigated foods and external exposure during aquatic recreation. The regional collective dose from 1998 Hanford Site operations was estimated by calculating the radiological dose to the population residing within an 80-km (50-mi) radius of the onsite operating areas. Results of the dose calculations are shown in Table 5.0.2. Food pathway, dietary, residency, and recreational activity assumptions for these calculations are given in Appendix D (Tables D.1 through D.4).

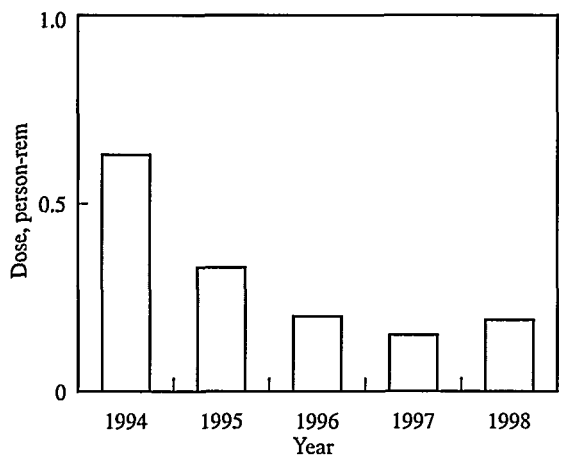
The collective dose calculated for the population was 0.2 person-rem (0.002 person-Sv) in 1998, and remained unchanged from the 1997 population dose. The 80-km (50-mi) collective doses attributed to Hanford operations from 1994 through 1998 are compared in Figure 5.0.3. Primary pathways contributing to the 1998 population dose were the following:

- consumption of drinking water (57%) contaminated with radionuclides released to the Columbia River at Hanford, principally tritium
- consumption of foodstuffs (33%) contaminated with radionuclides released in gaseous effluents, primarily tritium from the 300 and 400 Areas and iodine-129 from the Plutonium-Uranium Extraction Plant stack
- inhalation of radionuclides (14%) that were released to the air, principally tritium emitted from the 300 Area stacks and the 400 Area, and plutonium-239,240 released from the 200 Area stacks.

Table 5.0.2. Dose to the Population from 1998 Hanford Operations

Effluent	Pathway	Dose Contributions from Operating Areas, person-rem: 100 Areas	200 Areas	300 Area	400 Area	Pathway Total
Air	External	2.2×10^{-6}	5.5×10^{-6}	1.1×10^{-7}	5.9×10^{-7}	8.4×10^{-6}
	Inhalation	1.8×10^{-3}	1.5×10^{-2}	9.6×10^{-3}	6.3×10^{-4}	2.7×10^{-2}
	Foods	4.5×10^{-5}	1.8×10^{-3}	5.3×10^{-2}	2.5×10^{-3}	5.7×10^{-2}
	Subtotal air	1.8×10^{-3}	1.7×10^{-2}	6.3×10^{-2}	3.1×10^{-3}	8.4×10^{-2}
Water	Recreation	1.3×10^{-5}	2.0×10^{-4}	0.0[a]	0.0	2.1×10^{-4}
	Foods	9.0×10^{-4}	4.1×10^{-3}	0.0	0.0	5.0×10^{-3}
	Fish	2.6×10^{-4}	8.8×10^{-4}	0.0	0.0	1.1×10^{-3}
	Drinking water	2.1×10^{-3}	1.0×10^{-1}	0.0	0.0	1.0×10^{-1}
	Subtotal water	3.3×10^{-3}	1.1×10^{-1}	0.0	0.0	1.1×10^{-1}
Combined total		5.1×10^{-3}	1.2×10^{-1}	6.3×10^{-2}	3.1×10^{-3}	1.9×10^{-1}

(a) Zeros indicate no dose contribution to the population through the water pathway.



G99030045.91

Figure 5.0.3. Calculated Dose to the Population Within 80 km (50 mi) of the Hanford Site, 1994 Through 1998

The average per capita dose from 1998 Hanford Site operations based on a population of 380,000 within 80 km (50 mi) was 0.0005 mrem (5×10^{-6} mSv). To place this dose from Hanford activities into perspective, the estimate may be compared with doses from other routinely encountered sources of radiation such as natural terrestrial and cosmic background radiation, medical treatment and x-rays, natural radionuclides in the body, and inhalation of naturally occurring radon. The national average radiological dose from these other sources is illustrated in Figure 5.0.4. The estimated average per capita dose to members of the public from Hanford sources is only approximately 0.0002% of the annual per capita dose (300 mrem) from natural background sources.

The doses from Hanford effluents to the maximally exposed individual and to the population within 80 km (50 mi) are compared to appropriate standards and natural background radiation in Table 5.0.3. This table shows that the calculated radiological doses from Hanford operations in 1998 are a small percentage of the standards and of natural background.

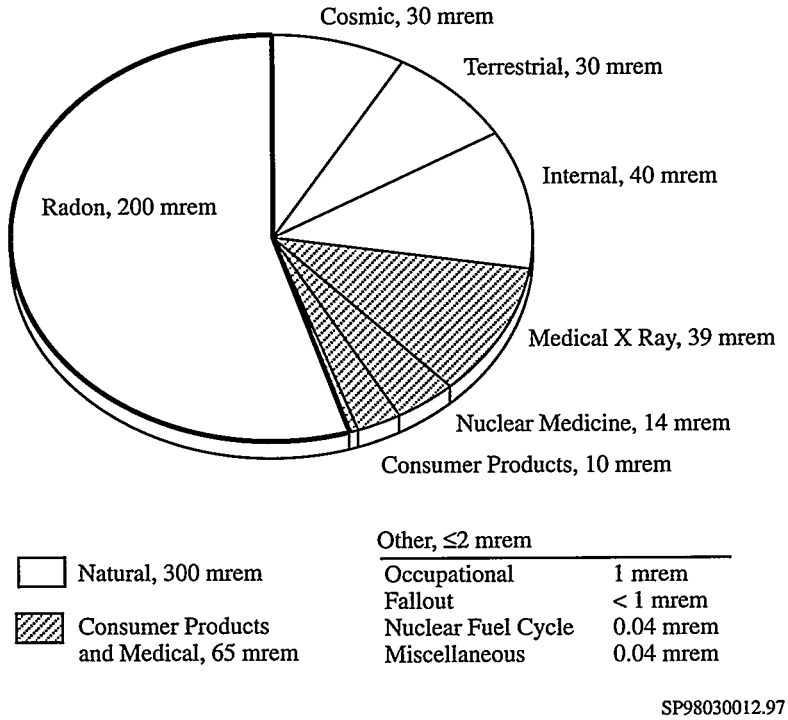


Figure 5.0.4. National Annual Average Radiological Doses from Various Sources (National Council on Radiation Protection and Measurements 1987)

Table 5.0.3. Summary of Doses to the Public in the Vicinity of the Hanford Site from Various Sources, 1998

Source	Maximum Individual	Population
All Hanford effluents	0.022 mrem[a]	0.2 person-rem[a]
DOE limit	100 mrem	--
Percent of DOE limit[b]	0.022	--
Background radiation	300 mrem	110,000 person-rem
Hanford dose percent of background	<0.01	2×10^{-4}
Doses from gaseous effluents	0.015 mrem	--
EPA air standard[c]	10 mrem	--
Percent of EPA standard	0.15	--

(a) To convert the dose values to mSv or person-Sv, divide by 100.
(b) DOE Order 5400.5.
(c) 40 CFR 61.

5.0.5 Doses from Other than DOE Sources

Various non-DOE industrial sources of public radiation exposure exist at or near the Hanford Site. These include the low-activity, commercial, radioactive waste burial ground at Hanford operated by US Ecology; the nuclear power generating station at Hanford operated by Energy Northwest (formerly known as the Washington Public Power Supply System); the nuclear fuel production plant operated by Siemens Power Corporation; the commercial, low-activity, radioactive waste compacting facility operated by Allied Technology Group Corporation; and a commercial decontamination facility operated by PN Services (see Figure 5.0.1). DOE maintains an awareness of other man-made sources of radiation, which, if combined with the DOE sources, might have the potential to cause a dose exceeding 10 mrem (0.1 mSv) to any member of the public. With information gathered from these companies, it was conservatively estimated that the total 1998 individual dose from their combined activities is on the order of 0.05 mrem (5×10^{-4} mSv). Therefore, the combined dose from Hanford area non-DOE and DOE sources to a member of the public for 1998 was well below any regulatory dose limit.

5.0.6 Hanford Public Radiological Dose in Perspective

This section provides information to put the potential health risks of radionuclide emissions from the Hanford Site into perspective. Several scientific studies (National Research Council 1980, 1990; United Nations Science Committee on the Effects of Atomic Radiation 1988) have been performed to estimate the possible risk of detrimental health effects from exposure to low levels of radiation. These studies have provided vital information to government and scientific organizations that recommend radiological dose limits and standards for public and occupational safety.

Although no increase in the incidence of health effects from low doses of radiation has actually been confirmed by the scientific community, some scientists accept the hypothesis that low-level doses might increase the probability of cancer or other health effects. Regulatory agencies conservatively (cautiously) assume that the probability of these types of health effects at low doses (down to zero dose) is the same per unit dose as the same health effects observed at much higher doses (e.g., in atomic bomb victims, radium dial painters). This is also known as the linear no threshold hypothesis. Under these assumptions, even natural background radiation (which is hundreds of times greater than radiation from current Hanford releases) increases each person's probability or chance of developing a detrimental health effect.

Not all scientists agree on how to translate the available data on health effects into the numerical probability (risk) of detrimental effects from low-level radiological doses. Some scientific studies have indicated that low radiological doses may cause beneficial effects (Sagan 1987). Because cancer and hereditary diseases in the general population may be caused by many sources (e.g., genetic defects, sunlight, chemicals, background radiation), some scientists doubt that the risk from low-level radiation exposure can ever be conclusively proved. In developing Clean Air Act regulations, the EPA uses a probability value of approximately 4 per 10 million (4×10^{-7}) for the risk of developing a fatal cancer after receiving a dose of 1 mrem (0.01 mSv) (EPA 520/1-89-005). Additional data (National Research Council 1990) support the reduction of even this

small risk value, possibly to zero, for certain types of radiation when the dose is spread over an extended time.

Government agencies are trying to determine what level of risk is safe for members of the public exposed to pollutants from industrial activities (e.g., DOE facilities, nuclear power plants, chemical plants, hazardous waste sites). All of these industrial activities are considered beneficial to people in some way such as providing electricity, national defense, waste disposal, and consumer products. These government agencies have a complex task in establishing environmental regulations that control levels of risk to the public without unnecessarily reducing needed benefits from industry.

One perspective on risks from industrial activities is to compare them to risks involved in other typical activities. For instance, two risks that an individual receives from flying on an airliner are the risks of added radiological dose (from a stronger cosmic radiation field that exists at higher altitudes) and the possibility of being in an aircraft accident. Table 5.0.4 compares the estimated risks from various radiological doses to the risks of some activities encountered in everyday life. Table 5.0.5 lists some activities considered approximately equal in risk to that from the dose received by the maximally exposed individual from monitored Hanford effluents in 1998.

Table 5.0.4. Estimated Risk from Various Activities and Exposures[a]

Activity or Exposure Per Year	Risk of Fatality
Smoking 1 pack of cigarettes per day (lung/heart/other diseases)	$3{,}600 \times 10^{-6}$
Home accidents	100×10^{-6}[b]
Taking contraceptive pills (side effects)	20×10^{-6}
Drinking 1 can of beer or 0.12 L (4 oz) of wine per day (liver cancer/cirrhosis)	10×10^{-6}
Firearms, sporting (accidents)	10×10^{-6}[b]
Flying as an airline passenger (cross-country roundtrip--accidents)	8×10^{-6}[b]
Eating approximately 54 g (4 tbsp) of peanut butter per day (liver cancer)	8×10^{-6}
Pleasure boating (accidents)	6×10^{-6}[b]
Drinking chlorinated tap water (trace chloroform--cancer)	3×10^{-6}
Riding or driving in a passenger vehicle (483 km [300 mi])	2×10^{-6}[b]
Eating 41 kg (90 lb) of charcoal-broiled steaks (gastrointestinal tract cancer)	1×10^{-6}
Natural background radiation dose (300 mrem, 3 mSv)	0 to 120×10^{-6}
Flying as an airline passenger (cross-country roundtrip--radiation)	0 to 5×10^{-6}
Dose of 1 mrem (0.01 mSv) for 70 yr	0 to 0.4×10^{-6}
Dose to the maximally exposed individual living near Hanford in 1998 (0.02 mrem, 2×10^{-4} mSv)	0 to 0.008×10^{-6}

(a) These values are generally accepted approximations with varying levels of uncertainty; there can be significant variation as a result of differences in individual lifestyle and biological factors (Atallah 1980; Dinman 1980; Ames et al. 1987; Wilson and Crouch 1987; Travis and Hester 1990).

(b) Real actuarial values. Other values are predicted from statistical models. For radiation dose, the values are reported in a possible range from the least conservative (0) to the currently accepted most conservative value.

Table 5.0.5. Activities Comparable in Risk to the 0.02-mrem (2×10^{-4} mSv) Dose Calculated for the 1998 Maximally Exposed Individual

Driving or riding in a car 1.1 km (approximately 0.66 mi)
Smoking less than 1/100 of a cigarette
Flying 2.7 km (1.7 mi) on a commercial airliner
Eating approximately 4/5 tbsp of peanut butter
Eating one 0.18-kg (0.4-lb) charcoal-broiled steak
Drinking approximately 1 L (1.1 qt) of chlorinated tap water
Being exposed to natural background radiation for approximately 19 min in a typical terrestrial location
Drinking approximately 0.056 L (<2 oz) of beer or 0.02 L (0.6 oz) of wine

5.0.7 Dose Rates to Animals

Conservative (upper) estimates have been made of the radiological dose to native aquatic organisms in accordance with the DOE Order 5400.5 interim requirement for management and control of liquid discharges. Possible radiological dose rates during 1998 were calculated for several exposure modes, including exposure to radionuclides in water entering the Columbia River from springs near the 100-N Area and internally deposited radionuclides measured in animals collected from the river and on the site.

The animal receiving the highest potential dose from N Springs water was a duck that consumes aquatic plants. The water flow of the N Springs is very low; no aquatic animal was observed to live directly in this spring water. Exposure to the radionuclides from the springs cannot occur until the spring water has been noticeably diluted in the Columbia River. The assumption was made that a few aquatic animals might be exposed to the maximum radionuclide activities measured in the spring water (see Table 4.2.4) after a 10-to-1 dilution by the river. Radiological doses were calculated for several different types of aquatic and riparian animals, using these extremely conservative assumptions and the CRITRII computer code (PNL-8150). If a duck spent 100% of its time in the one-tenth-diluted spring water and consumed only plants growing there, it would receive a dose rate of 0.11 mrad/d. This hypothetical dose rate is 0.011% of the limit of 1 rad/d for native aquatic animal organisms established by DOE Order 5400.5. The intent of the DOE Order 5400.5 native aquatic animal organism dose limit is to protect the population of a species, not necessarily individual organisms. It is not possible for a population of ducks to live in this spring for an entire year.

Doses also were estimated using the CRITRII code (PNL-8150) for aquatic and riparian organisms based on measured radionuclide activities in river water. The highest potential dose rate from all the radionuclides reaching the Columbia River from Hanford sources during 1998 was 6×10^{-6} rad/d for a hypothetical muskrat and a hypothetical duck, both of which consume contaminated vegetation. The radiological dose rate to individual animals collected on the site or from the Columbia River was calculated using the maximum activities of radionuclides measured in muscle. These doses ranged from 1×10^{-6} rad/d for a deer to 1×10^{-3} rad/d for a pheasant. Neither the doses calculated based on river water activities nor the doses based on actual biota activities approach the dose limit set forth in DOE Order 5400.5.

5.0.8 References

40 CFR 61. U.S. Environmental Protection Agency. "National Emission Standards for Hazardous Air Pollutants." *Code of Federal Regulations.*

40 CFR 61, Subpart H. U.S. Environmental Protection Agency. "National Emissions Standards for Emissions of Radionuclides Other Than Radon From Department of Energy Facilities." *Code of Federal Regulations.*

Ames, B. N., R. Magaw, and L. S. Gold. 1987. "Ranking Possible Carcinogenic Hazards." *Science* 236:271-280.

Atallah, S. 1980. "Assessing and Managing Industrial Risk." *Chemical Engineering* 9/8/80:94-103.

Clean Air Act. 1986. Public Law 88-206, as amended, 42 USC 7401 et seq.

Dinman, B. D. 1980. "The Reality and Acceptance of Risk." *Journal of the American Medical Association (JAMA)* (11):1226-1228.

DOE Order 5400.5. "Radiation Protection of the Public and the Environment."

DOE/RL-99-41. 1999. *Radionuclide Air Emissions Report for the Hanford Site, Calendar Year 1998.* B. P. Gleckler and K. Rhoads, Waste Management Federal Services of Hanford, Inc. for U.S. Department of Energy, Richland Operations Office, Richland, Washington.

EPA-402-B-92-001. 1992. *User's Guide for CAP88-PC, Version 1.0.* B. S. Parks, U.S. Environmental Protection Agency, Office of Radiation Programs, Las Vegas, Nevada.

EPA 520/1-89-005. 1989. *Risk Assessment Methodology: Draft Environmental Impact Statement for Proposed NESHAPS for Radionuclides, Vol. 1, Background Information Document.* U.S. Environmental Protection Agency, Washington, D.C.

EPS-87-367A. 1988. *Environmental Radiation Program, 26th Annual Report, January Through December 1987.* Washington State Department of Health, Olympia, Washington.

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

National Research Council. 1980. *The Effects on Populations of Exposure to Low Levels of Ionizing Radiation: 1980.* Committee on the Biological Effects of Ionizing Radiations, National Academy Press, Washington, D.C.

National Research Council. 1990. *Health Effects of Exposure to Low Levels of Ionizing Radiation.* Committee on the Biological Effects of Ionizing Radiations, National Academy Press, Washington, D.C.

PNL-6584. 1988. *GENII - The Hanford Environmental Radiation Dosimetry Software System.* B. A. Napier, R. A. Peloquin, D. L. Strenge, and J. V. Ramsdell, Pacific Northwest Laboratory, Richland, Washington, 3 vols.

PNL-7539. 1990. *Methodology Used to Compute Maximum Potential Doses from Ingestion of Edible Plants and Wildlife Found on the Hanford Site.* J. K. Soldat, K. R. Price, and W. H. Rickard, Pacific Northwest Laboratory, Richland, Washington.

PNL-7803. 1991. *Hanford Area 1990 Population and 50-Year Projections.* D. M. Beck, B. A. Napier, M. J. Scott, A. G. Thurman, M. D. Davis, D. B. Pittenger, S. F. Shindle, and N. C. Batishko, Pacific Northwest Laboratory, Richland, Washington.

PNL-8150. 1992. *Methods for Estimating Doses to Organisms from Radioactive Materials Released into the Aquatic Environment.* D. A. Baker and J. K. Soldat, Pacific Northwest Laboratory, Richland, Washington.

PNNL-11472. 1997. *Hanford Site Environmental Report for Calendar Year 1996*. R. L. Dirkes and R. W. Hanf (eds.), Pacific Northwest National Laboratory, Richland, Washington.

PNNL-12088, APP. 1. 1999. *Hanford Site Environmental Surveillance Data Report for Calendar Year 1998*. L. E. Bisping, Pacific Northwest National Laboratory, Richland, Washington.

Sagan, L. A. 1987. *Health Physics Society Official Journal: Special Issue on Radiation Hormesis* 52(5).

Travis, C. C., and S. T. Hester. 1990. "Background Exposure to Chemicals: What Is the Risk?" *Risk Analysis* 10(4).

United Nations Science Committee on the Effects of Atomic Radiation. 1988. *Sources, Effects and Risks of Ionizing Radiation*. Report E.88.1X.7, United Nations, New York.

Washington Administrative Code (WAC) 246-247. "Radiation Protection—Air Emissions." Olympia, Washington.

Wilson, R., and E.S.C. Crouch. 1987. "Risk Assessment and Comparisons: An Introduction." *Science* 236 (4799):267-270.

6.0 Groundwater and Vadose Zone Monitoring

6.0.1 Groundwater Monitoring

The Hanford Groundwater Monitoring Project includes sitewide groundwater monitoring mandated by U.S. Department of Energy (DOE) Orders and near-field groundwater monitoring conducted to ensure that operations in and around specific waste disposal facilities are in compliance with applicable regulations.

Collection and analysis of groundwater samples to determine the distributions of radiological and chemical constituents were major parts of the groundwater monitoring effort. In addition, hydrogeologic characterization and modeling of the groundwater flow system were used to assess the monitoring network and to evaluate potential impacts of Hanford Site groundwater contamination. Other activities are data management, interpretation, and reporting. The purpose of this section is to provide an overall summary of groundwater monitoring during 1998. Additional details concerning the Hanford Groundwater Monitoring Project are available in PNNL-12086.

6.0.1.1 Monitoring Objectives

Groundwater monitoring was conducted for the following:

- assess the impact of radiological and hazardous chemicals on groundwater as a result of Hanford Site operations
- provide an integrated assessment of groundwater quality on the Hanford Site
- evaluate potential offsite impacts from the groundwater pathway
- verify compliance with applicable environmental laws and regulations
- evaluate effectiveness of groundwater remediation activities
- identify new or existing groundwater quality problems.

Sitewide groundwater monitoring activities are designed to meet the project objectives stated in DOE Order 5400.1 and described above. The impacts of Hanford Site operations on groundwater have been monitored for >50 yr under this project and its predecessors. Near-field monitoring of groundwater around specific waste facilities was performed to meet the requirements of the Resource Conservation and Recovery Act of 1976 (RCRA) of Title 40, Code of Federal Regulations, Part 265 (40 CFR 265) and Washington Administrative Codes (WACs) 173-303 and 173-304 as well as applicable DOE Orders (e.g., 5400.1, 5400.5). Groundwater monitoring was also performed in conjunction with cleanup investigations under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) (40 CFR 300).

6.0.1.2 Monitoring Design

Groundwater monitoring was designed to satisfy regulatory requirements using various criteria. Specific chemicals and radionuclides analyzed at each monitoring well and their sampling frequencies were selected based on past waste disposal activities (PNL-6456, WHC-EP-0527-2) and on previous analytical results. Also considered was information on the location of potential contaminant sources and hydrogeology, including groundwater flow directions. Selections involved determining those chemicals and radionuclides important in assessing health risk and for understanding contaminant distribution and movement.

Groundwater surveillance was conducted using established quality assurance plans (see Section 8.0, "Quality Assurance") and written procedures (ES-SSPM-001). Computerized data management systems are used to schedule sampling activities; generate sample labels and chain-of-custody forms; track sample status; and load, store, and report data. The Hanford Environmental Information System is the central, consolidated database for storing and managing the results of groundwater monitoring.

Groundwater samples were collected from both the unconfined and upper confined aquifers. The unconfined aquifer was monitored extensively because it contains contaminants from Hanford Site operations (PNNL-12086) and provides a potential pathway for contaminants to reach points of human exposure (e.g., water supply wells, Columbia River). The upper confined aquifer was monitored, though less extensively than the unconfined aquifer, because it also provides a potential pathway for contaminants to migrate off the site. Also, some sampling was conducted at the request of the Washington State Department of Health.

Contaminant source areas were monitored to characterize and define trends in the condition of the groundwater and to identify and quantify existing, emerging, or potential problems in groundwater quality. Source areas included active waste disposal facilities or facilities that had generated or received wastes in the past. Most of these facilities are located within the 100, 200, and 300 Areas. However, some sources such as the Solid Waste Landfill are located outside the operational areas.

Wells located within known contaminant plumes were monitored to characterize and define trends in the concentrations of the associated radiological or chemical constituents. These wells were also monitored to quantify existing groundwater quality problems and to provide a baseline of environmental conditions against which future changes can be assessed. Even though releases of liquid waste to all but a few permitted disposal facilities have ceased, these wells will continue to be monitored as cleanup of the Hanford Site continues. This will provide a continuing assessment of the effect of remediation efforts on groundwater.

Water supplies on and near the Hanford Site potentially provide the most direct route for human exposure to contaminants in groundwater. In 1998, three of the site's 12 drinking water systems provided groundwater for human consumption on the site. One system supplied water at the Fast Flux Test Facility, one supplied water to personnel at the Yakima Barricade guardhouse, and one was located at the Hanford Patrol Training Academy (see Section 4.3, "Hanford Site Drinking Water Surveillance"). Water supply wells used by the city of Richland are located near the site's southern boundary. Monitoring wells near these water systems were routinely sampled to ensure that any potential water quality problems would be identified long before regulatory limits were reached.

To assess the impact of Hanford Site operations on groundwater quality, background conditions, or the quality of groundwater on the site unaffected by operations, must be known. Data on the concentration of contaminants of concern in groundwater that existed before site operations began are not available. Therefore, concentrations of naturally occurring chemical and radiological constituents in groundwater sampled from wells located in areas unaffected by site operations, including upgradient locations, provide the best estimate of pre-Hanford groundwater quality. A summary of background conditions is tabulated in PNL-6886 and PNL-7120.

Groundwater samples are collected at various frequencies, depending on the historical trends of constituent data, regulatory or compliance requirements, and characterization needs. Sampling frequencies range from monthly to every 3 yr.

Summary results for 1998 are discussed in Section 6.1, "Hanford Groundwater Monitoring Project."

6.0.2 Vadose Zone Monitoring

The vadose zone is defined as the area between the ground surface and the water table. This subsurface zone is also referred to as the unsaturated zone, zone of suspended water, or zone of aeration. The vadose zone functions as a transport pathway or storage area for water and other materials located between the soil surface and the groundwater aquifers. Historically, the vadose zone at the Hanford Site has been contaminated with large amounts of radioactive and nonradioactive materials through the intentional and unintentional discharge of liquid wastes to the soil column, the burial of contaminated solid wastes, and the deposition of airborne contaminants to the ground. Depending on the makeup of the soil, the geology of the area, the nature of the wastes, the amount of water or other fluids available to mobilize the contaminant, and other factors, contaminants can move downward and laterally through the soil column, can be chemically bound to soil particles (and immobilized), or can be contained by geologic formations.

Because of concerns of the impact of some vadose zone contaminants on the groundwater beneath the Hanford Site and the potential for contaminated groundwater to reach the Columbia River, characterization efforts are under way to learn more about the nature and extent of vadose zone contamination. At Hanford, the primary method for investigating radiological contamination in the vadose zone consists of borehole logging (monitoring radiation levels in narrow shafts bored or drilled into the soil column). Borehole logging is being conducted in existing boreholes located in and around the 200 Areas single-shell tank farms and beneath former waste disposal facilities also in or near the 200 Areas. Additionally, soil-vapor extraction and monitoring are being conducted as part of an expedited response action in the 200-West Area to remove carbon tetrachloride from the vadose zone.

Results for the 1998 vadose zone monitoring program are discussed in Section 6.2, "Vadose Zone Characterization and Monitoring." Section 6.2 has been divided into vadose zone characterization activities in the 200 Areas tank farms and the vadose zone monitoring beneath former 200 Areas waste disposal facilities and carbon tetrachloride remediation work in the 200-West Area.

6.1 Hanford Groundwater Monitoring Project

D. R. Newcomer and M. J. Hartman

The strategy for managing and protecting groundwater resources at the Hanford Site was recently presented in DOE/RL-98-48, Draft C and DOE/RL-98-56. The strategy focuses on protection of the Columbia River, protection of human health and the environment, treatment of groundwater contamination, and limitation of contaminant migration from the 200 Areas. Implementation of the strategy includes continued monitoring of groundwater quality through the Hanford Groundwater Monitoring Project. The project is designed to detect new contaminant plumes and to document the distribution and movement of existing groundwater contamination. Monitoring provides the historical baseline for evaluating current and future risk from exposure to groundwater contamination and for deciding on remedial options. Hydrogeologic studies are an integral part of the project because the geology and hydrology of the site control the movement of contaminants in groundwater.

The effort to protect groundwater quality at the Hanford Site is being implemented through programs to minimize wastes being discharged to the soil column and through site remediation activities. The Hanford Federal Facility Agreement and Consent Order (also known as the Tri-Party Agreement; Ecology et al. 1989) provides a framework for remediation of the Hanford Site, including groundwater, over a 40-yr period. A summary of accomplishments in waste minimization and site remediation is presented in Section 2.3, "Activities, Accomplishments, and Issues."

DOE prepared a *Plan and Schedule to Discontinue Disposal of Liquids Into the Soil Column at the Hanford Site* (DOE 1987), which includes an alternative for treatment and disposal of contaminated effluents discharged to the soil. Of the 33 major waste streams identified in DOE (1987), the Phase I (higher-priority) streams have either been eliminated or are being treated and diverted to the 200 Areas Treated Effluent Disposal Facility. In addition, process condensate from the 242-A Evaporator is treated at the 200 Areas Effluent Treatment Facility and then discharged to the 616-A Crib (also known as the State-Approved Land Disposal Site) north of the 200-West Area. The State-Approved Land Disposal Site is the only facility at Hanford that received radionuclide-bearing liquid effluent discharged to the soil column in 1998. The locations of active permitted facilities are shown in Figures 1.0.2 and 6.1.1 and are discussed in detail in Section 2.3, "Activities, Accomplishments, and Issues." All other facilities (e.g., cribs, trenches) that historically discharged liquid waste to the soil column are out of service. The only operational injection wells are associated with pump-and-treat remediation systems. Disposal of liquids to soil has been significantly reduced during the last several years. For example, in 1987, >23 billion L (6 billion gal) of liquid effluents were discharged to the soil. This was reduced to approximately 4.9 billion L (1.3 billion gal) in 1995 and <0.9 billion L (<240 million gal) in 1998. In 1998, approximately 10% of the liquid volume was discharged to the State-Approved Land Disposal Site and approximately 90% was discharged to the 200 Areas Treated Effluent Disposal Facility.

Groundwater is used for drinking water and other purposes at a few locations on the Hanford Site. DE&S Hanford, Inc., DynCorp Tri-Cities Services, Inc., and Pacific Northwest National Laboratory monitor drinking water supplies at the point of use or

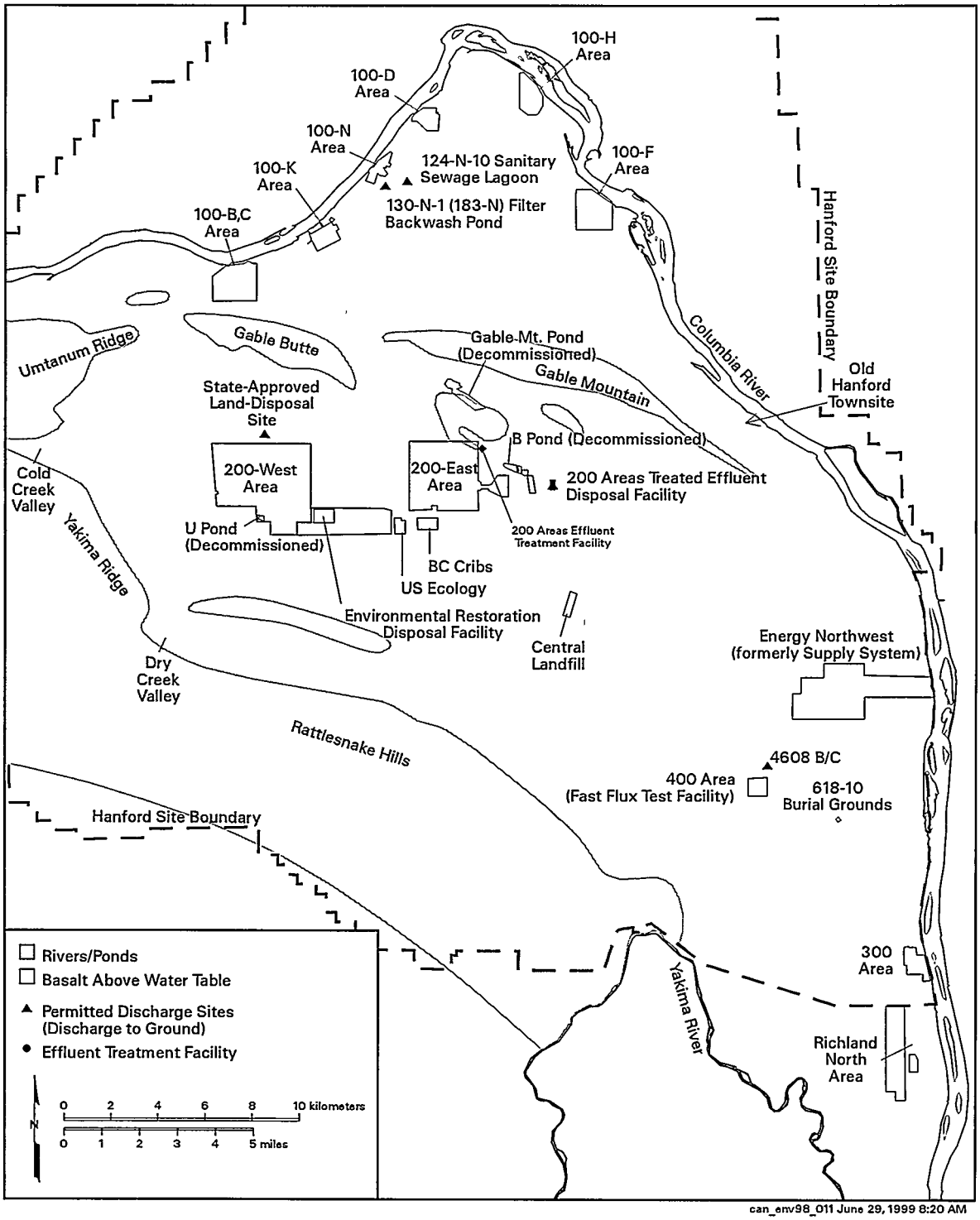


Figure 6.1.1. Active Liquid Wastewater Discharge Sites at Hanford

at the source. DynCorp Tri-Cities Services, Inc. monitors for nonradiological constituents and DE&S Hanford, Inc. and Pacific Northwest National Laboratory monitor for radiological constituents. Results of the radiological monitoring are summarized in Section 4.3, "Hanford Site Drinking Water Surveillance." The locations of wells completed in the unconfined aquifer that provide water for drinking, fire suppression, and cooling are shown in Figure 6.1.2.

6.1.1 Geologic Setting

The Hanford Site lies within the Pasco Basin, one of several structural basins within the Columbia Plateau. Principal geologic units beneath the Hanford Site include, in ascending order, the Columbia River Basalt Group, the Ringold Formation, and the Hanford formation (informal name) (Figure 6.1.3).

The Columbia River basalts were formed from lava that periodically erupted from volcanic fissures. The regional river system eroded the basalt and deposited sediments across the basalt surfaces between eruptions. Zones between the basalt flows and the sediments deposited as interbeds between basalt eruptions are frequently water bearing zones that are used as water sources in areas around the Hanford Site.

During the period of basalt deposition, tectonic pressure was very slowly deforming the basalt flows into the generally east-west trending ridges that border the Pasco Basin today. After the last major basalt eruption, sand and gravel of the Ringold Formation were deposited in the central portion of the Pasco Basin by the ancestral Columbia River as it meandered back and forth across the relatively flat basalt surface. Following uplift of the basalts and overlying sediments, the Columbia River began to erode, rather than deposit, sediments in the Pasco Basin. The uppermost mud layer was eroded from much of the Pasco Basin, and a caliche layer, part of the Plio-Pleistocene unit, developed in places on the eroded surface of the Ringold Formation.

More recently, the Hanford formation sediments were deposited by catastrophic ice age floods. Fine sands and silts were deposited in slackwater areas at the margins of the basin. However, primarily sand and gravel were deposited on the Hanford Site. In places, these sediments are covered by up to a few meters (feet) of recent stream or windblown deposits.

More-detailed information on the geology of the Pasco Basin can be found in BHI-00184, DOE/RW-0164 (Vol. 1), PNNL-12086 (Section 3.1), WHC-MR-0391, WHC-SD-EN-TI-014, and WHC-SD-EN-TI-019.

6.1.2 Groundwater Hydrology

Both confined and unconfined aquifers are present beneath the Hanford Site. An aquifer is a water-saturated geologic interval or unit that has a high permeability, meaning it can transmit significant quantities of water. A confined aquifer is bounded above and below by low-permeability materials that restrict the vertical movement of water. The confining layers may be dense rock, such as the central parts of basalt flows, silt, clay, or well-cemented sediments. Areally extensive, confined aquifers at the site are found primarily within interflows and interbeds of the Columbia River basalts. These are referred to as basalt-confined aquifers. Locally confined aquifers are also found below the clays and silts of the Ringold Formation.

An unconfined aquifer, or water-table aquifer, is overlain by unsaturated sediments. The upper surface of the saturated zone in an unconfined aquifer,

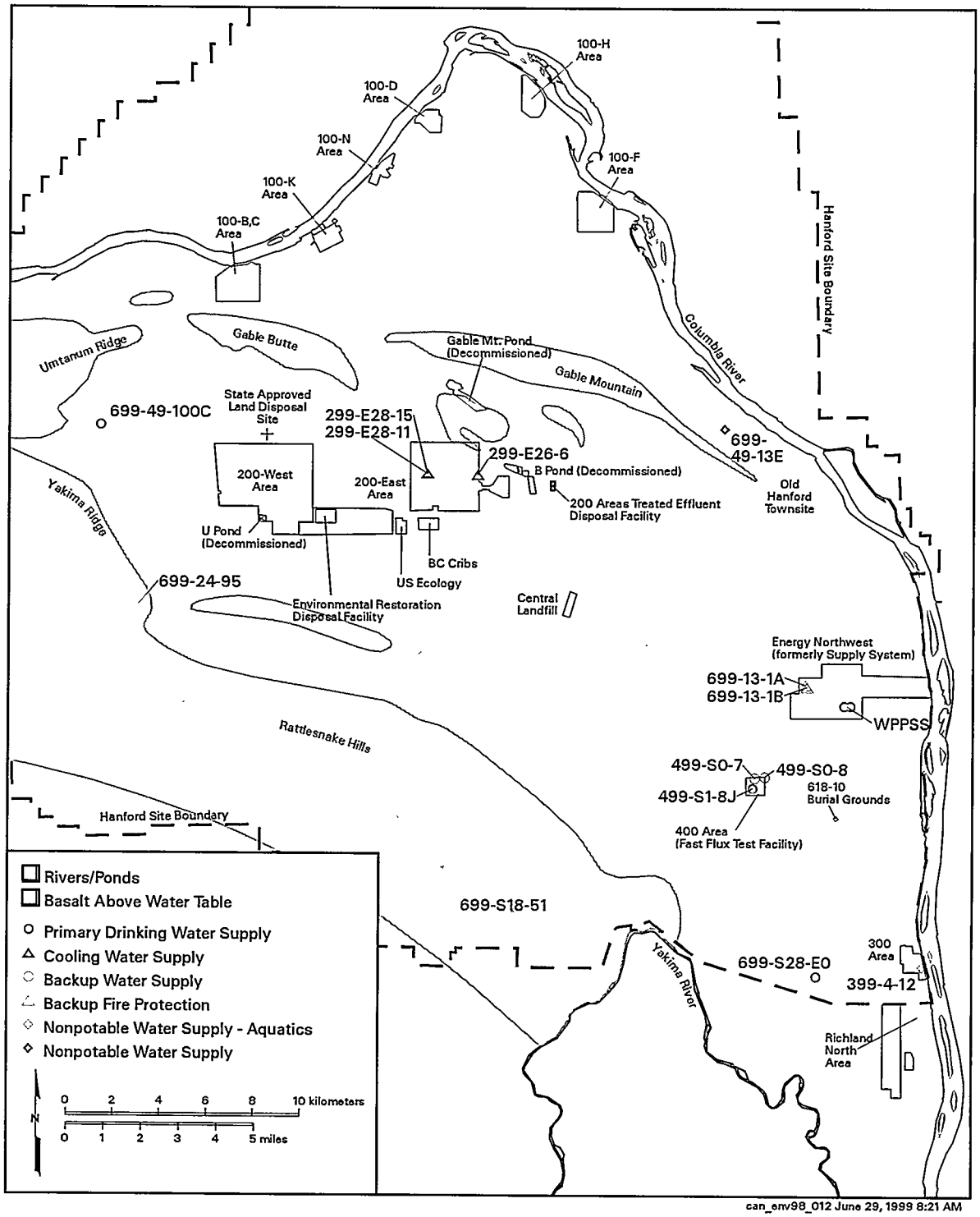


Figure 6.1.2. Water Supply Wells in the Unconfined Aquifer

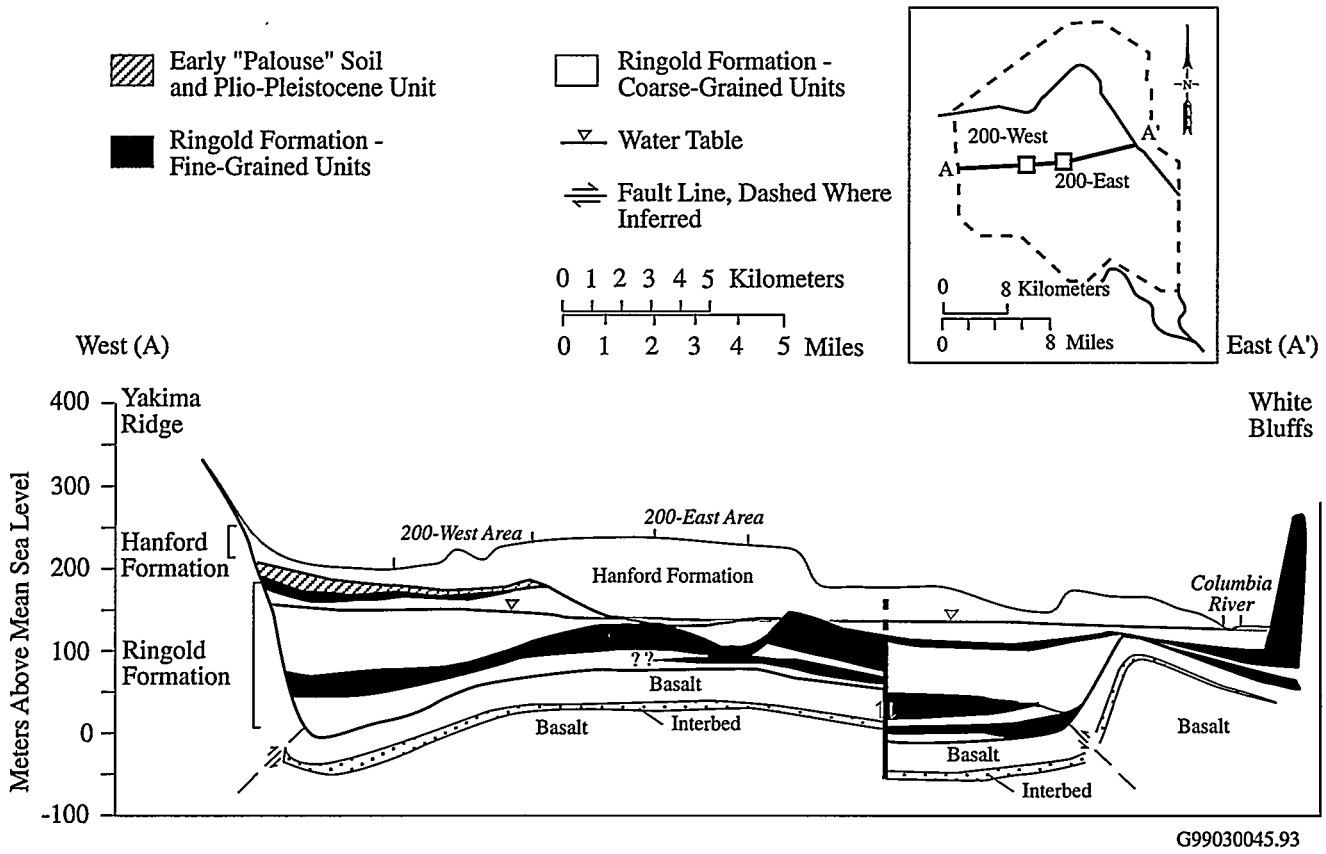


Figure 6.1.3. Geologic Cross Section of the Hanford Site

which is called the water table, rises and falls in response to changes in the volume of water stored in the aquifer. In general, the unconfined aquifer at the Hanford Site is located in the Hanford and Ringold Formations. In some areas, the water table is below the bottom of the Hanford formation and the unconfined aquifer is entirely within the Ringold Formation. The Hanford formation sands and gravels are unconsolidated and are generally much more permeable than the compacted and silty Ringold Formation gravels. Clay and silt units and zones of natural cementation form low-permeability zones within the Ringold Formation.

The unconfined aquifer forms the uppermost groundwater zone and has been directly impacted by wastewater disposal at the Hanford Site. The unconfined aquifer discharges primarily into the Columbia River and is the most thoroughly monitored aquifer beneath the site. The Rattlesnake Ridge interbed is the uppermost, basalt-confined aquifer within the Pasco Basin and the Hanford Site. This aquifer and other confined aquifers are generally isolated from the unconfined aquifer by dense rock that forms the interior of the basalt flows. However, interflow between the unconfined aquifer and the basalt-confined aquifer system is known to occur at faults that bring a water bearing interbed in contact with other sediments or where the overlying basalt has been eroded to reveal an interbed (Newcomb et al. 1972, RHO-RE-ST-12 P, WHC-MR-0391). Additional information on the basalt-confined aquifer system can be found in PNL-10158 and PNL-10817.

The thickness of saturated sediments above the basalt bedrock is >200 m (656 ft) in some areas of the

Hanford Site and thins out along the flanks of the uplifted basalt ridges (Figures 6.1.3 and 6.1.4). Depth from the ground surface to the water table ranges from <0.3 m (1 ft) near the Columbia River to >106 m (348 ft) in the center of the site. The unconfined aquifer is bounded below by either the basalt surface or, in places, by relatively impervious clays and silts within the Ringold Formation. The water table defines the upper boundary of the unconfined aquifer. Laterally, the unconfined aquifer is bounded by basalt ridges and by the Yakima and Columbia Rivers. The basalt ridges have a low permeability and act as a barrier to the lateral flow of groundwater where they rise above the water table (RHO-BWI-ST-5, p. II-116).

The water-table elevation contours shown in Figure 6.1.5 indicate the direction of groundwater flow and the magnitude of the hydraulic gradient in the unconfined aquifer. Groundwater flow is generally perpendicular to the water-table contours from areas of higher elevation, or head, to areas of lower head. Areas where the contours are closer together are high-gradient areas, where the "driving force" for groundwater flow is greater. However, because sediments with low permeabilities inhibit groundwater flow, producing steeper gradients, a high gradient does not necessarily mean high groundwater velocity. Lower transmissivity and steeper gradients are often associated with areas where the water table is below the bottom of the Hanford formation and the aquifer is entirely within the less-permeable Ringold sediments. Figure 6.1.6 shows the generalized distribution of transmissivity as determined from aquifer pumping tests and groundwater flow model calibration. Additional information on aquifer hydraulic properties at Hanford is presented in DOE/RW-0164 (Vol. 2) and PNL-8337.

Recharge of water within the unconfined aquifer (RHO-ST-42) comes from several sources. Natural recharge occurs from infiltration of precipitation along the mountain fronts, runoff from intermittent streams such as Cold and Dry Creeks on the western margin of the site, and limited infiltration of precipitation on the site. The Yakima River, where it flows along the southern boundary of the site, also recharges the unconfined aquifer. The Columbia River is the primary discharge area for the unconfined aquifer. However, the Columbia River also recharges the unconfined aquifer for short periods during high-river stage, when river water is transferred into the aquifer along the riverbank. Recharge from infiltration of precipitation is highly variable on the Hanford Site both spatially and temporally. The rate of natural recharge depends primarily on soil texture, vegetation, and climate (Gee et al. 1992, PNL-10285) and ranges from near zero, where fine-grained soils and deep-rooted vegetation are present, to >10 cm/yr (4 in./yr) in areas where soils are coarse textured and bare of vegetation.

Large-scale, artificial recharge to the unconfined aquifer occurred as a result of liquid waste disposal in the operating areas and offsite agricultural irrigation to the west and south. Discharge of wastewater caused the water table to rise over most of the Hanford Site. Local areas with elevated water tables are called groundwater mounds. Figure 6.1.7 shows the change in water-table elevations between 1944 and 1979, when the water table had stabilized over most of the site. Figure 6.1.8 shows the water table decline between 1979 and 1995, when many waste streams were consolidated and wastewater discharge was reduced. The greatest decline in the water table occurred in the 200-West Area and is discussed below. The water table continues to decline over much of the Hanford Site, as illustrated by Figure 6.1.9, which shows the water-level changes between 1997 and 1998.

Two major groundwater mounds formed in the vicinity of the 200-East and 200-West Areas in response to wastewater discharges. The first of these mounds was created by disposal at the 216-U-10 Pond (U Pond) in the 200-West Area. After U Pond was decommissioned in 1984, the mound slowly dissipated and has become much less distinct over

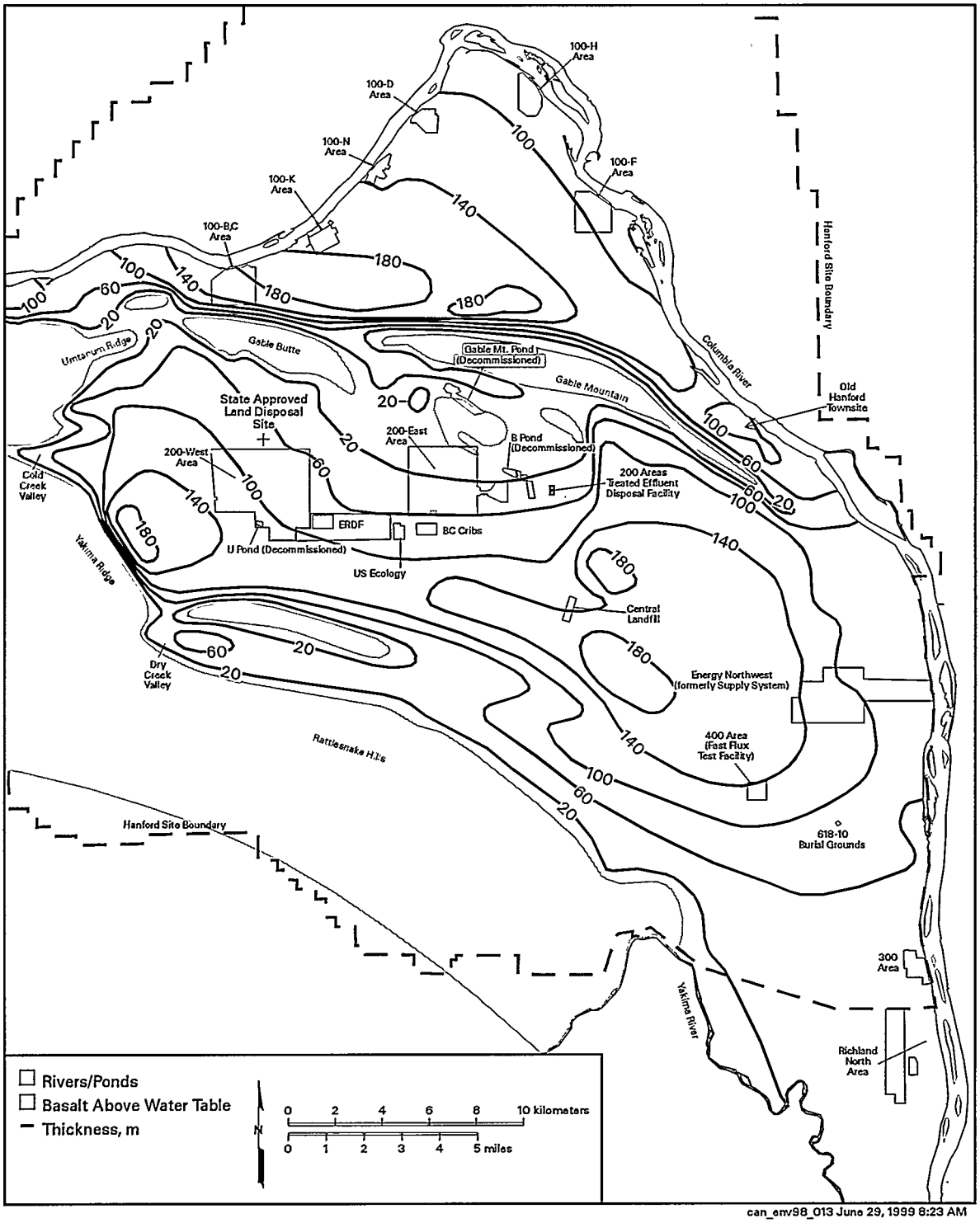


Figure 6.1.4. Saturated Thickness of the Unconfined Aquifer

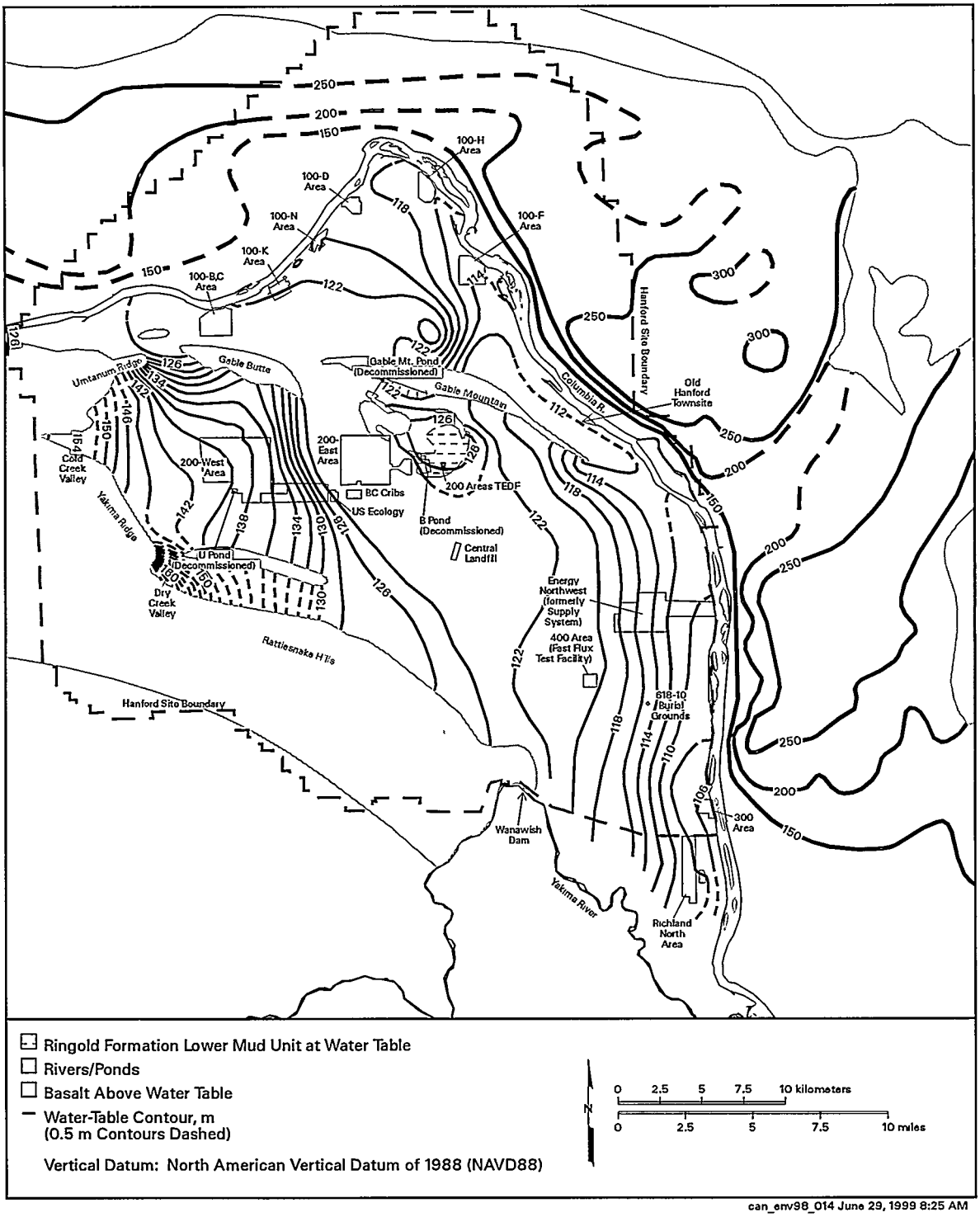


Figure 6.1.5. Water-Table Evaluations for the Unconfined Aquifer at the Hanford Site and in Adjacent Areas East and North of the Columbia River, June 1998

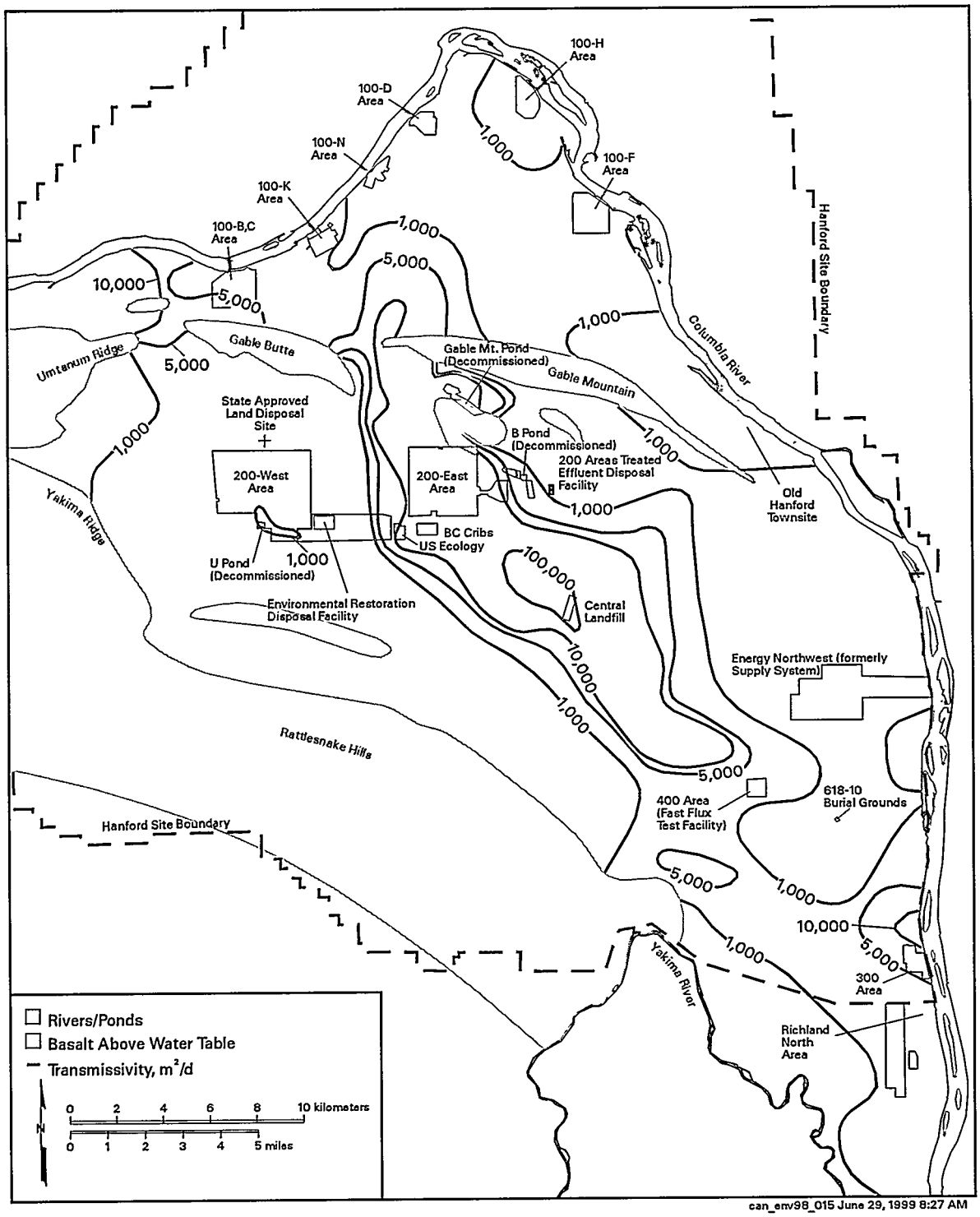


Figure 6.1.6. Transmissivity Distribution in the Unconfined Aquifer

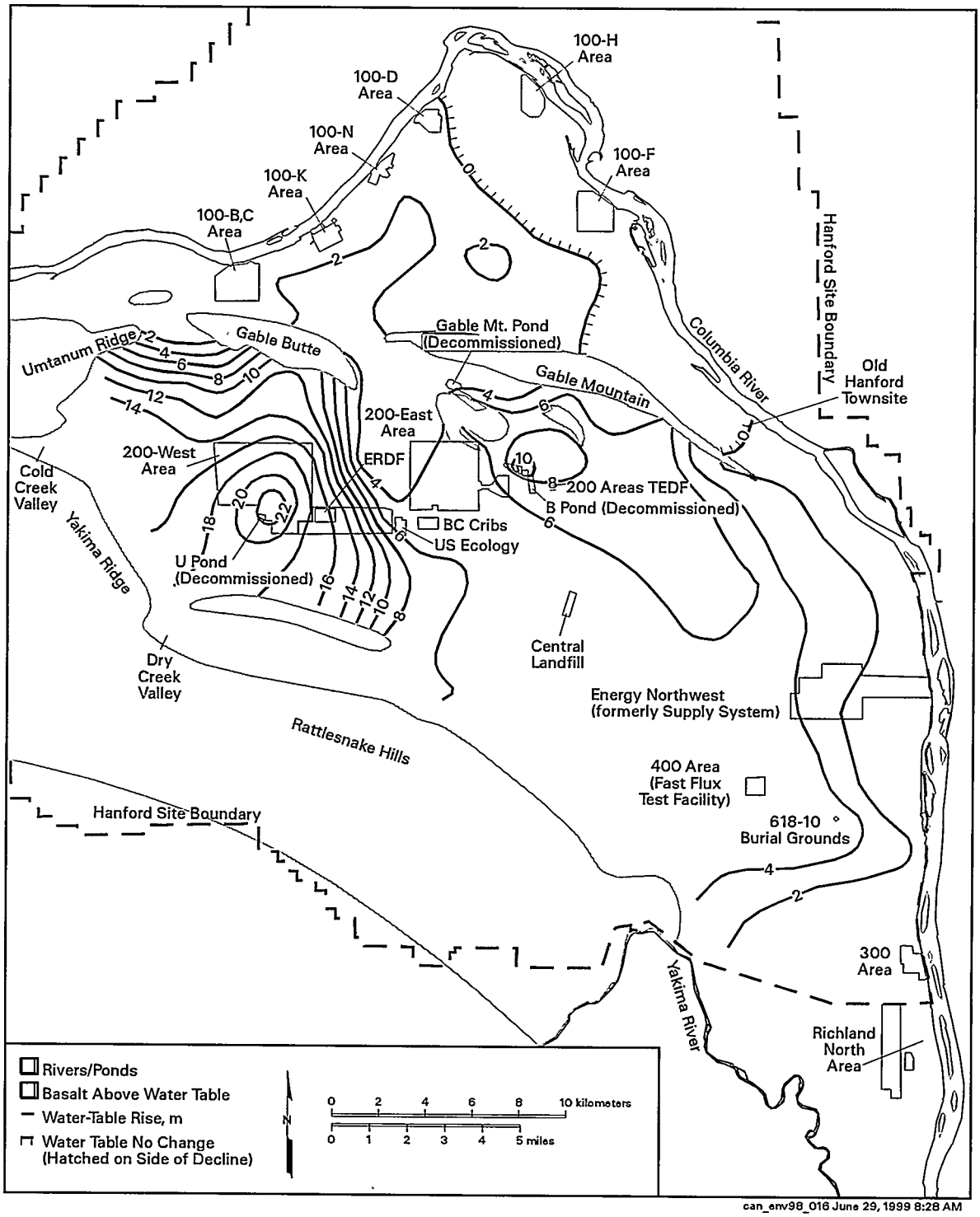


Figure 6.1.7. Change in Water-Table Elevations Between 1949 and 1979

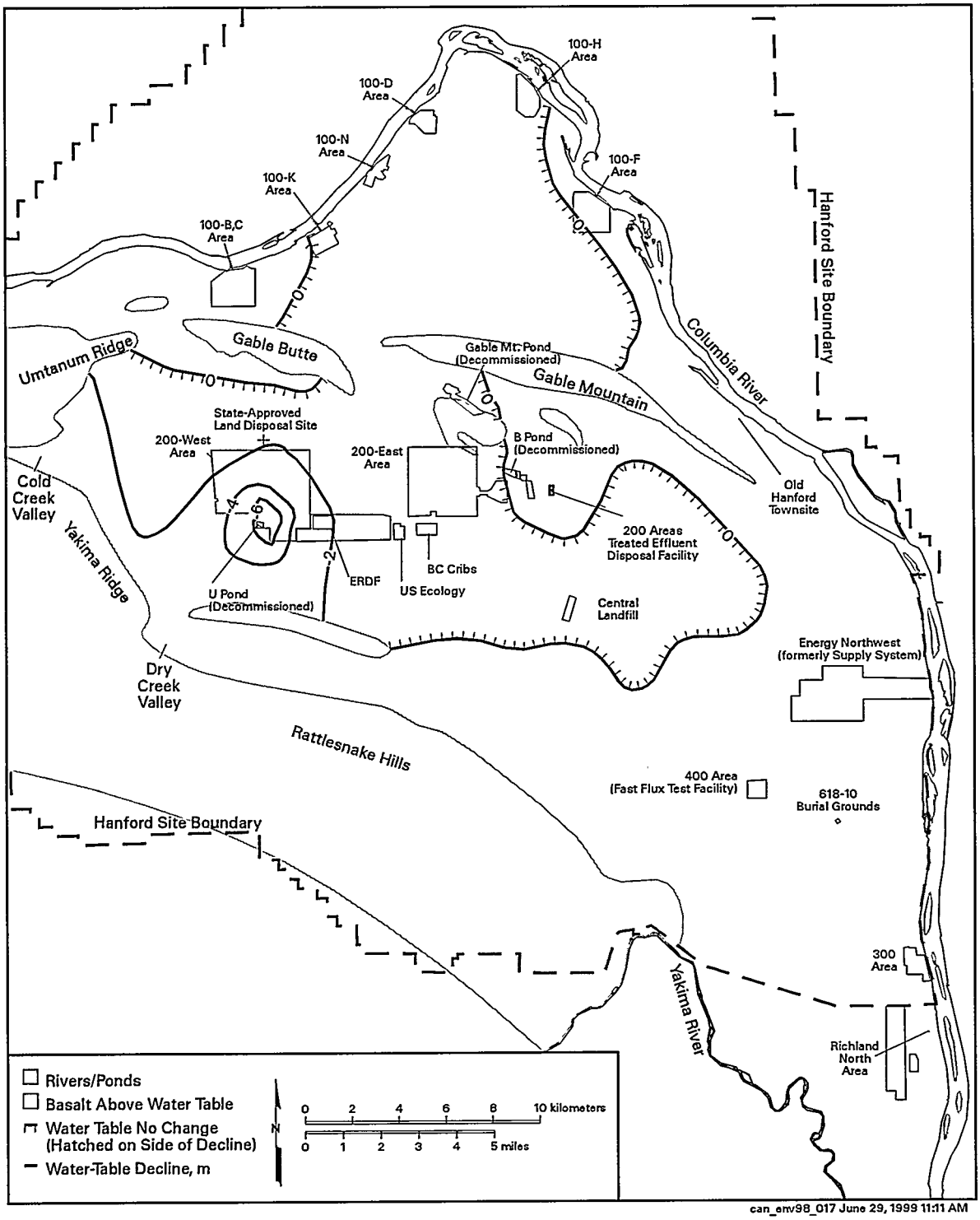


Figure 6.1.8. Change in Water-Table Elevations Between 1979 and 1995

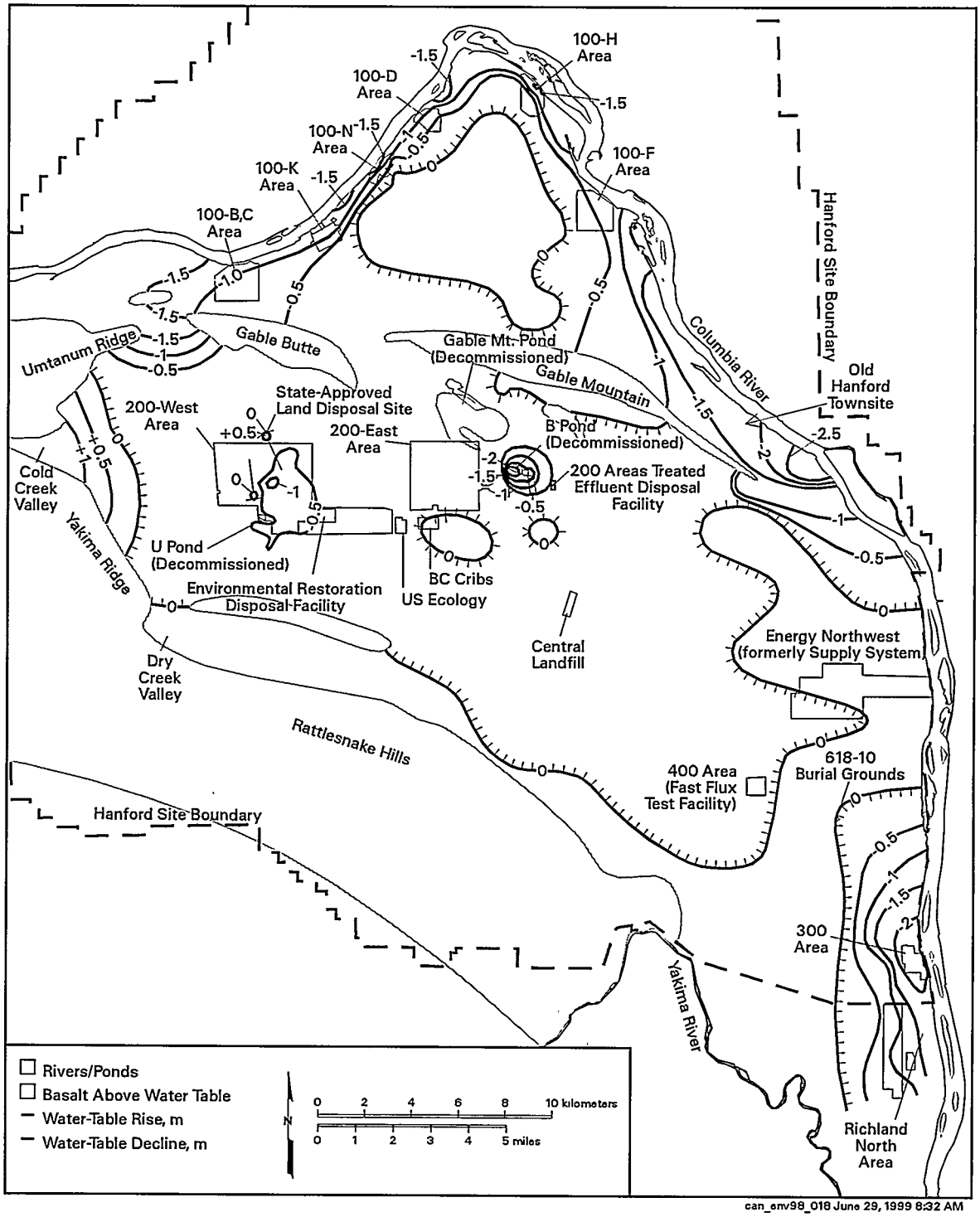


Figure 6.1.9. Change in Water-Table Elevations Between 1997 and 1998

the last several years. The water table continues to decline in this area (see Figure 6.1.9). The second major mound was created by discharge to the decommissioned, or former, 216-B-3 Pond (B Pond), east of the 200-East Area. The water-table elevation near B Pond increased to a maximum before 1990 and then decreased because of reduced discharge. After discharge to B Pond ceased in August 1997, the decline in the water-table elevation accelerated. The recent decline in the water-table elevation at B Pond is illustrated by the contours in Figure 6.1.9. These mounds have altered the unconfined aquifer's natural flow pattern, which is generally from the recharge areas in the west to the discharge areas (primarily the Columbia River) in the east and north. Water levels in the unconfined aquifer have continually changed as a result of variations in the volume and location of wastewater discharge. Consequently, the movement of groundwater and its associated constituents has also changed with time. Groundwater mounding related to wastewater discharges has also occurred in the 100 and 300 Areas; however, groundwater mounding in these areas is not as great as in the 200 Areas primarily because of lower discharge volumes.

In the 100 Areas, 300 Area, and other locations near the Columbia River, groundwater levels are influenced by river stage (PNL-9437). The Columbia River stage returned to normal levels in 1998 after an unusually high-river stage throughout most of 1996 and 1997. This resulted in a lowering of the water table near the river. As a result, water flowed from the aquifer into the river during much of the year.

6.1.3 Contaminant Transport

The history of contaminant releases and the physical and chemical principles of mass transport control the distribution of radionuclides and chemicals in groundwater. Processes that control the movement of these contaminants at the Hanford Site are discussed below.

Most of the groundwater contamination at the Hanford Site resulted from discharge of wastewater from reactor operations, reactor fuel fabrication, and processing of spent reactor fuel. Table 6.1.1 lists the principal contaminants found in each operational area and the type of operation that generated them. In the 100 Areas, discharges included reactor cooling water, fuel storage basin water, filter backwash, and smaller amounts of waste from a variety of other processes. In the 200 Areas, large quantities of wastewater from fuel reprocessing were discharged. Other contamination sources in the 200 Areas included plutonium purification waste and decontamination waste. The plutonium purification process resulted in the discharge of large amounts of liquid organic chemicals in addition to aqueous solutions. This organic liquid, once in contact with groundwater, slowly dissolves and produces contaminant plumes. The presence of nonaqueous liquid has a major impact on the site's groundwater remediation strategy because the organic liquid in the subsurface represents a continuing source of contamination but is very difficult to clean up. Groundwater contamination in the 300 Area resulted mainly from discharge of fuel fabrication wastes.

Liquid effluents discharged to the ground at Hanford Site facilities percolated downward through the unsaturated zone toward the water table. Radionuclide and chemical constituents move through the soil column and, in some cases, enter the groundwater. In some locations, sufficient water was discharged to saturate the soil column to the surface. Not all contaminants move at the same rate as the water in the subsurface. Chemical processes such as adsorption onto soil particles, chemical precipitation, and ion exchange slow the movement of some constituents such as strontium-90, cesium-137, and plutonium-239,240. However, these processes may

Table 6.1.1. Chemical and Radiological Groundwater Contaminants and Their Link to Site Operations

Constituents Generated	Areas	Facilities Type
Tritium, ^{60}Co, ^{90}Sr, Cr^{6}, SO_4^{-2}	100	Reactor operations
Tritium, ^{90}Sr, ^{99}Tc, ^{129}I, ^{137}Cs, Pu, U, CN^-, Cr^{6}, F^-, NO_3^-	200	Irradiated fuel processing
Pu, carbon tetrachloride, chloroform, NO_3^-	200	Plutonium purification
^{99}Tc, U, Cr^{6}, trichloroethylene	300	Fuel fabrication

be affected by the chemical characteristics of the waste such as high ionic strength, acidity, or presence of chemical complexants. Other radionuclides, such as technetium-99, iodine-129, and tritium, and chemicals, such as nitrate, are not as readily retained by the soil and move vertically through the soil column at a rate nearly equal to the infiltrating water. When the contaminants reach the water table, their activities/concentrations are reduced by dilution with groundwater. As these dissolved constituents move with the groundwater, many radionuclides and chemicals adhere to sediment particle surfaces (adsorption) or diffuse into the particles (absorption). Radionuclide activities are reduced by radioactive decay.

Outside the source areas (i.e., liquid disposal sites), there is typically little or no downward gradient (driving force or head), so contamination tends to remain in the upper part of the aquifer. In the source areas, where large volumes of wastewater were discharged, a large vertical hydraulic gradient developed that moved contaminants downward in the aquifer. Layers of low-permeability silt and clay within the unconfined aquifer also limit the vertical movement of contaminants. Flow in the unconfined aquifer is generally toward the Columbia River, which acts as a drainage area for the groundwater flow system at Hanford. Contamination that reaches the river is further diluted by river water.

6.1.4 Groundwater Modeling

Numerical modeling of groundwater flow and contaminant transport is performed to simulate future groundwater-flow conditions and predict the migration of contaminants through the groundwater pathway. During 1998, a model was used to support the composite analysis (PNNL-11800) for low-level waste disposal at the Hanford Site. The objective of the composite analysis was to predict the flow of groundwater and transport of radioactive contaminants during a 1,000-yr compliance period following closure of the Hanford Site in the future. The transport simulation was based on radioactive contaminants that were expected to exist on the site in the year 2050, the assumed closure date, and on predicted future groundwater flow conditions. Simulated contaminants included tritium, carbon-14, chlorine-36, selenium-79, technetium-99, iodine-129, uranium, and other radionuclides from waste sites and the vadose zone. Other models were used in the design and evaluation of pump-and-treat activities aimed at remediation of contaminated groundwater in the 200-West Area. A brief description of these modeling efforts is provided here; additional details and results are presented in PNNL-12086 (Section 6.0) and DOE/RL-99-02.

During the past several years, a three-dimensional flow and transport model has been under

development. The objective of developing a three-dimensional model was to provide more accurate simulations of contaminant transport within the sitewide unconfined aquifer system. The model is based on the Coupled Fluid, Energy, and Solute Transport (CFEST) code (BMI/ONWI-660). The model has since been updated to a new version of the CFEST code called CFEST-96, which was used for the composite analysis. The model includes up to nine layers above the top of basalt to represent the major hydrogeologic units within the unconfined aquifer system.

The water table was predicted to decline significantly and return to near pre-Hanford Site groundwater flow conditions over an approximately 300-yr period following site closure. Wastewater discharges to the ground were assumed to be eliminated before site closure. The areas where the future water table was predicted to be different from pre-Hanford conditions include effects of increased offsite irrigation on the western part of the site and effects from the city of Richland's North Well Field recharge ponds near the southern part of the site.

Predicted distributions of contaminants in the unconfined aquifer during the 1,000-yr compliance period are presented in PNNL-11801.

Groundwater models were also used to assess the performance of groundwater pump-and-treat systems in the 200-UP-1 and 200-ZP-1 Operable Units in the 200-West Area. In these systems, contaminated water is removed by means of extraction wells, treated, and either disposed of to the State-Approved Land Disposal Site (200-UP-1) or returned to the aquifer through injection wells (200-ZP-1) (BHI-01126). The models were used to predict system performance and progress toward remediation goals. The modeling was used to evaluate different extraction and injection well configurations, predict effects of pumping, assess the extent of hydraulic influence and the capture zone, and evaluate groundwater travel times. Modeling was conducted using the Micro-FEM© finite-element code developed by C. J. Hemker, Amsterdam, The Netherlands. Groundwater modeling for the 200-UP-1 plume indicated that the area of high technetium-99 activity and uranium concentration was captured using the one extraction well (299-W19-39) (DOE/RL-99-02). Modeling of the 200-ZP-1 pump-and-treat operation predicts that the high-concentration area of the carbon tetrachloride plume will be captured. As of September 1998, measurable progress was made toward hydraulic containment of the high-concentration areas of the plumes at each of these pump-and-treat operations (DOE/RL-99-02).

6.1.5 Groundwater Monitoring

Groundwater monitoring at the Hanford Site is an integral part of the *Hanford Site Ground-Water Protection Management Plan* (DOE/RL-89-12, Rev. 2). That plan integrates monitoring at active waste disposal facilities to comply with requirements of the RCRA and Washington State regulations, as well as requirements for operational monitoring around reactor and chemical processing facilities and environmental surveillance monitoring. Pacific Northwest National Laboratory manages these monitoring efforts to assess the distribution and movement of existing groundwater contamination, to identify potential and emerging groundwater contamination problems, and to integrate the various groundwater projects to minimize redundancy.

The *Integrated Monitoring Plan for the Hanford Groundwater Monitoring Project* (PNNL-11989) describes how the DOE will implement the groundwater monitoring requirements outlined in DOE (1987) and DOE/RL-89-12, Rev. 2. The purpose of the integrated monitoring plan is to 1) describe the monitoring well networks, constituents, sampling frequencies, and criteria used to design the monitoring

program; 2) identify federal and state groundwater monitoring requirements and regulations; and 3) provide a list of wells, constituents, and sampling frequencies for groundwater monitoring conducted on the Hanford Site. Federal and state regulations include RCRA, CERCLA, and Washington Administrative Codes.

Information on contaminant distribution and transport are integrated into a sitewide evaluation of groundwater quality, which is documented in an annual groundwater monitoring report (e.g., PNNL-12086). Groundwater monitoring is also carried out during CERCLA cleanup investigations. These investigations, managed by Bechtel Hanford, Inc., are documented in annual summary reports (e.g., DOE/RL-99-02).

6.1.5.1 Groundwater Sampling and Analytes of Interest

Groundwater samples were collected from 671 wells for all monitoring programs during 1998. The locations of sampled wells are shown in Figures 6.1.10 and 6.1.11; well names are indicated only for those 400 and 600 Area wells specifically discussed in the text. Because of the density of unconfined aquifer wells in the operational areas, well names in these areas are shown on detailed maps in the following sections. Figure 6.1.12 shows the locations of facilities where groundwater monitoring was conducted to comply with RCRA (Appendix A in PNNL-12086). Wells at the Hanford Site generally follow a naming system that indicates the approximate location of the well. The prefix of the well name indicates the area of the site, as shown in Table 6.1.2. The names for 600 Area wells follow a local coordinate system in which the numbers indicate the distance relative to an arbitrary datum location in the south-central part of the site.

The monitoring frequency for the wells is selected based on regulatory requirements, variability of historical data, proximity to waste sources, and characteristics of the groundwater flow system at the sample location. Of the 671 wells sampled, 286 were sampled once, 174 twice, 25 three times, 99 four times, and 87 more than four times during the year. In 1998, the sampling frequency was changed to every 3 yr for several wells that showed concentrations with steady historical trends. Wells showing larger variability are sampled more frequently (annually or more often). Wells that monitor source areas are sampled more frequently than wells that do not monitor source areas. Contaminants with greater mobility (e.g., tritium) may be sampled more frequently than those that are not very mobile in groundwater (e.g., strontium-90).

Each monitoring program has access to groundwater data collected by other programs through a common database, the Hanford Environmental Information System. This database contains >1.5 million groundwater monitoring result records. After the data are verified and/or validated, they are made available to federal and state regulators for retrieval.

Most groundwater monitoring wells on the site are 10 to 20 cm (4 to 8 in.) in diameter. Monitoring wells for the unconfined aquifer are constructed with well screens or perforated casing generally in the upper 3 to 6 m (10 to 20 ft) of the unconfined aquifer, with the open interval extending across the water table. This construction allows sample collection at the top of the aquifer, where maximum activities of radionuclides tend to be found. Wells monitoring the shallowest of the basalt-confined aquifers have screens, perforated casing, or an open hole within the monitored aquifer. Wells drilled before 1985 were generally constructed with carbon steel casing. Since 1985, RCRA monitoring wells and CERCLA characterization wells have been constructed with stainless steel casing and screens. Most monitoring wells on the site are sampled using either submersible or Hydrostar™ pumps (a registered trademark of Instrumentation Northwest, Inc., Redmond, Washington), though some wells are sampled with bailers or airlift systems.

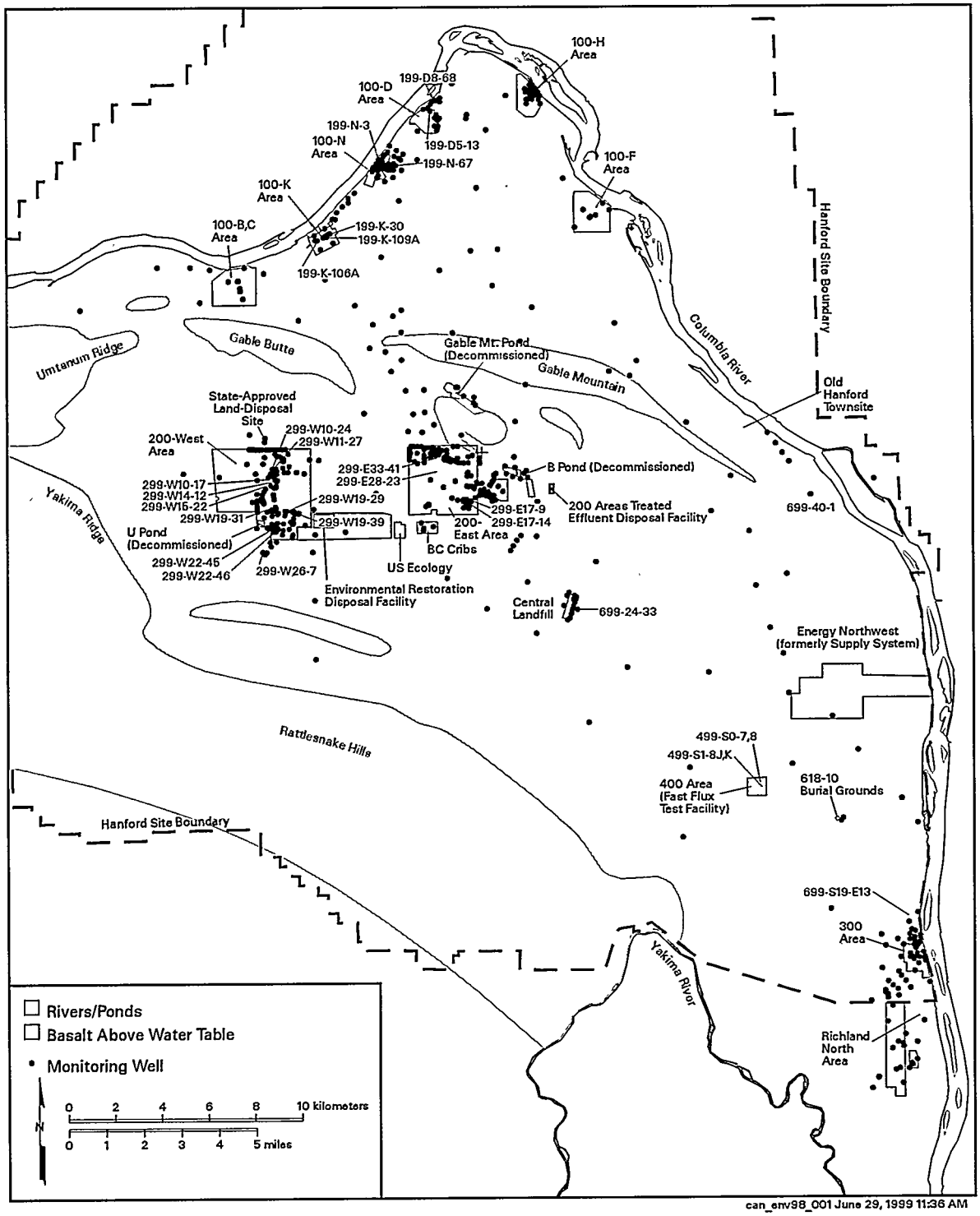


Figure 6.1.10. Unconfined Aquifer Monitoring Well Locations, 1998

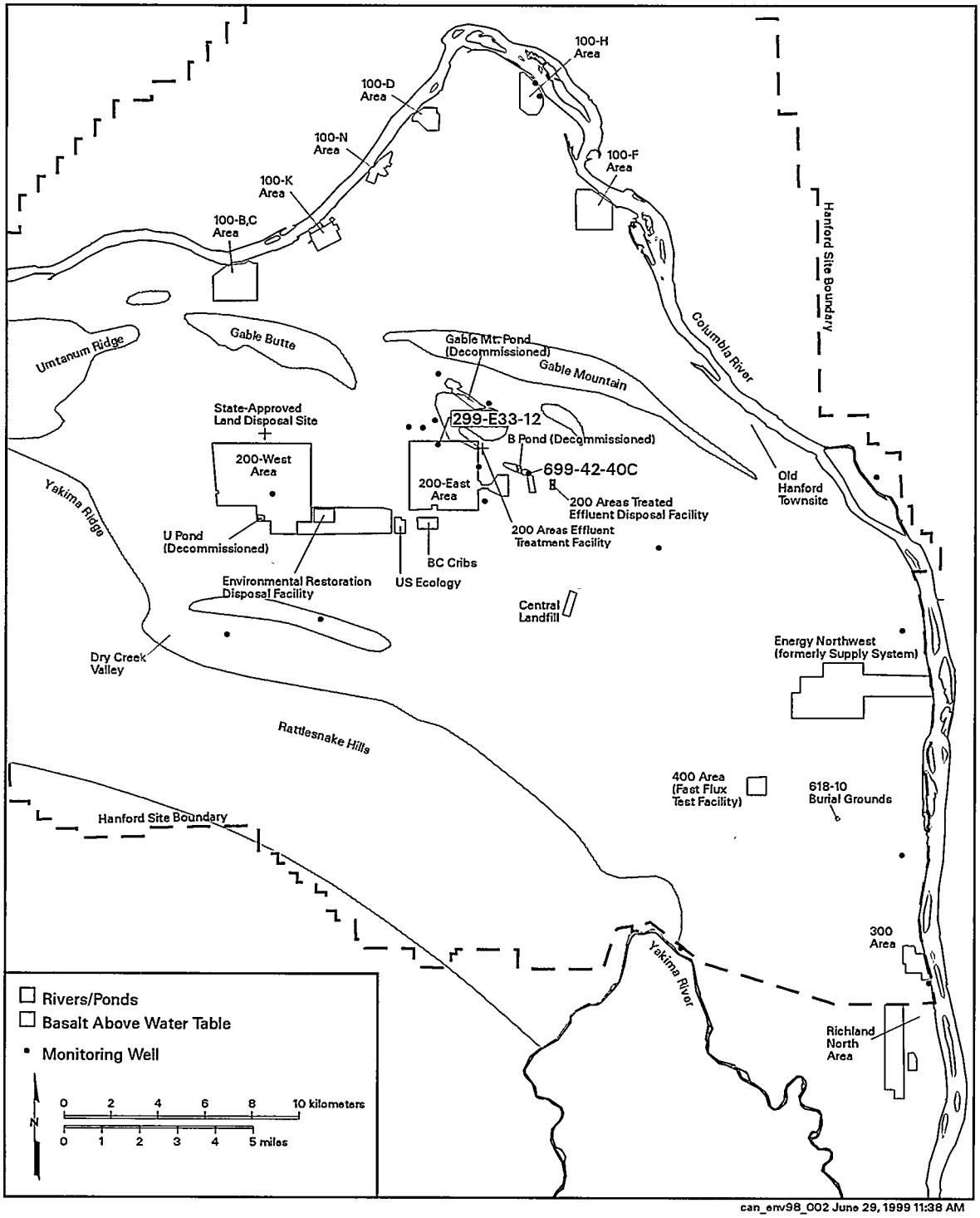
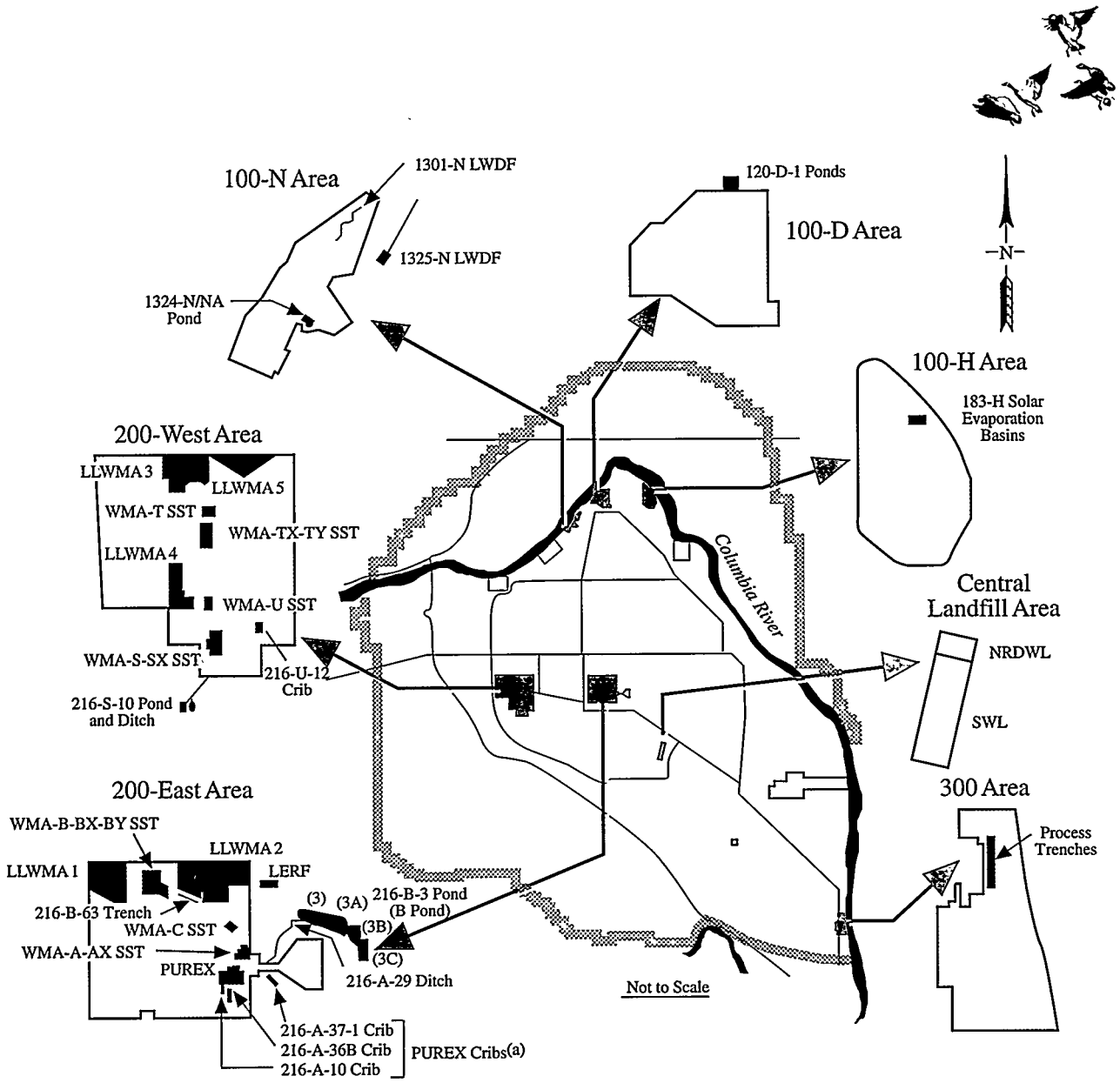


Figure 6.1.11. Confined Aquifer Monitoring Well Locations, 1998



LERF	Liquid Effluent Retention Facility	PUREX	Plutonium-Uranium Extraction (Plant)
LLWMA	Low-Level Waste Management Area	SST	Single-Shell Tank
LWDF	Liquid Waste Disposal Facility	SWL	Solid Waste Landfill
NRDWL	Nonradioactive Dangerous Waste Landfill	WMA	Waste Management Area

G99030045.94

(a) PUREX cribs are one RCRA groundwater monitoring project

Figure 6.1.12. Locations of RCRA Groundwater Monitoring Projects

Table 6.1.2. Hanford Site Well Naming System

Example Well Name	Area
199-	**100 Areas**
199-B3-47	100-B,C Area
199-D5-12	100-D Area
199-F8-3	100-F Area
199-H4-3	100-H Area
199-K-30	100-K Area
199-N-67	100-N Area
299-	**200 Areas**
299-W19-3	200-West Area
299-E28-4	200-East Area
399-	**300 Area**
399-1-17A	300 Area
499-	**400 Area**
499-S1-8J	400 Area
699-	**600 Area**
699-50-53A	600 Area north and west of datum
699-42-E9A	600 Area north and east of datum
699-S19-11	600 Area south and west of datum
699-S19-E13	600 Area south and east of datum

Note: Letters at end of well names distinguish either multiple wells located close together or multiple intervals within a single well bore.

Samples were collected for all programs following documented sampling procedures (PNL-6894, Rev. 1; ES-SSPM-001) based on U.S. Environmental Protection Agency (EPA) guidelines (OSWER 9950-1). Analytical techniques used are listed in DOE/RL-91-50, Rev. 2; PNL-10698 (Section 4.1.7); and CERCLA work plans. The radionuclides and chemicals analyzed for are listed in Table 6.1.3.

Most groundwater samples collected on the site in 1998 were analyzed for tritium. Selected samples were analyzed for other radionuclides. Sample results for radionuclides are generally presented in picocuries per liter; however, the results for total uranium, which is usually measured by laser fluorescence, are given in micrograms per liter.

Nitrate analyses were performed on many samples collected during 1998 because of the extensive areas with elevated nitrate concentrations that originate from onsite and offsite sources. However, nitrate concentrations were below the EPA 45-mg/L drinking water standard (40 CFR 141) for most of the affected area. Selected monitoring wells were used for additional chemical surveillance.

6.1.5.2 Data Interpretation

Each analysis of a groundwater sample provides information on the composition of groundwater at one time at one location in the aquifer. Uncertainty in the analyses results from a number of sources. Some of the sources of uncertainty are discussed below. Several techniques used to interpret the sample results are also discussed.

Groundwater sampling techniques are designed to collect a sample that is representative of the constituent concentration in the aquifer when the sample is taken. However, there are limitations in collecting representative samples or even defining precisely the volume of the aquifer represented by the sample. Proper well construction and maintenance, well purging, sample preservation, and, in some instances, filtering are used to help ensure consistent and representative samples. Careful sample labeling protocols, chain-of-custody documentation, and bottle preparation avoid many gross errors in sample results. Duplicate samples and field blanks are used to assess the sampling procedure.

Uncertainties are inherent in laboratory analysis of samples. Gross errors can be introduced in the laboratory or during sampling. Gross errors include transcription errors, calculation errors, mislabeling results, field equipment problems, or other errors that result from not following established procedures.

Table 6.1.3. Radionuclides and Chemicals Analyzed for in Groundwater, 1998

Radiological Parameters	Chemical Parameters
Tritium	pH (field and laboratory)
Beryllium-7	Conductance (field and laboratory)
Carbon-14	Total dissolved solids
Potassium-40	Alkalinity
Cobalt-58	Total carbon
Iron-59	Total organic carbon
Cobalt-60	Total organic halogens
Strontium-90	B, Be, Na, Mg, Al, K, Co, Si, As, Se
Technetium-99	Ca, V, Cr, Mn, Fe, Ni, Pb, Li, Hg
Ruthenium-106	Cu, Zn, Sr, Ag, Cd, Sb, Ba, Sn, Tl, Ti
Antimony-125	F^-, Cl^-, NO_3^-, PO_4^{-3}, SO_4^{-2}, NO_2^-, Br^-
Iodine-129	CN^-
Cesium-134	NH_4^+
Cesium-137	Hexavalent chromium
Neptunium-237	Volatile organic compounds
Americium-241	Semivolatile organic compounds
Gross alpha	Polychlorinated biphenyls
Gross beta	Pesticides/herbicides
Europium isotopes	Chemical oxygen demand
Plutonium isotopes	Dissolved oxygen
Radium isotopes	Total petroleum hydrocarbons
Uranium isotopes	Oil and grease
Uranium (total)	Diesel oil
	Gasoline

Often, these gross errors can be recognized because unreasonably high or unreasonably low values result. Data review protocols are used to investigate and correct gross errors.

Random errors are unavoidably introduced in the analytical procedures. Usually, there are insufficient replicate analyses to assess the overall random error at each sample location. Instruments for analysis of radioactive constituents count the number of radioactive decay products at a detector, and background counts are subtracted. The nature of radioactive decay and the instrument design result in a random counting error that is reported with the analytical result. Generally, a sample result less than the counting error indicates the constituent was not detected. The background subtraction may result in the reporting of results that are less than zero. Although below-zero results are physically impossible, the negative values are of use for some statistical analyses (see "Helpful Information" section for more details).

Systematic errors may result from problems with instrument calibration, standard or sample preparation, chemical interferences in analytical techniques, as well as sampling methodology and sample handling. Sample and laboratory protocols have been designed to minimize systematic errors. The analytical laboratories participate in interlaboratory comparisons, in which many laboratories analyze blind samples prepared by the EPA (see Section 8.0, "Quality Assurance").

In 1998, double-blind samples for specific constituents were analyzed (Section 8.0, "Quality Assurance," discusses double-blind results). Several wells were also cosampled with the Washington State Department of Health for comparison, and the results are available from that agency.

The chemical composition of groundwater may fluctuate from differences in the contaminant source, recharge, or groundwater flow field. The range of this concentration fluctuation can be estimated by taking many samples, but there is a limit to the number that can be practicably taken. Comparison of results through time helps interpret this variability.

Overall sample uncertainty may be factored into data evaluation by considering the concentration trend in a given well over time. This often helps identify gross errors, and overall, long-term trends can be distinguished from short-term variability. The interpretation of concentration trends depends on an understanding of chemical properties as well as site hydrogeology. The trend analysis, in turn, aids in refining the conceptual model of the chemical transport.

Plume maps presented in this section illustrate site groundwater chemistry. Although analytical data are available only at specific points where wells were sampled, contours are drawn to join the approximate locations of equal chemical concentration or radionuclide activity levels. The contour maps are simplified representations of plume geometry because of map scale, the lack of detailed information, and the fact that plume depth and thickness cannot be fully represented on a two-dimensional map. Plume maps are a powerful tool because knowledge of concentrations in surrounding wells, groundwater flow, site geology, and other available information are factored into their preparation.

6.1.6 Groundwater Monitoring Results

The following sections summarize the distribution of radioactive and chemical contaminants detected in Hanford Site groundwater during 1998. These discussions are followed by a summary of groundwater monitoring results for RCRA sites. More detailed information on groundwater monitoring, including listings of analysis results for each monitoring well in electronic format, is available in PNNL-12086. However, because PNNL-12086 (the annual groundwater report) covers the fiscal year, it does not include results from the last 3 mo of 1998.

One way to assess the impact of radionuclides and chemicals in groundwater is to compare them to EPA's drinking water standards and DOE's derived concentration guides (40 CFR 141 and DOE Order 5400.5; see Appendix C, Tables C.2 and C.5). The drinking water standards are for protecting public drinking water supplies. The derived concentration guides are for protecting the public from radionuclides resulting from DOE activities. Specific drinking water standards have been promulgated for only a few radiological constituents. Drinking water standards resulting in an annual dose of 4 mrem/yr have been calculated for other radionuclides by considering its half-life, the energy and nature of the radioactive decay, and the physiological factors such as its buildup in particular organs. Drinking water standards are more restrictive than derived concentration guides because the standards are based on an

annual dose to the affected organ of 4 mrem/yr, while the guides are based on an effective dose equivalent of 100 mrem/yr (see Appendix C, Tables C.2 and C.5). In addition, the standards use older factors for calculating the concentrations that would produce a 4-mrem/yr dose than are used in calculating the guides. Thus, the values used below for standards are not always in agreement with the guides, which are available only for radionuclides. Primary and secondary drinking water standards are given for some chemical constituents; secondary standards are based on aesthetic rather than health considerations.

6.1.6.1 Radiological Monitoring Results for the Unconfined Aquifer

The radionuclides for which analyses were conducted on Hanford Site groundwater were listed in Table 6.1.3. The distribution of tritium, iodine-129, technetium-99, uranium, strontium-90, carbon-14, cesium-137, cobalt-60, and plutonium are discussed in the following sections. Tritium and iodine-129 are the most widespread contaminants associated with past site operations. Technetium-99 and uranium plumes are extensive in the 200 Areas and adjacent 600 Area. Strontium-90 plumes exhibit very high concentrations in the 100 Areas but are of relatively smaller extent. A carbon-14 plume is widely distributed in the 100-K Area. Cesium-137, cobalt-60, and plutonium contamination occurs in isolated areas in the 200 Areas. Gross alpha and gross beta are used as indicators of radionuclide distribution and are not discussed in detail because the specific radionuclides contributing to these measurements are discussed individually. Several other radionuclides, including ruthenium-106, antimony-125, and americium-241, are associated with wastes from Hanford Site operations. Because of their very low activities in groundwater, they are not discussed in this section. Half-lives of the radionuclides are presented in Table H.5 in the "Helpful Information" section.

Tritium. Tritium is present in irradiated nuclear fuel and was released in process condensates associated with decladding and dissolution of the fuel. Tritium was also manufactured as part of the Hanford mission by irradiating targets containing lithium in several reactors from 1949 to 1952 (DOE/EIS-0119F, WHC-SD-EN-RPT-004). In the late 1960s, tritium production took place in N Reactor (WHC-MR-0388).

Tritium was present in many historical waste streams at the Hanford Site and is highly mobile, essentially moving at the same velocity as the groundwater. As a result, the extent of groundwater contamination from site operations is generally reflected by tritium distribution. For this reason, tritium is the radionuclide most frequently monitored for at the Hanford Site. Figure 6.1.13 shows the 1998 distribution of tritium in the unconfined aquifer. Tritium is one of the most widespread contaminants in groundwater across the Hanford Site and exceeded the 20,000-pCi/L drinking water standard in the 100, 200, 400, and 600 Areas. Tritium levels exceeded the 2,000,000-pCi/L derived concentration guide in the 100-K and 200 Areas. Tritium levels are expected to decrease because of dispersion and radioactive decay (half-life is 12.35 yr).

In 1998, the only tritium bearing liquid effluent discharged to the soil column on the Hanford Site occurred at the State-Approved Land Disposal Site, which began operating in 1995 and is located just north of the 200-West Area. The total radioactivity received by this facility in 1998 was 31.5 Ci.

Tritium in the 100 Areas. Tritium activities greater than the drinking water standard were detected in the 100-B,C, 100-D, 100-F, 100-K, and 100-N Areas. Tritium was detected above the derived concentration guide in the 100-K Area. The largest tritium plume in the 100 Areas with activities above the drinking water standard occurs along the Columbia River from the 100-N Area to the 100-D Area.

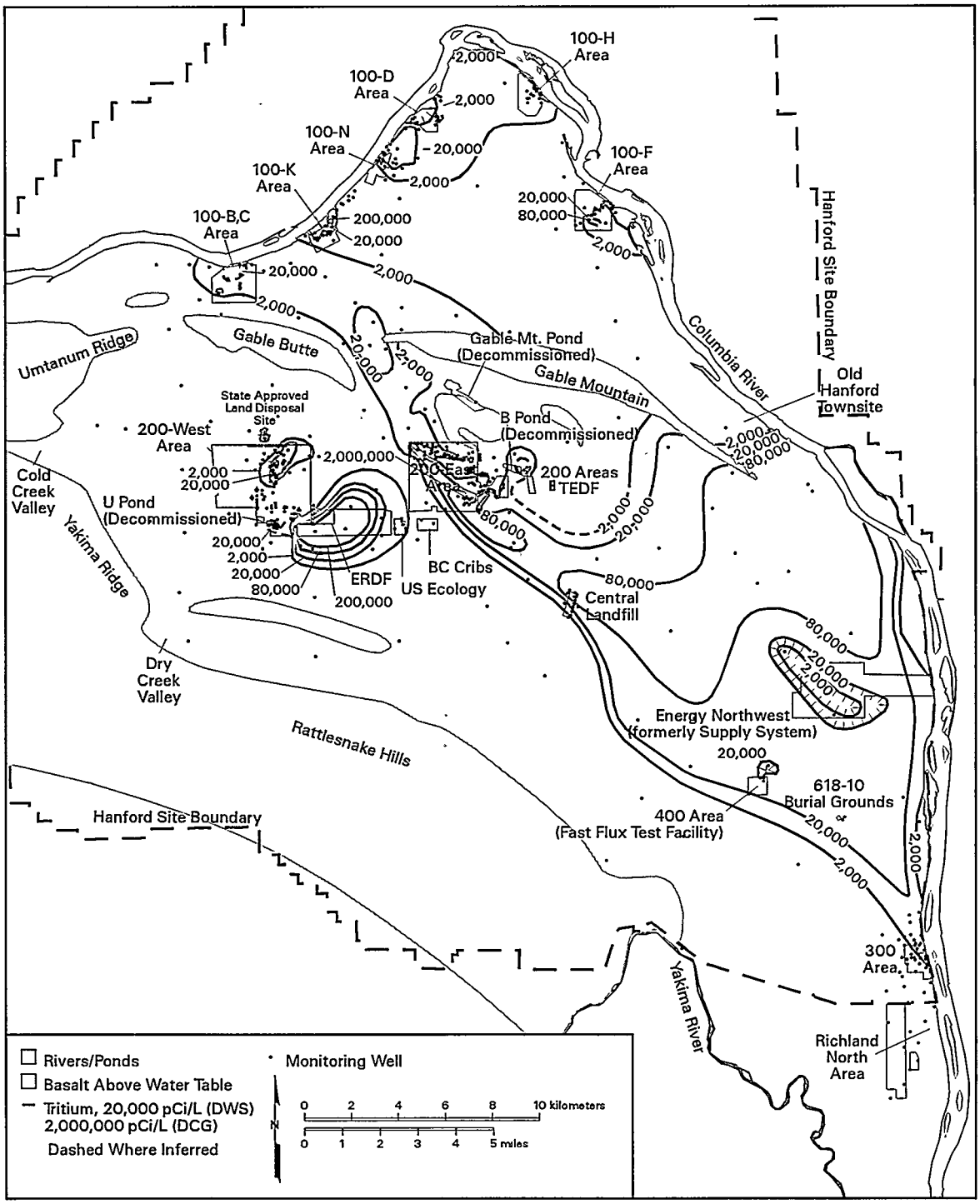


Figure 6.1.13. Average Tritium Activities in the Unconfined Aquifer, 1998

Tritium activities increased to levels above the drinking water standard in several wells in the northern and southwestern parts of the 100-B,C Area in 1998. Most of these are associated with past liquid disposal practices at the 116-B-11 and 116-C-5 Retention Basins and the 116-B-1 and 116-C-1 Trenches near the Columbia River. The maximum tritium activity was 91,900 pCi/L in the southwestern part of the 100-B,C Area. The maximum in the northern part of the 100-B,C Area was 88,100 pCi/L adjacent to the 116-B-11 Retention Basin.

In the 100-D Area, tritium activities were greater than the drinking water standard in the southwestern corner of the area and near D Reactor. The maximum tritium reported during 1998 was 47,000 pCi/L in the southwestern corner of the area and is associated with the tritium plume that extends southwest to the 100-N Area. High activities near D Reactor are associated with past liquid waste disposal to 100-D Area trenches.

One well in the 100-F Area contained tritium at activities greater than the drinking water standard. A maximum of 38,500 pCi/L occurred near the 118-F-1 Burial Ground in 1998. This burial ground received only solid waste, and the source of the tritium contamination is not known.

Well 199-K-30, located near the KE Reactor in the 100-K Area, continued to contain the highest tritium within the 100 Areas, with a maximum activity of 2,360,000 pCi/L. This is the only tritium activity in the 100 Areas that exceeded the derived concentration guide in 1998. The tritium trend for well 199-K-30 is shown in Figure 6.1.14. The probable source is past disposal to a French drain east of the reactor building (DOE/EIS-0119F). The tritium plume with levels greater than the drinking water standard extends downgradient at least 900 m (3,000 ft) from the KE Reactor toward the Columbia River.

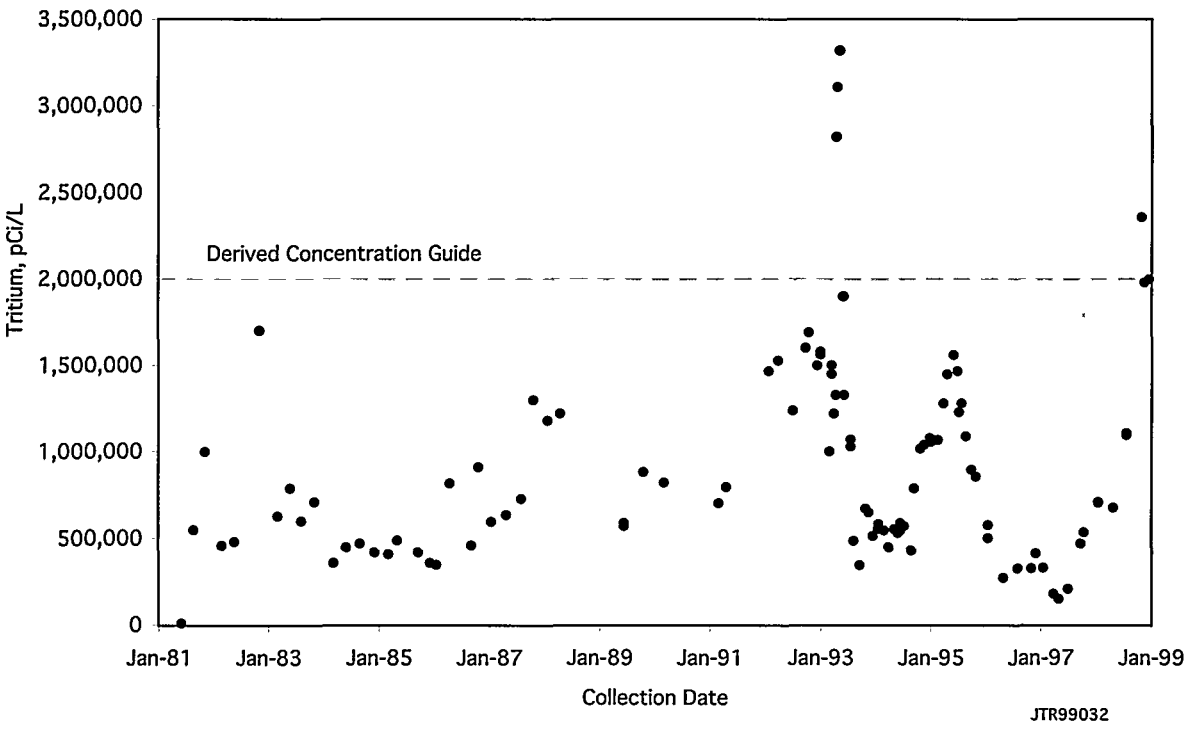


Figure 6.1.14. Tritium Activities in Well 199-K-30, 1982 Through 1998

Tritium in the northern part of the 100-N Area is found at levels greater than the drinking water standard. The tritium plume in this area extends northeast to the 600 and 100-D Areas. This plume is associated with past liquid disposal to the 1301-N and 1325-N Liquid Waste Disposal Facilities. The highest activities, which have decreased in recent years, continued to decrease in 1998. The maximum tritium level reported in the 100-N Area in 1998 was 59,700 pCi/L between the 1301-N facility and the Columbia River.

Tritium in the 200-East and 600 Areas. The highest tritium activities in the 200-East Area continued to be measured in wells near cribs that received effluent from the Plutonium-Uranium Extraction Plant. However, tritium levels are generally decreasing slowly in this area. Levels greater than the derived concentration guide were detected in only one well (299-E17-9) in 1998 in the 200-East Area. The maximum tritium level detected in this well, which monitors the 216-A-36B Crib in the southeastern part of the 200-East Area, was 3,870,000 pCi/L. This was the highest tritium level detected in any well on the Hanford Site.

In the plume that extends from the southeastern portion of the 200-East Area, tritium activities >200,000 pCi/L occurred in a small area downgradient of the Plutonium-Uranium Extraction Plant and did not extend beyond the 200-East Area boundary. These levels were generally lower in 1998 than in previous years as a result of dispersion and radioactive decay. The plume area at levels >200,000 pCi/L has extended at least as far southeast as the Central Landfill in the recent past (PNL-8073).

The movement of the widespread tritium plume (see Figure 6.1.13), extending from the southeastern portion of the 200-East Area to the Columbia River, was consistent with patterns noted in recent monitoring reports (Section 6.1.6.1 in PNNL-11795, Section 5.10.3.2 in PNNL-12086). Separate tritium pulses associated with the two episodes of Plutonium-Uranium Extraction Plant operations can be distinguished in the plume. High-tritium activities east of the 200-East Area near the Columbia River result from discharges to the ground during the operation of the Plutonium-Uranium Extraction Plant from 1956 to 1972. Following an 11-yr shutdown, plant operation began in 1983 and ceased in December 1988. This resulted in elevated tritium levels measured in several wells downgradient from the 200-East Area. Movement of the leading edge of this second pulse is clearly observable near the Central Landfill (Figure 6.1.15), which shows arrival in early 1987. Tritium activities from the first pulse were much higher than from the second. The effects of the second operational period have not been detected near the Columbia River. A trend plot (Figure 6.1.16) of the tritium activities in well 699-40-1 near the shore of the Columbia River shows the arrival of the first pulse in the mid-1970s, but shows no indication that the second pulse has yet arrived.

The tritium plume has been monitored since the 1960s and provides information on the extent of groundwater contamination over time. Figure 6.1.17 shows the distribution of tritium in selected years from 1964 through 1988. This figure was created from maps in BNWL-90, BNWL-1970, PNL-5041, and PNL-6825 (Section 5.0). The contours in the original references were recalculated and interpreted to provide uniform contour intervals. Figure 6.1.17 shows that tritium at levels greater than the drinking water standard reached the Columbia River in approximately the mid-1970s.

The configuration of the western portion of the tritium plume shown in Figure 6.1.13 closely matches previous predictions of the direction of contaminant movement from the 200-East Area (PNL-6328). Movement is forced to the south by the flow that originates at the groundwater mound beneath the former B Pond. Flow to the southeast also appears to be controlled by a zone of highly permeable sediments, stretching from the 200-East Area toward the 400 Area (PNL-7144).

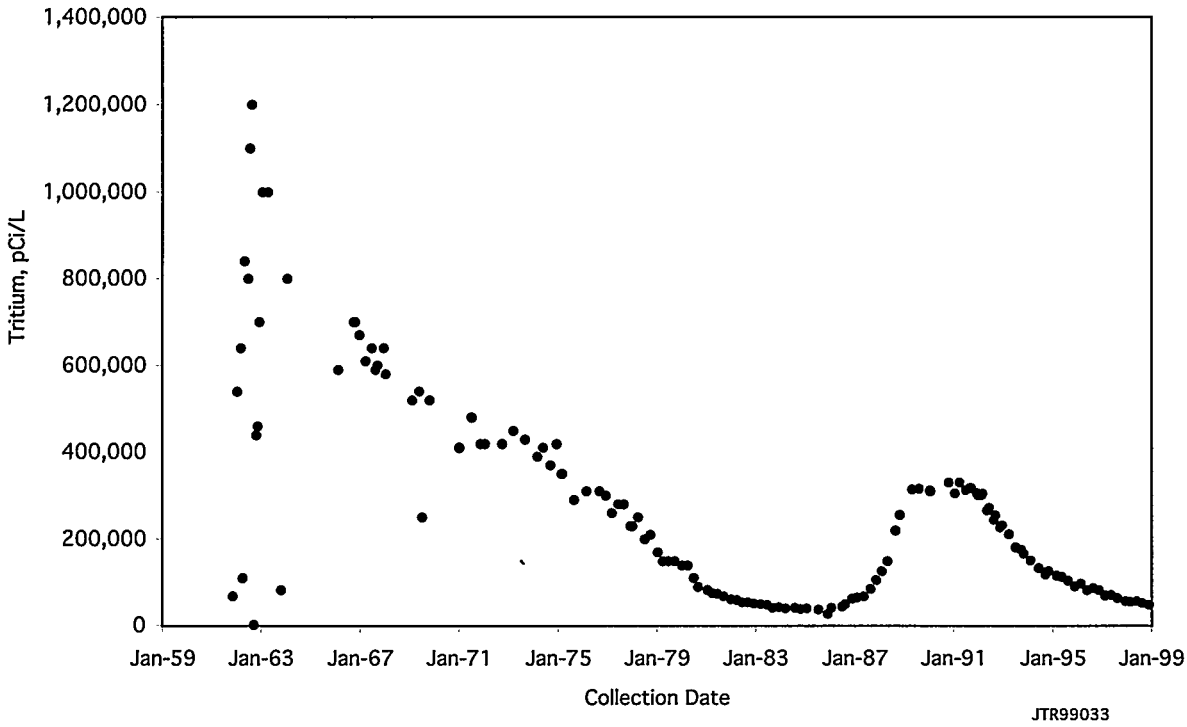


Figure 6.1.15. Tritium Activities in Well 699-24-33, 1962 Through 1998

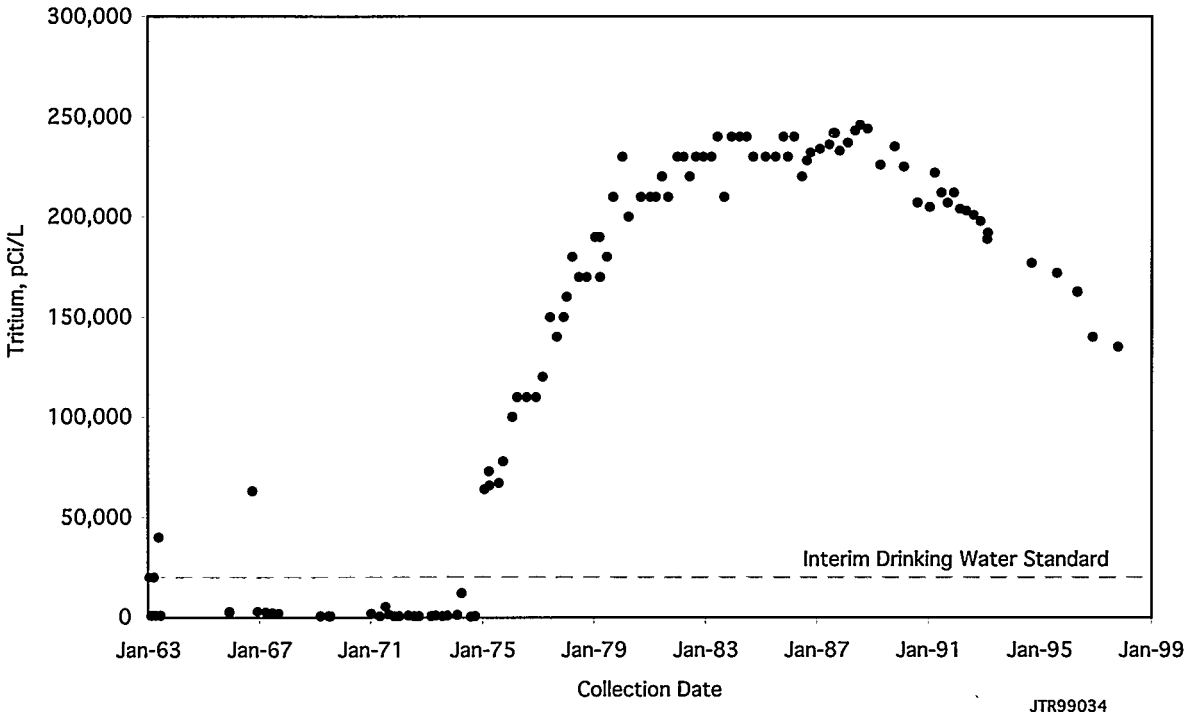


Figure 6.1.16. Tritium Activities in Well 699-40-1, 1963 Through 1998

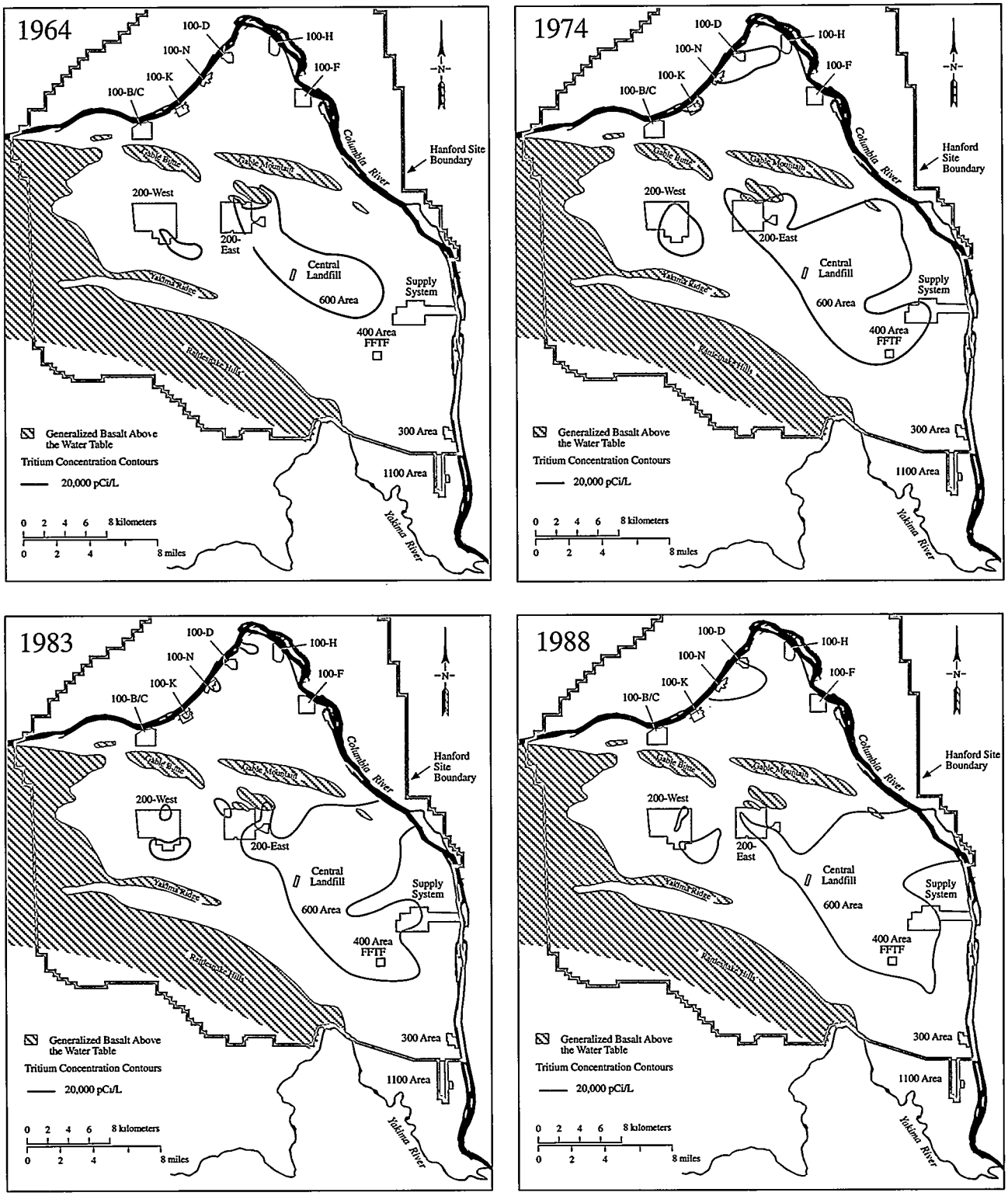


Figure 6.1.17. Historical Tritium Activities on the Hanford Site

The distribution of tritium near the former B Pond shows an area of activity above the drinking water standard in a limited area near the former B Pond. B Pond produced a radial flow pattern of groundwater that mostly had low contaminant levels. The mound under the former B Pond has begun to dissipate since wastewater flow was diverted to the 200 Areas Treated Effluent Disposal Facility in August 1997.

Tritium is also found at levels above the drinking water standard in the northwestern part of the 200-East Area (see Figure 6.1.13). This plume appears to extend to the northwest through the gap between Gable Mountain and Gable Butte. The tritium distribution to the northwest and southeast of the 200-East Area indicates a divide in groundwater flow direction across the 200-East Area. A pulse of tritium levels above the standard also occurred between Gable Mountain and Gable Butte.

Tritium in the 200-West Area. Tritium from sources near the Reduction-Oxidation Plant forms the most extensive plume in the 200-West Area. The Reduction-Oxidation Plant is located in the southeastern part of the 200-West Area and operated from 1951 through 1967. This plume extends into the 600 Area east of the 200-West Area to US Ecology's facility. The eastern part of the plume curves to the north, but the tritium activities in the northern part of the plume are declining. However, activities continue to increase slowly in the eastern part of the plume near the US Ecology facility. Tritium activities exceeded the drinking water standard in much of the plume, including a small area near the former 216-S-25 Crib upgradient of the Reduction-Oxidation Plant. The maximum activity in this plume in 1998 was 451,000 pCi/L in the 600 Area east of the Reduction-Oxidation Plant. The movement of groundwater in the 200-West Area is slow because Ringold Formation sediments have low permeability. Movement of the plumes in the 200-West Area is also slow as a result of declining hydraulic gradients since the closure of U Pond in 1984.

A smaller tritium plume that covers much of the northern part of the 200-West Area occurs in the vicinity of the TX and TY Tank Farms (see Figures 6.1.12 and 6.1.13) and T Plant disposal facilities, which received liquid waste from historical T Plant operations. The highest tritium activity was 3,210,000 pCi/L detected near the TX and TY Tank Farms. This was a sharp increase from 1997 levels and was the only activity that exceeded the derived concentration guide in the 200-West Area in 1998. The area where the drinking water standard was exceeded extends northeast past the northern boundary of the 200-West Area.

Two wells monitoring the State-Approved Land Disposal Site just north of the 200-West Area showed tritium activities that exceeded the drinking water standard, with one of the wells showing a maximum value (2,100,000 pCi/L) that exceeded the derived concentration guide in 1998. These activities are associated with the disposal site, which receives treated effluent containing tritium. This disposal site has been in operation since 1995.

Tritium in the 300 Area. The eastern portion of the tritium plume that emanates from the 200-East Area continues to move to the east-southeast and discharge into the Columbia River (see Figure 6.1.13). The southern edge of the tritium plume extends into the 300 Area, as shown in Figure 6.1.18. Figure 6.1.19 shows the trend of tritium activities in well 699-S19-E13 just north of the 300 Area. Tritium in this well decreased slightly in 1998 after reaching a maximum in 1997. Even though tritium in the 300 Area is below the drinking water standard, a concern has been the potential migration of the tritium plume to an offsite municipal water supply to the south. The municipal water supply consists of the city of Richland's well field recharge basins (see Figure 6.1.18).

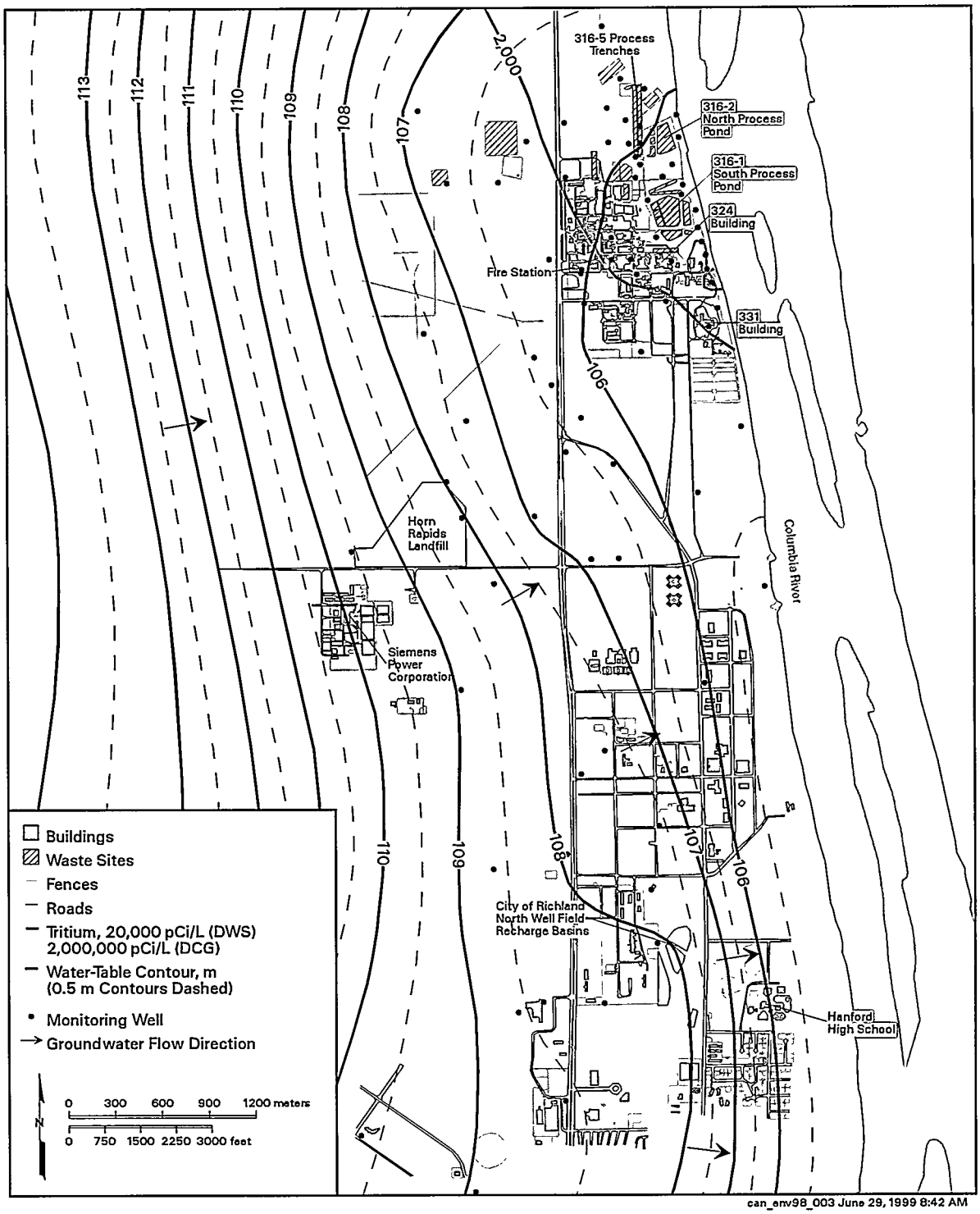


Figure 6.1.18. Average Tritium Activities and Groundwater Flow Near the 300 Area, 1998

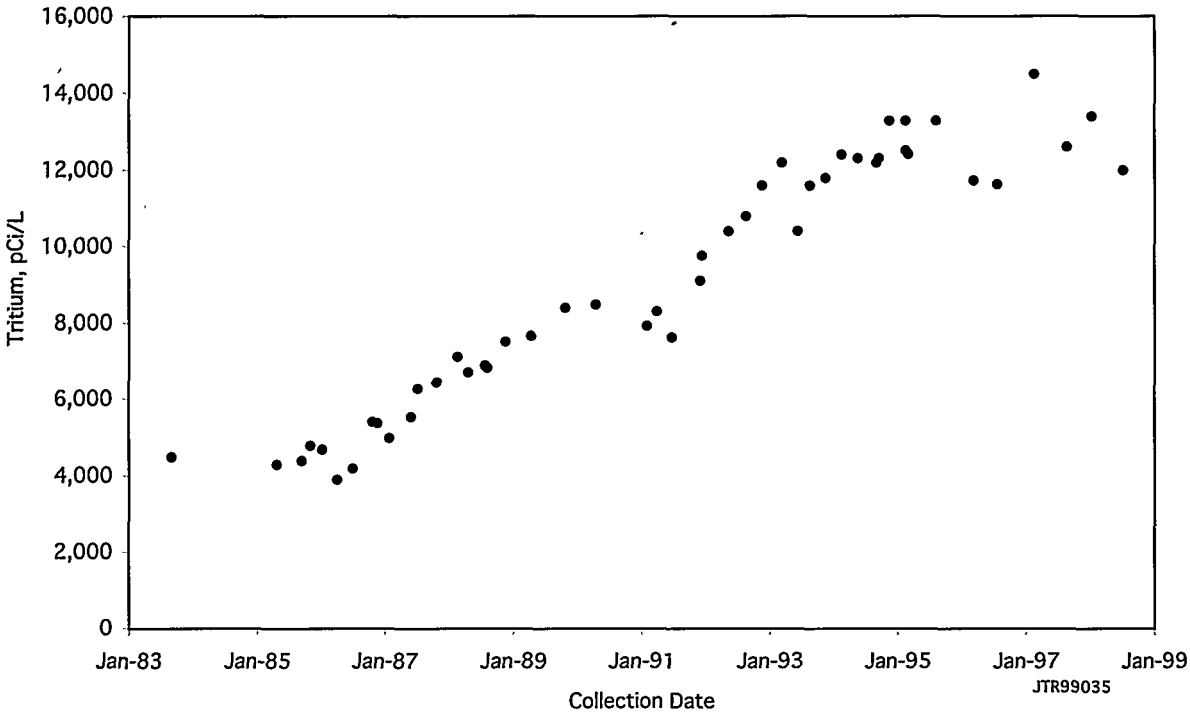


Figure 6.1.19. Tritium Activities in Well 699-S19-E13, 1983 Through 1998

The tritium plume is not expected to impact the well field recharge basins because of the influence of groundwater flow from the Yakima River, recharge from agricultural irrigation, and recharge from infiltration ponds at the well field (see Figure 6.1.18). The Yakima River is at a higher elevation and recharges the groundwater in this area. As a result, groundwater flows from west to east (see Figure 6.1.18), minimizing the southward movement of the contaminant plume. Recharge from agricultural irrigation occurs south of the Hanford Site boundary and also contributes to eastward flow. The recharge basins are supplied with Columbia River water, which infiltrates to the groundwater. The amount of recharge water exceeds the amount pumped at the well field by a factor of approximately 2:1, resulting in groundwater flow away from the well field. This further ensures that tritium-contaminated groundwater will not reach the well field. Ongoing monitoring is performed to confirm this interpretation.

Tritium in the 400 Area. The tritium plume that originated in the 200-East Area extends under the 400 Area. The observed maximum in this area during 1998 was 36,300 pCi/L in well 499-S1-8K. The primary water supply well for the 400 Area (499-S1-8J) is completed in the lower part of the aquifer and had a maximum tritium activity of 19,500 pCi/L. However, the sample may have been switched and mislabeled with a sample from a backup water supply well. The average activity in the primary water supply in 1998 was 5,947 pCi/L. The activities at wells used for backup water supply (499-S0-7 and 499-S0-8) were above the drinking water standard. The maximum in the backup water supply was 31,500 pCi/L, which is an increase from 1997 levels. The water supply wells are located in the northern part of the 400 Area. Additional information on the 400 Area water supply is provided in Section 4.3, "Hanford Site Drinking Water Surveillance."

Samples collected from wells near the 400 Area Process Ponds showed a maximum tritium activity (22,300 pCi/L) that exceeded the drinking water standard. The 400 Area Process Ponds are located in the 600 Area north of the 400 Area. Discharge of wastewater to this facility does not contribute tritium contamination to groundwater because the source of the wastewater is water supply usage from local groundwater wells.

Iodine-129. Iodine-129 has a relatively low drinking water standard (1 pCi/L), has the potential for accumulation in the environment as a result of long-term releases from nuclear fuel reprocessing facilities (Soldat 1976), and has a long half-life (16,000,000 yr). The relatively low fission yield for production of iodine-129 combined with its long half-life limits its specific activity in Hanford Site wastes. Iodine-129 may be released as a vapor during fuel dissolution and other elevated temperature processes and, thus, may be associated with process condensate wastes. At the site, the main contributor of iodine-129 to groundwater has been liquid discharges to cribs in the 200 Areas. Iodine-129 has essentially the same high mobility in groundwater as tritium. No groundwater samples showed iodine-129 activities above the 500-pCi/L derived concentration guide in 1998.

Iodine-129 in the 200-East Area. The highest iodine-129 activities in the 200-East Area are in the northwest near the BY Cribs and in the southeast near the Plutonium-Uranium Extraction Plant. The maximum level of iodine-129 detected in 1998 in the 200-East Area was 12.9 pCi/L south of the Plutonium-Uranium Extraction Plant near the 216-A-10 Crib. The iodine-129 plume extends from the Plutonium-Uranium Extraction Plant area southeast into the 600 Area and appears coincident with the tritium plumes (see Figure 6.1.13). The plume appears smaller than the tritium plume because of the lower initial activity of iodine-129. The iodine-129 contamination can be detected as far east as the Columbia River but at levels below the drinking water standard. Data indicate that iodine-129 at levels above the drinking water standard is approaching the Columbia River (Figure 6.1.20). The plume likely had the same sources as the tritium plume. Iodine-129 is also present in groundwater at levels above the drinking water standard in the northwestern 200-East Area; however, a definite source for this plume has not been determined. This plume extends northwest into the gap between Gable Mountain and Gable Butte.

Iodine-129 in the 200-West Area. The distribution of iodine-129 in Hanford Site groundwater is shown in Figure 6.1.20. The highest level observed in 1998 was 81.4 pCi/L near the T, TX, and TY Tank Farms in the northern part of the 200-West Area. This level occurs in a plume that originates near the tank farms and nearby disposal facilities and extends northeast toward T Plant. The iodine-129 plume is coincident with the technetium-99 and tritium plumes in this area. A much larger iodine-129 plume occurs in the southeastern part of the 200-West Area, which originates near the Reduction-Oxidation Plant, and extends east into the 600 Area. This plume is essentially coincident with the tritium plume, though there appears to be a contribution from cribs to the north near U Plant. In 1998, the maximum in this plume was 49.6 pCi/L in an area east of the Reduction-Oxidation Plant.

Technetium-99. Technetium-99, which has a half-life of 210,000 yr, is produced as a fission byproduct and is present in waste streams associated with fuel reprocessing. Reactor operations may also result in the release of some technetium-99 associated with fuel element breaches. Under the chemical conditions that exist in Hanford Site groundwater, technetium-99 is normally present in solution as anions that sorb poorly to sediments. Therefore, technetium-99 is very mobile in site groundwater.

Technetium-99 was found at activities greater than the 900-pCi/L interim drinking water standard in the 200-East and 200-West Areas, with the highest

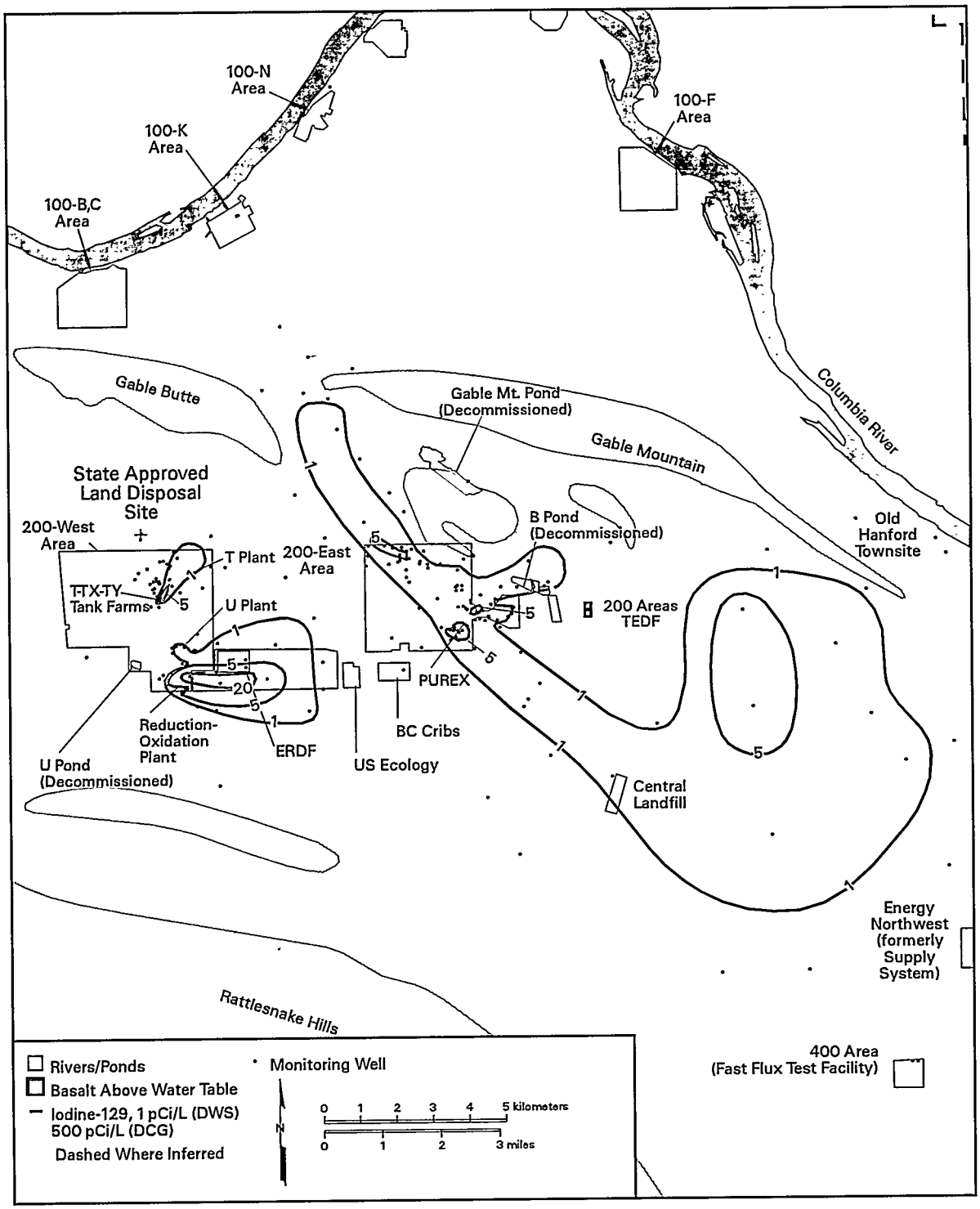


Figure 6.1.20. Average Iodine-129 Activities in the Unconfined Aquifer, 1998

measured in the 200-West Area. In the 100-H Area, levels in a localized area fell below the interim drinking water standard in 1998. The derived concentration guide for technetium-99 is 100,000 pCi/L.

Technetium-99 in the 200-East Area. Groundwater in the northwestern part of the 200-East Area and a part of the 600 Area north of the 200-East Area contains technetium-99 at activities above the interim drinking water standard (Figure 6.1.21). The source of these technetium plumes was apparently the BY Cribs (Section 5.8.2 in PNL-10698). However, some of this contamination is believed to originate from the B, BX, and BY Tank Farms (PNNL-11826). Technetium-99 increased in several monitoring wells during 1998, creating a new local center of high technetium-99 levels in the area north and west of the tank farms. The largest increase occurred in the northwestern corner of the BY Cribs, where the maximum in the 200-East Area was 7,030 pCi/L. The maximum technetium-99 in the plume north of the 200-East Area in 1998 was 2,210 pCi/L. This plume appears to be moving through the gap between Gable Mountain and Gable Butte.

Technetium-99 in the 200-West Area. The largest technetium-99 plume in the 200-West Area originates from the cribs that received effluent from U Plant and extends into the 600 Area to the east (Figure 6.1.22). The technetium plume is approximately in the same location as the uranium plume because technetium-99 and uranium, which are typically associated with the same fuel reprocessing cycle, were disposed to the same cribs. The highest technetium-99 activities in this plume in 1998 were measured in several wells in the vicinity of the 216-U-17 Crib, where remediation by the pump-and-treat method is occurring. The high-activity portion of the plume, which has decreased in size, appears to be moving downgradient toward the extraction center (well 299-W19-39). The maximum level was detected in well 299-W19-29 at a level of 22,600 pCi/L, the highest observed at the Hanford Site. This well is located approximately midway between the 216-U-1, 216-U-2, and the 216-U-17 Cribs. Technetium-99 activities in the extraction well decreased in 1998.

The purpose of the pump-and-treat system near the 216-U-17 Crib is to contain and reduce the highest activities/concentrations in the technetium-99 and uranium plumes (Record of Decision 1997). As of September 1998, approximately 53.9 g (1.9 oz) of technetium-99 have been removed from approximately 338 million L (89 million gal) of extracted groundwater since pump-and-treat operations began in 1994 (DOE/RL-99-02). This mass of technetium-99 is equivalent to approximately 0.9 Ci of radioactivity. Contaminated groundwater is currently pumped from one extraction well (299-W19-39) and transported via pipeline to the 200 Areas Effluent Treatment Facility, where it is treated using a number of processes. The treated groundwater is disposed of to the State-Approved Land Disposal Site north of the 200-West Area.

Technetium-99 occurs at levels above the interim drinking water standard in the vicinity of the T, TX, and TY Tank Farms (see Figure 6.1.22). Four wells that monitor these tank farms consistently showed technetium-99 activities above the interim drinking water standard in 1998. Near the TX and TY Tank Farms, the highest was 3,680 pCi/L in the southwestern corner of the tank farms (well 299-W15-22), where technetium-99 levels have been increasing. In the northeastern corner of T Tank Farm, technetium-99 levels were above the interim drinking water standard in two wells. The maximum in this area was 13,000 pCi/L in 1998 (well 299-W11-27). The sources of this technetium-99 contamination were the T, TX, and TY Tank Farms (PNNL-11809).

The small plume in the southern part of the 200-West Area originates near the S and SX Tank Farms and the 216-S-13 Crib. The maximum detected in this area was approximately 4,330 pCi/L near the southeastern corner of the SX Tank Farm. Leakage

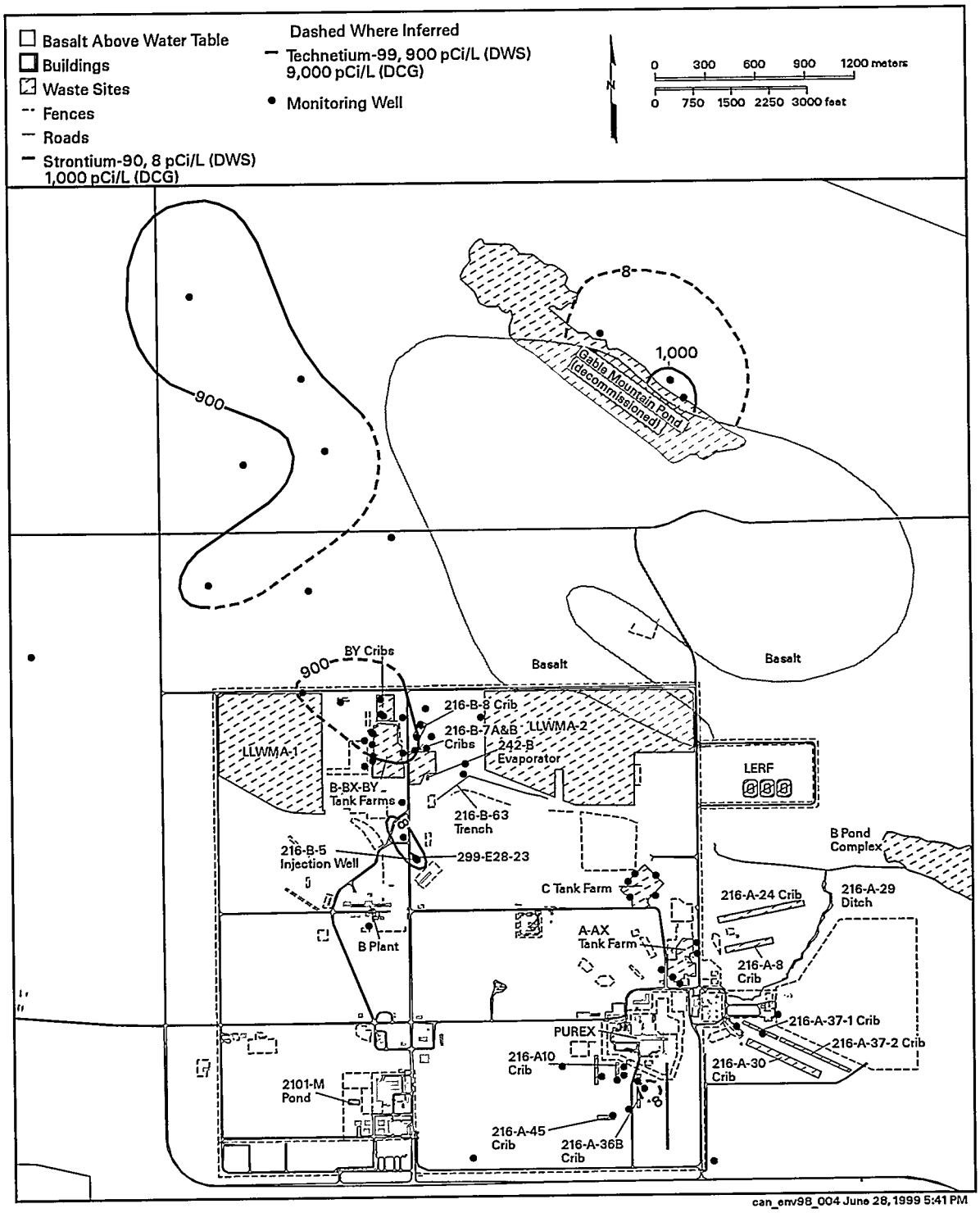
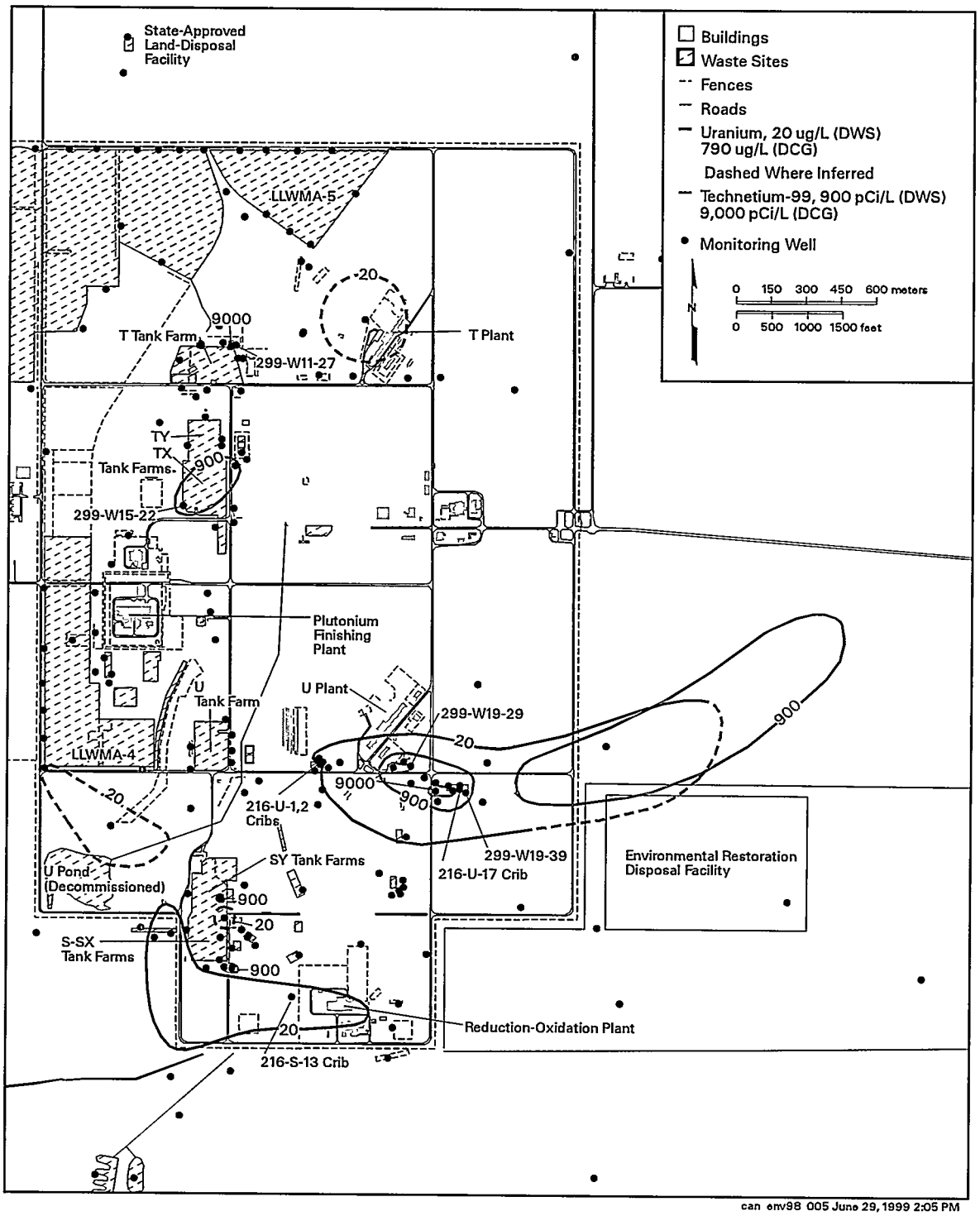


Figure 6.1.21. Average Technetium-99 and Strontium-90 Activities in the Unconfined Aquifer Near the 200-East Area, 1998



can env98 005 June 29, 1999 2:05 PM

Figure 6.1.22. Average Technetium-99 Activities and Uranium Concentrations in the Unconfined Aquifer in the 200-West Area, 1998

from the single-shell tanks is believed to be a source of the technetium-99 in this vicinity (PNNL-11810).

Uranium. There were numerous possible sources of uranium released to the groundwater at the Hanford Site, including fuel fabrication, fuel reprocessing, and uranium recovery operations. Uranium may exist in several states, including elemental uranium or uranium oxide as well as tetravalent and hexavalent cations. Only the hexavalent form has significant mobility in groundwater, largely by forming dissolved carbonate species. Uranium mobility is thus dependent on both oxidation state and pH. Uranium is observed to migrate in site groundwater but is retarded relative to more-mobile species such as technetium-99 and tritium. The EPA's proposed drinking water standard is 20 µg/L for uranium. The derived concentration guide that represents an annual effective dose equivalent of 100 mrem/yr is 790 µg/L for uranium.

Uranium has been detected at concentrations greater than the proposed drinking water standard in portions of the 100, 200, 300, and 600 Areas. The highest levels detected at the Hanford Site in 1998 were in the 200-West Area near U Plant, where uranium levels exceeded the derived concentration guide.

Uranium in the 100 Areas. In 1998, uranium was detected at a concentration greater than the 20-µg/L proposed drinking water standard in one well near F Reactor in the 100-F Area. The maximum detected was 20.3 µg/L.

Uranium was detected at levels higher than the proposed drinking water standard in three wells in the 100-H Area. The maximum detected in 1998 was 57 µg/L. Past leakage from the 183-H Solar Evaporation Basins is considered to be the source of the 100-H Area uranium contamination. These basins were remediated in 1996.

Uranium in the 200-East Area. In 1998, several wells in the northwestern part of the 200-East Area contained uranium at levels greater than the proposed drinking water standard. The distribution of uranium in this area suggests that contamination is of limited extent, with the highest concentrations in the vicinity of the B, BX, and BY Tank Farms; BY Cribs; and 216-B-5 Injection Well that has been inactive since 1947. The highest detected was 282 µg/L east of the BY Tank Farm (southeast of the BY Cribs). The source of the uranium contamination in this area is unclear. Near the inactive 216-B-5 Injection Well, one well showed a uranium concentration greater than the proposed drinking water standard. The concentration at this well was 69 µg/L. Near B Plant, uranium concentrations have been increasing in one well and reached 20 µg/L in 1998. One well adjacent to the inactive 216-B-62 Crib showed a concentration of 21 µg/L in 1998.

Uranium in the 200-West Area. The highest uranium concentrations in Hanford Site groundwater occurred near U Plant, at wells adjacent to the inactive 216-U-1, 216-U-2, and 216-U-17 Cribs (see Figure 6.1.22). The uranium plume, which extends into the 600 Area to the east, is approximately in the same location as the technetium-99 plume discussed above. Uranium and technetium-99 are typically associated with the same fuel reprocessing cycle and were disposed to the same cribs. The high concentrations exceeded the derived concentration guide for uranium. The maximum detected in this area in 1998 was 2,800 µg/L adjacent to the 216-U-17 Crib. Uranium concentrations in this area have been increasing as a result of a pump-and-treat operation at an extraction well (299-W19-39) located near the 216-U-17 Crib. However, the size of the overall plume did not change significantly between 1997 and 1998.

As of September 1998, the pump-and-treat system removed a total of 80.4 kg (177 lb) of uranium from approximately 338 million L (89 million gal) of extracted groundwater since operations began in 1994 (DOE/RL-99-02).

Other areas with uranium contamination at levels above the proposed drinking water standard are also shown in Figure 6.1.22, including fairly widespread areas west and northwest of the Reduction-Oxidation Plant. Uranium concentrations in those areas are considerably lower than the concentrations detected near U Plant. The maximum uranium in these areas was 90.5 µg/L immediately east of the S and SX Tank Farms (northwest of the Reduction-Oxidation Plant). In the northern part of the 200-West Area, a localized area of uranium contamination, where a single sample showed a concentration above the proposed drinking water standard, was found near T Plant.

Uranium in the 300 Area. A plume of uranium contamination exists in the vicinity of uranium fuel fabrication facilities and inactive sites known to have received uranium waste. The plume extends downgradient from inactive liquid waste disposal facilities to the Columbia River (Figure 6.1.23). The major source of the contamination is the inactive 316-5 Process Trenches, as indicated by the distribution of the uranium concentrations downgradient from these trenches (see Section 5.13.3.1 in PNNL-12086). Movement of the plume toward the Columbia River has resulted in increased uranium concentrations near the river in recent years, as shown by the trend plots for wells 399-2-1 and 399-2-2 in Figure 6.1.23. The maximum detected in 1998 was 252 µg/L. Elevated concentrations at the south end of the 316-5 Process Trenches indicate that the soil column is contributing uranium contamination to the groundwater.

A localized area of elevated levels of uranium between the 324 Building and the Columbia River showed a maximum concentration of 128 µg/L in 1998 (see Figure 6.1.23).

Uranium in the 600 Area. The uranium concentration in a well southeast of the 400 Area (adjacent to Route 4S) decreased to a maximum of 91.3 µg/L in 1998. The contamination at this well is attributed to the nearby inactive 316-4 Crib (Section 5.12.3.3 in PNNL-11793). The retired 618-10 Burial Grounds are also located near this well.

Strontium-90. Strontium-90 was produced as a high-yield fission product and was present in waste streams associated with fuel reprocessing. Reactor operations also resulted in the release of some strontium-90 associated with fuel element breaches. Strontium-90 mobility in Hanford Site groundwater is reduced by adsorption onto sediment particles. However, strontium-90 is moderately mobile in groundwater because its adsorption is much weaker than for other radionuclides such as cesium-137 and plutonium. Because of sorption, a large proportion of the strontium-90 in the subsurface is not present in solution. The half-life of strontium-90 is 29.1 yr.

In 1998, strontium-90 activities at greater than the 8-pCi/L interim drinking water standard were found in one or more wells in each of the 100, 200, and 600 Areas. Levels of strontium-90 were greater than the 1,000-pCi/L derived concentration guide in portions of the 100, 200, and 600 Areas. The 100-N Area had the widest distribution with the highest activities detected at the Hanford Site during 1998.

Strontium-90 in the 100 Areas. Strontium-90 activities greater than the interim drinking water standard extend from the B Reactor complex to the Columbia River in the northeastern part of the 100-B,C Area (Figure 6.1.24). The highest continued to be found in wells near the inactive 116-B-1 and 116-C-1 Trenches. The maximum detected in 1998 was 170 pCi/L near the inactive 116-C-1 Trench. The sources for the strontium-90 appear to be liquid waste disposal sites near B Reactor and liquid overflow trenches near the Columbia River (DOE/EIS-0119F).

Strontium-90 is not widely distributed in the 100-D Area. One well continues to show levels that are consistently greater than the interim drinking water standard near the inactive D Reactor fuel

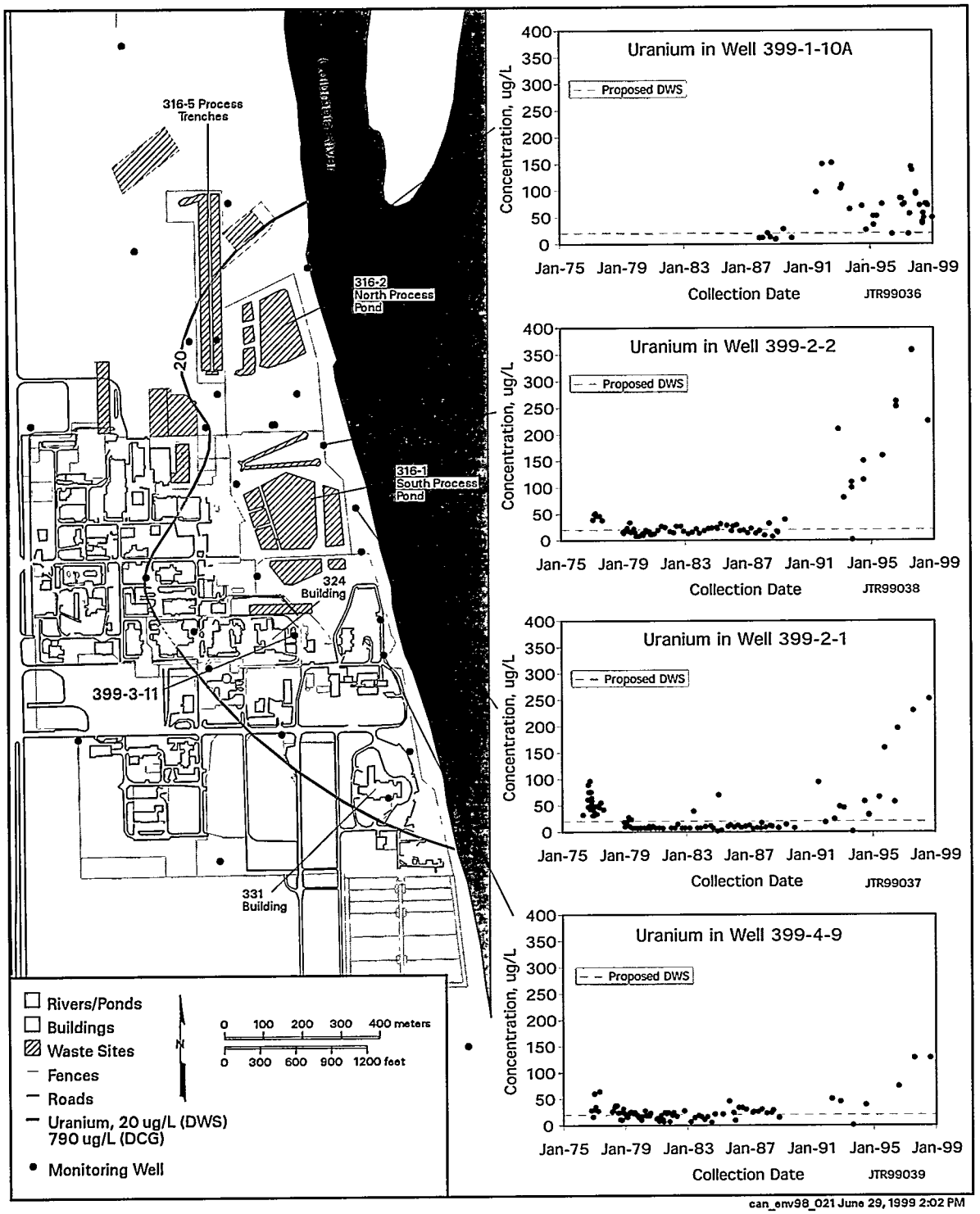
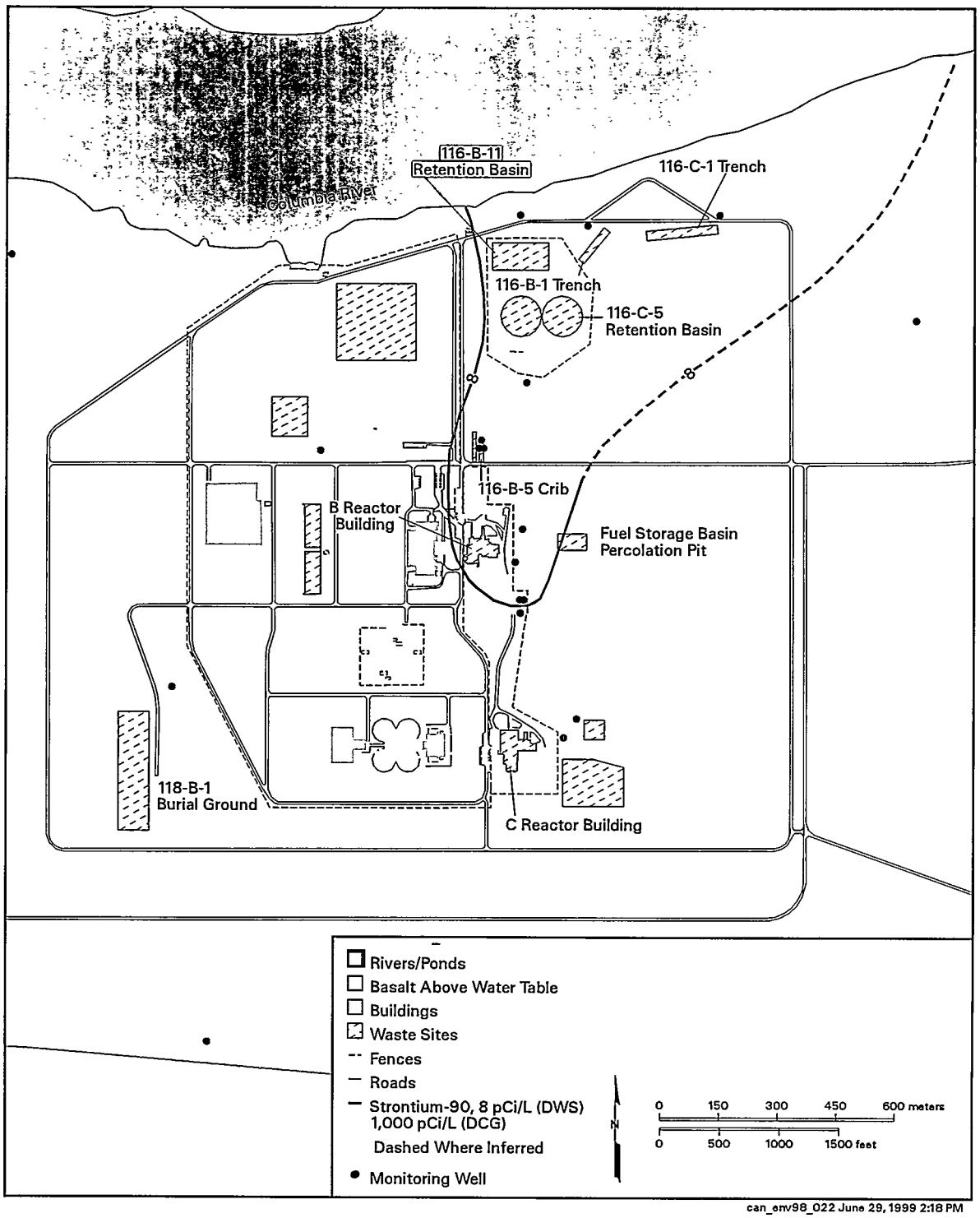


Figure 6.1.23. Average Uranium Concentrations in the Unconfined Aquifer in the 300 Area, 1998, and Concentration Trends for Select Wells



can_env98_022 June 29, 1999 2:18 PM

Figure 6.1.24. Average Strontium-90 Activities in the Unconfined Aquifer in the 100-B,C Area, 1998

storage basin. The maximum level was 42 pCi/L in 1998. Strontium-90 was detected at levels greater than the interim drinking water standard in well 199-D8-68 near the former 116-D-7 Retention Basin in the northern part of the 100-D Area.

Strontium-90 exceeded the interim drinking water standard in several wells near the 116-F-14 Retention Basins and 116-F-2 Trench in the eastern part of the 100-F Area. The maximum detected in 1998 was 359 pCi/L.

In the 100-H Area, strontium-90 contamination levels greater than the interim drinking water standard were present in an area adjacent to the Columbia River near the 107-H Retention Basin. The maximum detected in the 100-H Area in 1998 was 50 pCi/L between the retention basin and the Columbia River. The source of the contamination is past disposal of liquid effluent containing strontium-90 to retention basins and trenches in the 100-H Area.

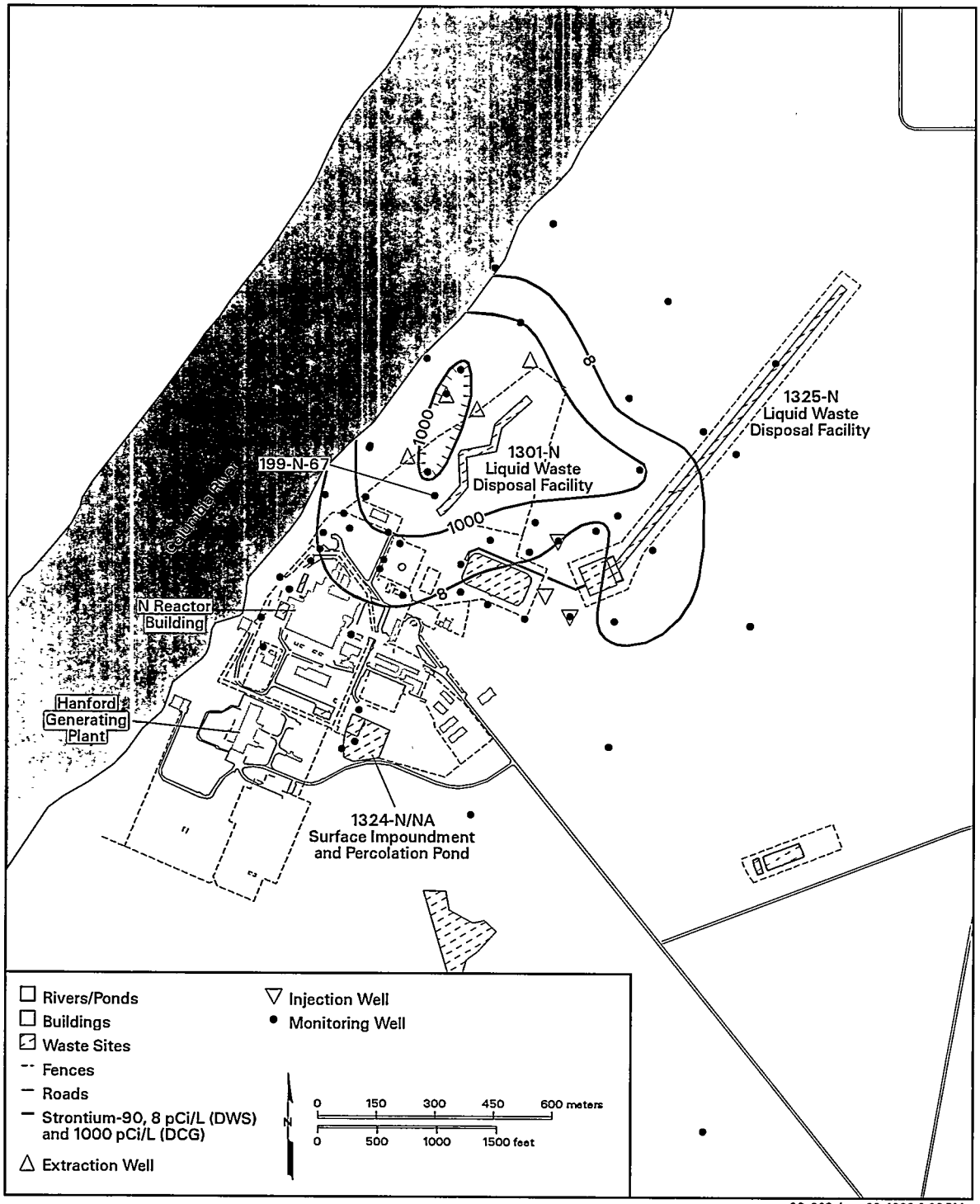
Strontium-90 at levels greater than the interim drinking water standard continues to show up in isolated areas in the 100-K Area. These areas include the vicinity of the KE and KW Reactors and between the 116-K-2 Liquid Waste Disposal Trench and the Columbia River. The maximum detected in 1998 was 6,290 pCi/L at well 199-K-109A, the only well in the 100-K Area where levels were above the derived concentration guide. The original source of the strontium-90 in this well, located near the KE Reactor, is believed to be the former 116-K-3 Injection Well/Drain Field. Maximum strontium-90 activities near the KW Reactor and the disposal trench were significantly lower than those near KE Reactor by approximately two orders of magnitude.

The distribution of strontium-90 in the 100-N Area is shown in Figure 6.1.25. Strontium-90 was detected at activities greater than the derived concentration guide in several wells located between the 1301-N Liquid Waste Disposal Facility, a source of the strontium-90, and the Columbia River. The 1325-N Liquid Waste Disposal Facility is also a source of strontium-90 in groundwater. The maximum level detected in 1998 was 26,000 pCi/L near the head end of the 1301-N facility (well 199-N-67). Strong, positive correlations between high-elevation groundwater levels and high-strontium-90 activities in wells indicate that strontium-90 is remobilized during periods of high water levels.

Strontium-90 discharges to the Columbia River through springs along the shoreline in the 100-N Area. Section 4.2, "Surface Water and Sediment Surveillance" and Section 3.2, "Near-Facility Environmental Monitoring," give the results of springs water sampling. Because of large levels in wells near the river, it was expected that strontium-90 exceeded the interim drinking water standard at the interface between the groundwater and the river (DOE/RL-96-102). Groundwater contaminated with strontium-90 entering the river could potentially reach an aquatic and riparian ecological receptor through direct uptake.

A pump-and-treat method began in 1995 to remove strontium-90 in the 100-N Area. The objective is to pump from the extraction wells to create a hydraulic barrier between the river and the 1301-N facility, thus reducing the volume of contaminated groundwater to the river. The pump-and-treat system, which uses ion-adsorption technology, removed approximately 0.1 Ci of strontium-90 from extracted groundwater during fiscal year 1998 (DOE/RL-99-02). This is compared to an estimated total of 76 to 88 Ci in the aquifer (in groundwater and adsorbed on the saturated sediments) (DOE/RL-95-110).

Strontium-90 in the 200 Areas. Strontium-90 distribution in the 200-East Area is shown in Figure 6.1.21. Strontium-90 activities in the 200-East Area were above the derived concentration guide in two wells near the inactive 216-B-5 Injection Well. The maximum was 10,800 pCi/L in well 299-E28-23. This injection well received an estimated 27.9 Ci of strontium-90 during 1945 and 1946 (PNL-6456). Strontium-90 was detected at a level above the



can_env98_023 June 29, 1999 2:28 PM

Figure 6.1.25. Average Strontium-90 Activities in the Unconfined Aquifer in the 100-N Area, 1998

interim drinking water standard in one well near the Plutonium-Uranium Extraction Plant cribs in the 200-East Area and in one well near the Reduction-Oxidation Plant cribs in the 200-West Area.

Strontium-90 in the 600 Area. In the 600 Area, the highest strontium-90 activities were detected in four wells in the former Gable Mountain Pond area (see Figure 6.1.21). In three of the wells, levels exceeded the derived concentration guide and reached a maximum of 1,350 pCi/L in 1998. Strontium-90 contamination in this area resulted from the discharge of radioactive liquid waste to the former Gable Mountain Pond during its early use.

Carbon-14. Carbon-14 activities are widely distributed in the 100-K Area and exceed the 2,000-pCi/L interim drinking water standard in two plumes near the KE and KW Reactors (Figure 6.1.26). The sources of the carbon-14 were the 116-KE-1 and 116-KW-1 Cribs, respectively. The maximum in 1998 was 35,000 pCi/L near the 116-KW-1 Crib. The derived concentration guide for carbon-14 is 70,000 pCi/L. Carbon-14 has a half-life of 5,730 yr.

Cesium-137. Cesium-137, which has a half-life of 30 yr, is produced as a high-yield fission product and is present in waste streams associated with fuel processing. Former reactor operations also may have resulted in the release of some cesium-137 associated with fuel element breaches. Cesium-137 is normally strongly sorbed on soil and, thus, is very immobile in Hanford Site groundwater. The interim drinking water standard for cesium-137 is 200 pCi/L; the derived concentration guide is 3,000 pCi/L.

Cesium-137 was detected in three wells located near the inactive 216-B-5 Injection Well in the 200-East Area. The injection well received cesium-137 bearing wastes from 1945 to 1947. The maximum cesium-137 in 1998 was 1,840 pCi/L, which is greater than the interim drinking water standard. Cesium-137 appears to be restricted to the immediate vicinity of the former injection well by its extremely low mobility in groundwater.

Cobalt-60. Cobalt-60 in groundwater is typically associated with wastes generated by reactor effluent. Cobalt-60 is normally present as a divalent transition metal cation and, as such, tends to be highly immobile in groundwater. However, complexing agents may mobilize it. All groundwater samples analyzed for cobalt-60 in 1998 were below the 100-pCi/L interim drinking water standard. The derived concentration guide for cobalt-60 is 5,000 pCi/L.

Cobalt-60 activities were less than the interim drinking water standard in the northwestern part of the 200-East Area and the adjacent 600 Area north of the 200-East Area, which are the same areas where the technetium-99 contamination associated with the BY Cribs is found. Apparently, cobalt in this plume is mobilized by reaction with cyanide or ferrocyanide in the waste stream, forming a dissolved cobalt species. The maximum measured in 1998 was 66 pCi/L at the BY Cribs. Because of its relatively short half-life (5.3 yr), much of the cobalt-60 in groundwater in this area has decayed to lower activities.

Plutonium. Plutonium has been released to the soil column in several locations in both the 200-West and 200-East Areas. Plutonium is generally considered to sorb strongly to sediments and, thus, has limited mobility in the aquifer. The derived concentration guide for both plutonium-239 and plutonium-240 is 30 pCi/L. Analytical detection is incapable of distinguishing between plutonium-239 and plutonium-240; thus, the results are expressed as a concentration of plutonium-239,240. There is no explicit drinking water standard for plutonium-239,240; however, the gross alpha drinking water standard of 15 pCi/L would be applicable at a minimum. Alternatively, if the derived concentration guide that is based on a 100-mrem dose standard is converted to the 4-mrem dose equivalent used for the drinking water standard, 1.2 pCi/L would be the relevant guideline. The half-lives of plutonium-239 and plutonium-240 are 24,000 and 6,500 yr, respectively.

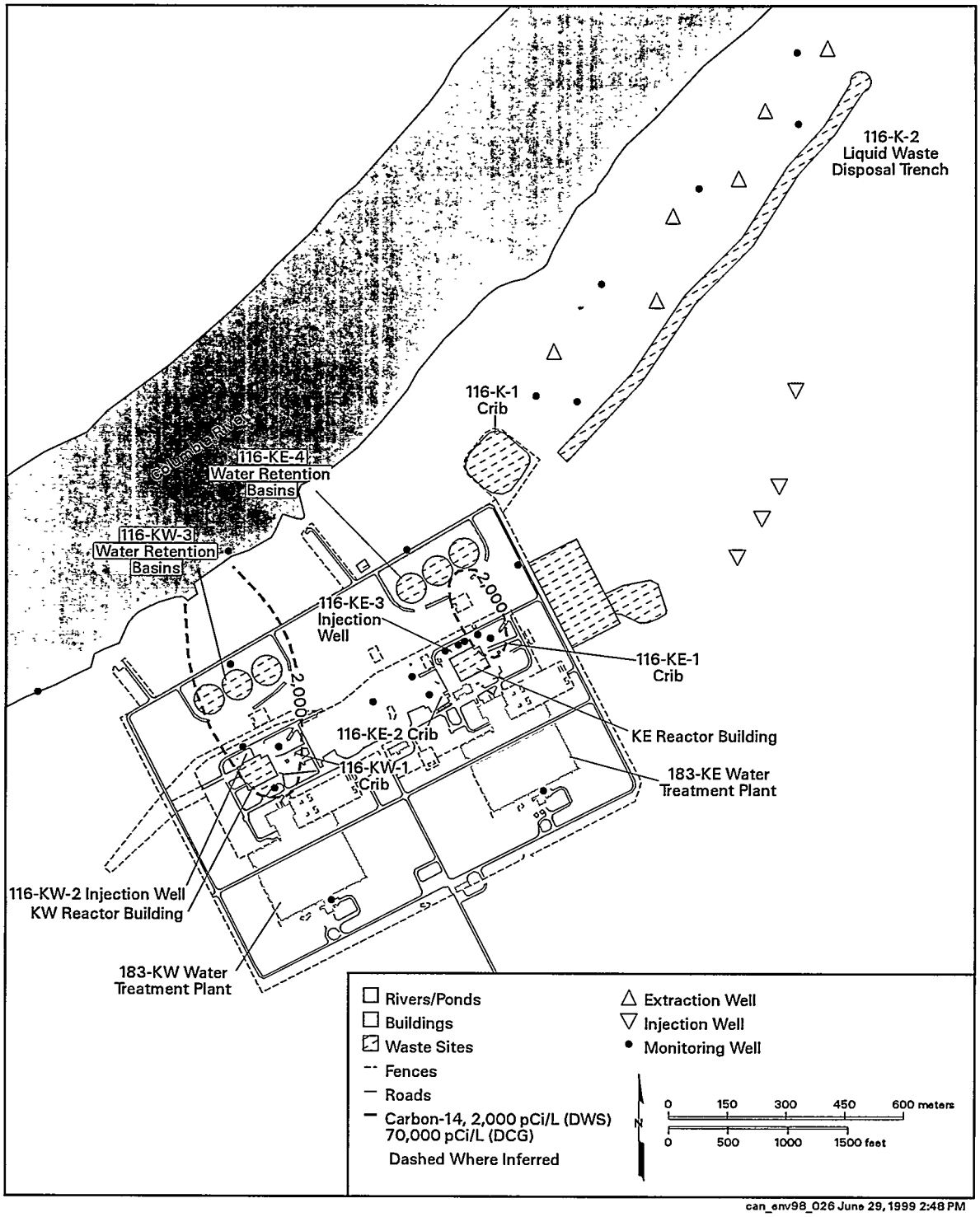


Figure 6.1.26. Average Carbon-14 Activities in the 100-K Area, 1998

The only location where plutonium isotopes were detected in groundwater was near the inactive 216-B-5 Injection Well in the 200-East Area. Groundwater sampled during 1998 at wells located near this injection well ranged up to 66 pCi/L of plutonium-239,240. Because plutonium is strongly adsorbed to sediments and may have been injected into the aquifer as suspended particles, it is likely that the values measured result in part from solid rather than dissolved material. The injection well received an estimated 244 Ci of plutonium-239,240 during its operation from 1945 to 1947 (PNL-6456).

6.1.6.2 Chemical Monitoring Results for the Unconfined Aquifer

In recent years, chemical analyses performed by various monitoring programs at the Hanford Site have identified several hazardous chemicals in groundwater at concentrations greater than their respective drinking water standards. Nitrate, chromium, and carbon tetrachloride are the most widely distributed of these hazardous chemicals and have the highest concentrations in groundwater at the Hanford Site. Chemicals that are less widely distributed and have lower concentrations in groundwater include chloroform, trichloroethylene, tetrachloroethylene, cis-1,2-dichloroethylene, cyanide, and fluoride.

A number of parameters such as pH, specific conductance, total carbon, total organic carbon, and total organic halides are used as indicators of contamination. These are mainly discussed in Section 6.1.7, "RCRA Summary." Other chemical parameters listed in Table 6.1.3 are indicators of the natural chemical composition of groundwater and are usually not contaminants from operations at the Hanford Site. These include alkalinity, aluminum, calcium, iron, magnesium, manganese, potassium, silica, and sodium. Chloride and sulfate occur naturally in groundwater and can also be introduced as contaminants from site operations. There is no primary drinking water standard for chloride or sulfate. The secondary standard for each is 250 mg/L and is based on aesthetic rather than health considerations; therefore, they will not be discussed in detail. The analytical technique used to determine the concentration of metals in groundwater provides results for a number of constituents such as antimony, barium, beryllium, boron, cadmium, copper, nickel, silver, strontium, vanadium, and zinc that are rarely observed at greater than background concentrations.

The following presents a summary of the chemical constituents in groundwater at concentrations greater than existing or proposed drinking water standards (40 CFR 141 and EPA 822-R-96-001; see Appendix C).

Nitrate. Many groundwater samples collected in 1998 were analyzed for nitrate. Nitrate was measured at concentrations greater than the drinking water standard (45 mg/L as nitrate ion) in wells in all operational areas. Nitrate is associated primarily with process condensate liquid wastes, though other liquids discharged to the ground also contained nitrate. Nitrate contamination in the unconfined aquifer reflects the extensive use of nitric acid in decontamination and chemical reprocessing operations. However, additional sources of nitrate are located off the site to the south, west, and southwest. The distribution of nitrate on the Hanford Site is shown in Figure 6.1.27; this distribution is similar to previous evaluations. Although nitrate contamination can be detected over large areas of the site, the areas impacted by levels greater than the drinking water standard are small. The widespread distribution of nitrate below the drinking water standard is shown in Figure 5.2-2 of PNNL-12086.

Nitrate in the 100 Areas. A plume containing slightly elevated levels of nitrate occurs in the northeastern part of the 100-B,C Area. In 1998, the maximum nitrate concentration in this area was 49 mg/L, which exceeded the drinking water standard.

Nitrate is found at levels greater than the drinking water standard in much of the 100-D Area. The highest nitrate level found in the 100-D Area in 1998

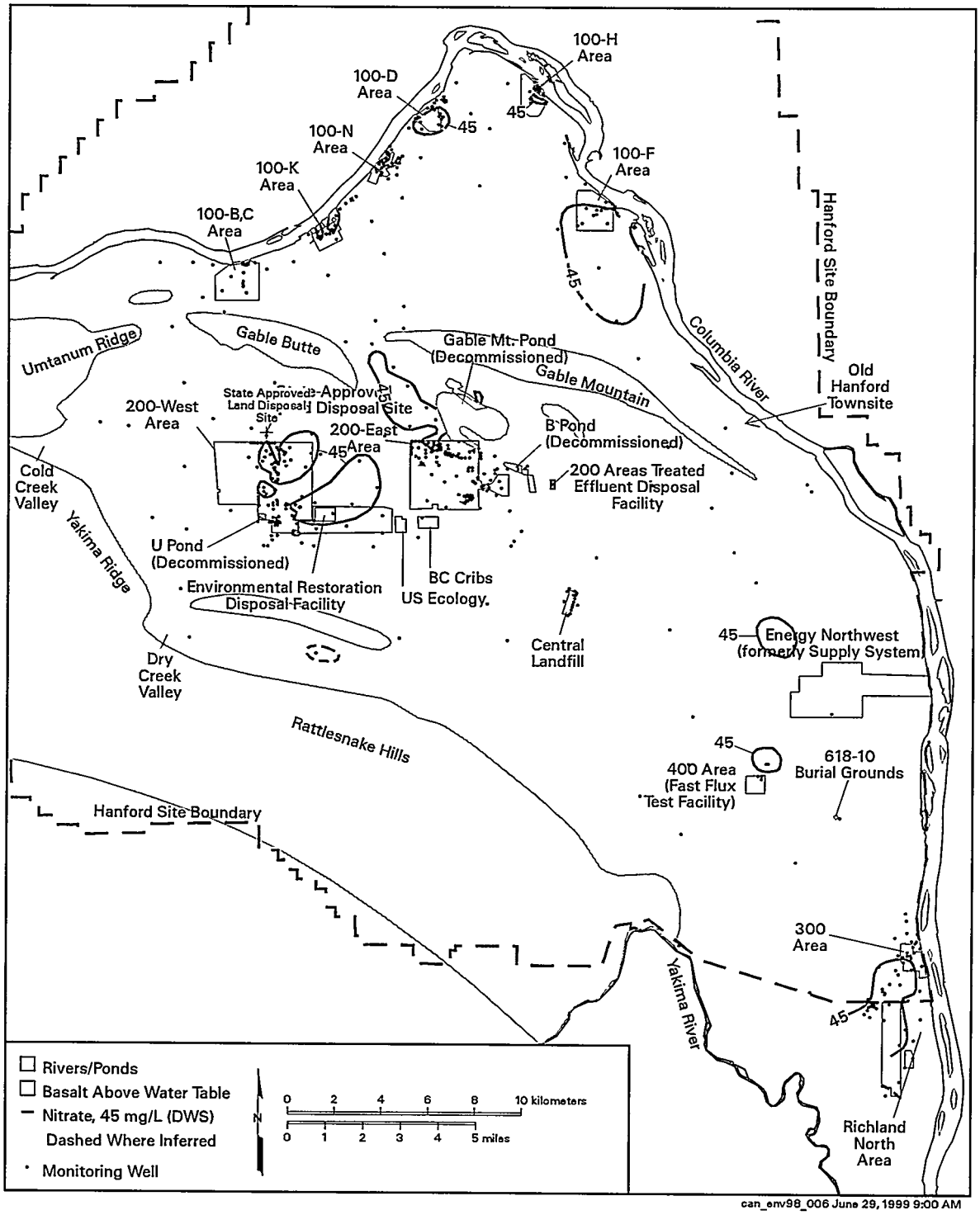


Figure 6.1.27. Average Nitrate Concentrations in the Unconfined Aquifer, 1998

was 103 mg/L, the same as in 1997, in the southwestern part of the area. Slightly lower levels were found in the northeastern part of the 100-D Area.

The central and southern portions of the 100-F Area contain nitrate in groundwater at levels greater than the drinking water standard. This plume appears to extend to the south and southeast into the 600 Area from upgradient sources near F Reactor. In the vicinity of the reactor, groundwater flow was to the south and southeast in 1998. The maximum nitrate detected in the 100-F Area in 1998 was 198 mg/L in the southwestern part of the 100-F Area.

Nitrate above the drinking water standard in the 100-H Area is restricted to a small area downgradient of the former 183-H Solar Evaporation Basins. The concentrations in this area have been some of the highest on the site; however, levels decreased in 1998. The maximum nitrate detected was 273 mg/L. The levels of nitrate exhibited in this area are related to the groundwater levels and Columbia River stage.

Nitrate at levels greater than the drinking water standard in the 100-K Area are found downgradient of both the KE and KW Reactors and appear to reach the Columbia River. The maximum concentration detected in 1998 was 175 mg/L in a well adjacent to the KE Reactor.

Although detected over most of the 100-N Area, nitrate contamination above the drinking water standard occurs at isolated locations in the 100-N Area. The areas where concentrations exceed the drinking water standard grew in size in 1998. The maximum was 280 mg/L in a well located between the 1301-N Liquid Waste Disposal Facility and the Columbia River.

Nitrate in the 200-East Area. The nitrate plume in the 200-East Area covers a nearly identical area to that of the tritium plume. However, the area with nitrate exceeding the drinking water standard is smaller than the area with tritium exceeding its drinking water standard. Nitrate exceeds the drinking water standard near the Plutonium-Uranium Extraction Plant and near cribs in the northern part of the 200-East Area. In 1998, the highest concentrations were reported in several wells near the 216-B-8 and BY Cribs. The maximum concentration in the 200-East Area was 491 mg/L in a well adjacent to the inactive 216-B-8 Crib. High nitrate concentrations in the 600 Area north of the 200-East Area, ranging up to 119 mg/L, are apparently related to past disposal practices at the BY Cribs.

High nitrate concentrations continued to be found near liquid waste disposal facilities that received effluent from Plutonium-Uranium Extraction Plant operations. Nitrate concentrations in wells near the inactive 216-A-10 and 216-A-36B Cribs generally have tended to decrease in the past few years but remained greater than the drinking water standard, even though these facilities were removed from service in 1987. The maximum nitrate concentration detected in this vicinity was 192 mg/L adjacent to the 216-A-36B Crib.

Nitrate is also elevated in a few wells near the former Gable Mountain Pond north of the 200-East Area. The highest measured concentration in this area in 1998 was 127 mg/L.

Nitrate in the 200-West Area. Nitrate concentrations greater than the drinking water standard were widespread in groundwater beneath the 200-West Area and adjacent parts of the 600 Area. The major nitrate plumes were found in wells east of U Plant and wells in the north-central part of the 200-West Area. Some of the highest nitrate concentrations across the site continued to be found in wells southeast of U Plant, where the maximum detected in 1998 was 1,673 mg/L adjacent to the inactive 216-U-17 Crib. This was the highest nitrate concentration observed on the Hanford Site in 1998. The presence of nitrate in wells near this crib was observed before February 1988 when the crib went into operation. The source of nitrate is believed to be wastes

disposed of in the 216-U-1 and 216-U-2 Cribs southwest of U Plant. These cribs received >1,000,000 kg (2,200,000 lb) of nitrate bearing chemicals during their operation from 1951 to 1967 (PNL-6456). As of September 1998, a pump-and-treat system near the 216-U-17 Crib has removed 7,910 kg (17,442 lb) of nitrate from approximately 338 million L (89 million gal) of extracted groundwater (DOE/RL-99-02).

Nitrate concentrations (maximum of 238 mg/L) continued to be elevated above the drinking water standard near other inactive cribs to the south that are associated with the U Plant and Reduction-Oxidation Plant. These elevated levels represent nitrate plumes that coalesce with the plume emanating from the U Plant area. A small, isolated plume of elevated nitrate occurs west of the Reduction-Oxidation Plant near the inactive 216-S-25 Crib and S and SX Tank Farms, where the maximum concentration was 121 mg/L.

A large area, encompassing the northern half of the 200-West Area, continued to contain nitrate in groundwater at concentrations much greater than the drinking water standard. Wells showing the highest concentrations are located near several inactive liquid waste disposal facilities that received waste from early T Plant operations. A large amount of nitrate was disposed to these cribs (e.g., approximately 2,300,000 kg [5,100,000 lb] of nitrate to the 216-T-7 Crib). Maximum concentrations in these wells in 1998 ranged up to 726 mg/L west of T Plant near the inactive T, TX, and TY Tank Farms. High concentrations of nitrate (306 mg/L) were also found in 1998 at the northeastern boundary of the 200-West Area.

A smaller area of elevated nitrate concentrations above the drinking water standard is located in the vicinity of the Plutonium Finishing Plant in the central part of the 200-West Area. The highest reported concentration was 483 mg/L near the 216-Z-9 Crib. This crib had received an estimated 1,300,000 kg (2,900,000 lb) of nitrate bearing chemicals during its operation from 1955 to 1962.

Nitrate in Other Areas. Nitrate concentrations near the city of Richland and in the former 1100 Area, Richland North Area, and adjacent parts of the 600 Area along the southern boundary of the Hanford Site are also apparently affected by offsite nitrate sources. These sources may include agriculture, food processing, urban horticulture, and nuclear fuel manufacturing at offsite commercial facilities. The part of this plume with nitrate concentrations greater than the drinking water standard extends from off the site, south of the former Horn Rapids Landfill, to the 300 Area to the northeast. The area of the nitrate plume at levels greater than the drinking water standard expanded in the southern part of the Hanford Site in 1998. The maximum nitrate concentration in 1998 was 174 mg/L on the northeastern edge of the Horn Rapids Landfill.

Although most nitrate observed on the site is the result of Hanford Site operations, elevated nitrate concentrations in wells in the western part of the site appear to be the result of increasing agricultural activity in offsite areas (e.g., Cold Creek Valley). There is no known source of nitrate in these areas associated with site operations, and the groundwater flow is from the west toward the Hanford Site facilities to the east. Nitrate levels have fluctuated considerably in wells upgradient of the 200 Areas over the past 30 yr. In Cold Creek Valley, nitrate levels have been near or greater than the drinking water standard in one well since 1985. A maximum nitrate concentration of 54 mg/L was found in a well located just north of the Rattlesnake Hills.

Nitrate was detected at levels exceeding the drinking water standard in a well downgradient of the 400 Area process ponds. These levels were attributed to a former sanitary sewage lagoon west of the process ponds. The maximum concentration observed was 97 mg/L.

High nitrate concentrations have been reported off the site in parts of Grant, Adams, and Franklin Counties to the east and north of the Hanford Site. Ryker and Jones (1995) reported that 28% of the wells sampled in this area had nitrate concentrations above the drinking water standard. The nitrate is related, in general, to fertilizer and water usage and has been increasing since the 1950s. This nitrate may impact surface-water quality (see Section 4.2, "Surface Water and Sediment Surveillance") and groundwater in the northern part of the Hanford Site north of the Columbia River.

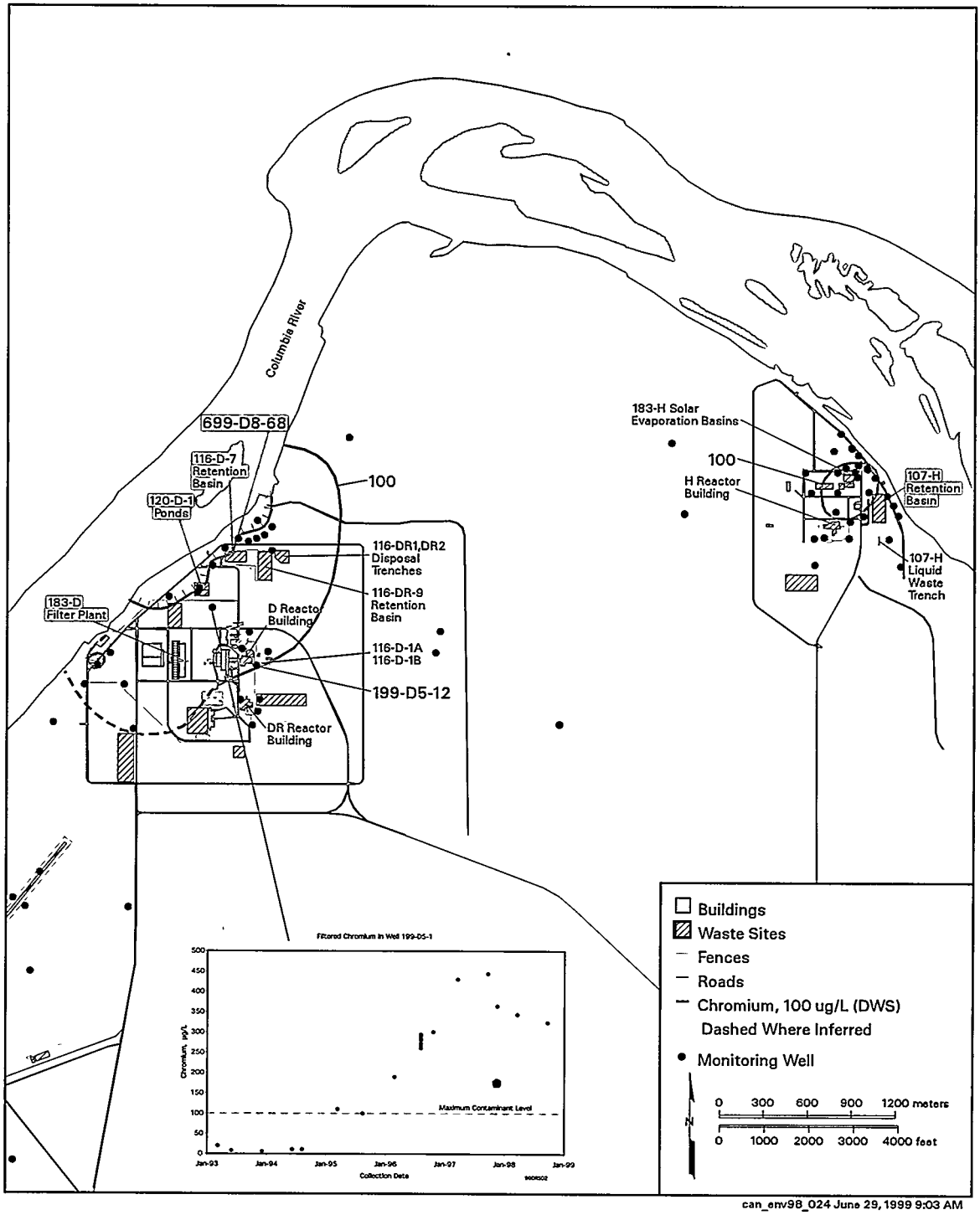
Chromium. Use of chromium on the Hanford Site has been extensive. In the 100 Areas, sodium dichromate was added to cooling water as a corrosion inhibitor, and some residual chromium remains from that use. Chromium was used for decontamination in the 100, 200, and 300 Areas and also was used for oxidation state control in the Reduction-Oxidation Plant process. In the hexavalent form, chromium is present in an anionic state. Thus, hexavalent chromium is freely mobile in the groundwater. The drinking water standard for chromium is 100 µg/L.

Both filtered and unfiltered samples were collected for analyses of chromium and other metals from several of the wells onsite. Unfiltered samples may contain metals present as particulate matter, whereas filtered samples are representative of the more-mobile, dissolved metals. Filtered samples also may contain some colloidal particles that are fine enough to pass through the filter. Drinking water standards are based on unfiltered concentrations; however, differences in well construction and pumping practices between monitoring wells and water supply wells make it difficult to predict potential drinking water concentrations from monitoring well data when the metals are present as particulate matter. In general, filtered samples provide the best indication of groundwater contamination levels for chromium because unfiltered samples are subject to greater variability introduced by the sampling process. Chromium concentrations in filtered samples, which are considered to be representative of dissolved hexavalent chromium, will be used to describe the level of contamination in the discussion below.

Chromium in the 100 Areas. Chromium has been detected above the drinking water standard in the 100-B,C, 100-D, 100-H, 100-K, and 100-N Areas. Groundwater pump-and-treat systems continued to operate in 1998 to reduce the amount of hexavalent chromium entering the Columbia River at the 100-D, 100-H, and 100-K Areas. The purpose of the pump-and-treat systems is to prevent discharge of hexavalent chromium into the Columbia River at concentrations exceeding 11 µg/L, which is the EPA's standard for protection of freshwater aquatic life.

Chromium exceeded the drinking water standard from a filtered sample in the 100-B,C Area in 1998. The maximum concentration was 113 µg/L downgradient of former water treatment facilities, where sodium dichromate may have leaked from storage tanks and transfer facilities.

The chromium distribution in the 100-D Area is shown in Figure 6.1.28. An area of chromium concentrations greater than the drinking water standard extends from northeast to southwest across the 100-D Area near the Columbia River. The source of chromium in groundwater is sodium dichromate released to the ground at former facilities near D Reactor. Leakage from inactive retention basins and liquid waste disposal trenches north of D Reactor may also have contributed to the chromium plume. In 1998, the maximum chromium concentration from filtered samples was 2,200 µg/L in a well in the vicinity of a chromium hot spot in the southwestern portion of the 100-D Area. The source of this hot spot is unknown. In situ redox manipulation technology is currently being demonstrated in the hot spot area to address hexavalent chromium contamination in groundwater. This technology immobilizes hexavalent chromium by reducing the soluble chromate ion to highly insoluble chromium hydroxide or iron chromium hydroxide. In 1998, results of a



can_env98_024 June 29, 1999 9:03 AM

Figure 6.1.28. Average Filtered Chromium Concentrations in the 100-D and 100-H Areas, 1998, and Concentration Trends for Selected Wells

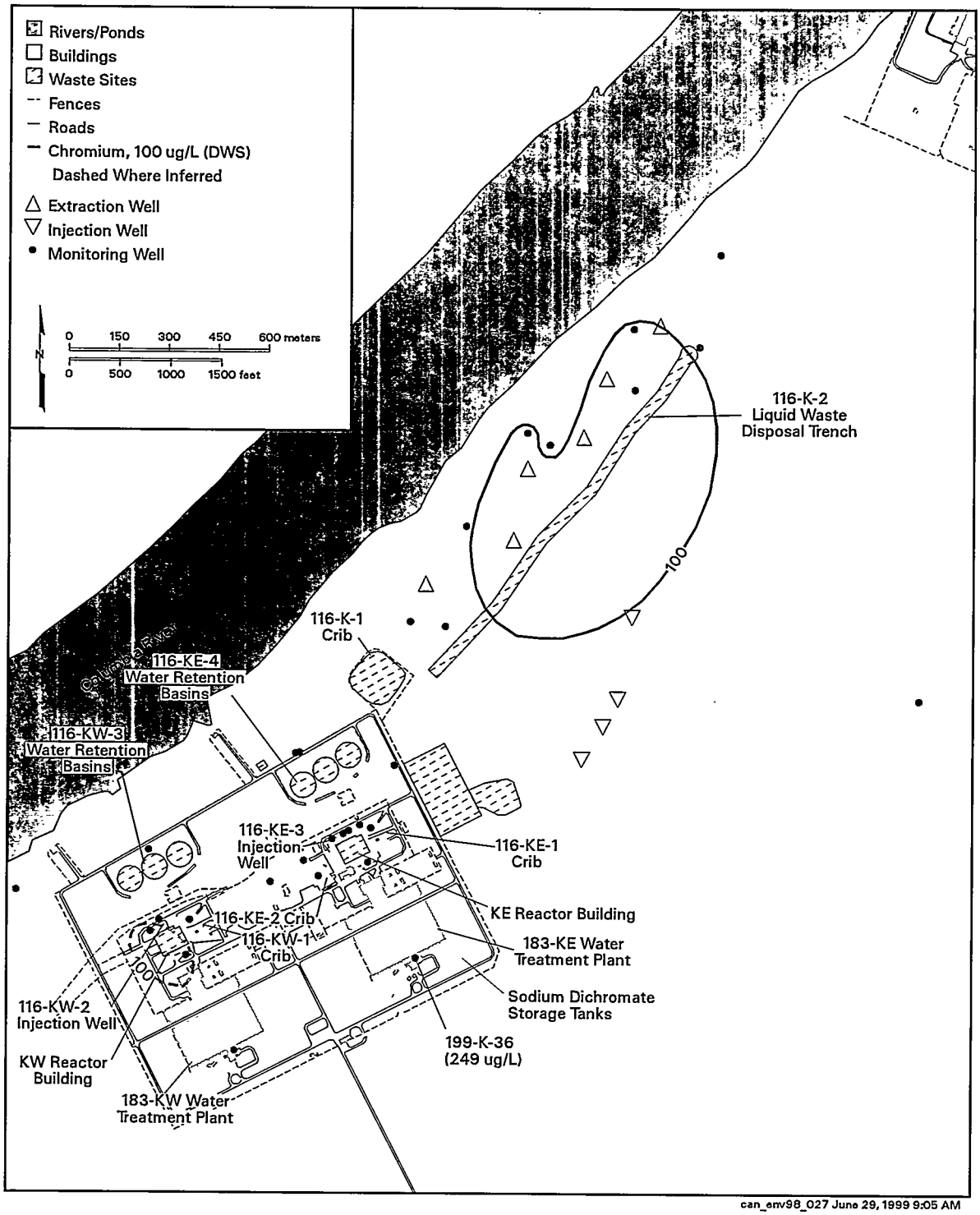
treatability study indicated that hexavalent chromium concentrations were decreased from ~1,000 µg/L to less than detection limits (7 µg/L) within the treatment zone. In the area near the inactive 120-D-1 Ponds, chromium concentrations increased in response to ceased discharges of noncontaminated water to the ponds in 1994, as shown by the trend plot for well 199-D5-13 in Figure 6.1.28. Chromium concentrations decreased in late 1997 through 1998.

Many samples from 100-H Area wells contained chromium at levels greater than the drinking water standard (see Figure 6.1.28). In 1998, the maximum chromium concentration from filtered samples collected from the shallow parts of the unconfined aquifer was 259 µg/L in a well near the former 183-H Solar Evaporation Basins. Chromium was also found at levels above the drinking water standard in one well monitoring the deeper part of the unconfined aquifer. Filtered samples from this well, located near the former 183-H Basins, contained 201 µg/L of chromium in 1998. Potential sources include past disposal of sodium dichromate near H Reactor, disposal to the inactive 107-H Liquid Waste Disposal Trench, and chromium in acid wastes stored in the former 183-H Basins (Peterson and Connelly 1992). Chromium was also detected above the drinking water standard in the 600 Area west of the 100-H Area. The maximum concentration in this area in 1998 was 102 µg/L. The primary sources of the chromium plume west of 100-H Area were former 100-D Area liquid waste disposal facilities. Effluent releases at the 100-D Area during operations produced groundwater mounding, which altered flow conditions. This contributed to the spreading of chromium contamination into the 600 Area.

A groundwater remediation pump-and-treat system to decrease the amount of hexavalent chromium entering the Columbia River from the aquifer continued to operate in the 100-D and 100-H Areas in 1998. Groundwater extracted from the 100-D Area wells downgradient of the inactive retention basins is piped to the 100-H Area for treatment. Groundwater extracted from the 100-D and 100-H Area wells is treated using ion-exchange technology and then reinjected into the aquifer in the southwestern part of the 100-H Area. Performance of the interim action to pump and treat has shown that hydraulic containment, resulting from the operation of the extraction wells, has reduced the amount of chromium entering the river from the aquifer in both the 100-D and 100-H Areas (DOE/RL-97-96, DOE/RL-99-13). By the end of December 1998, approximately 53 kg (116 lb) of chromium were removed from >401.5 million L (106.1 million gal) of groundwater extracted from these areas since pump-and-treat operations began in July 1997.

Chromium in the 100-K Area occurs in groundwater near or at levels greater than the drinking water standard (Figure 6.1.29). Two localized areas of chromium contamination occur near the KW Reactor and the water treatment basins southeast of the KE Reactor. The maximum concentration in 1998 was 443 µg/L near the KW Reactor. By late 1998, chromium concentrations reached a maximum of 249 µg/L in a well (199-K-36) adjacent to the 183-KE Water Treatment Basins and inactive sodium dichromate storage tanks. A much wider area of chromium contamination is found in the vicinity of the former 116-K-2 Liquid Waste Disposal Trench to the northeast. A pump-and-treat system for treating chromium in groundwater between the trench and the Columbia River, which began operating in October 1997, continued to operate in 1998. Groundwater extracted from a network of wells is treated using ion-exchange technology and then returned to the aquifer upgradient of the 116-K-2 Trench. By the end of December 1998, approximately 42 kg (93 lb) of chromium have been removed from >311 million L (82 million gal) of extracted groundwater (DOE/RL-99-13).

In the 100-N Area, chromium contamination is not widespread in groundwater. However, filtered samples in one well that monitors a locally confined



can_env98_027 June 29, 1999 9:05 AM

Figure 6.1.29. Average Filtered Chromium Concentrations in the 100-K Area, 1998

unit within the Ringold Formation have consistently shown concentrations greater than the drinking water standard northwest of the 1301-N Liquid Waste Disposal Facility. A filtered sample from a well upgradient of the inactive 1301-N facility contained a concentration of 124 µg/L, which exceeded the drinking water standard in this well for the first time. The source for the contamination at these locations is unknown.

Chromium in the 200 Areas. Chromium at concentrations greater than the drinking water standard in the 200-East Area was found in one well on the southern boundary of the A and AX Tank Farms. The maximum concentration detected in the sample was 2,820 µg/L. Concentrations in this well have been sporadic, and the source of the chromium is unknown.

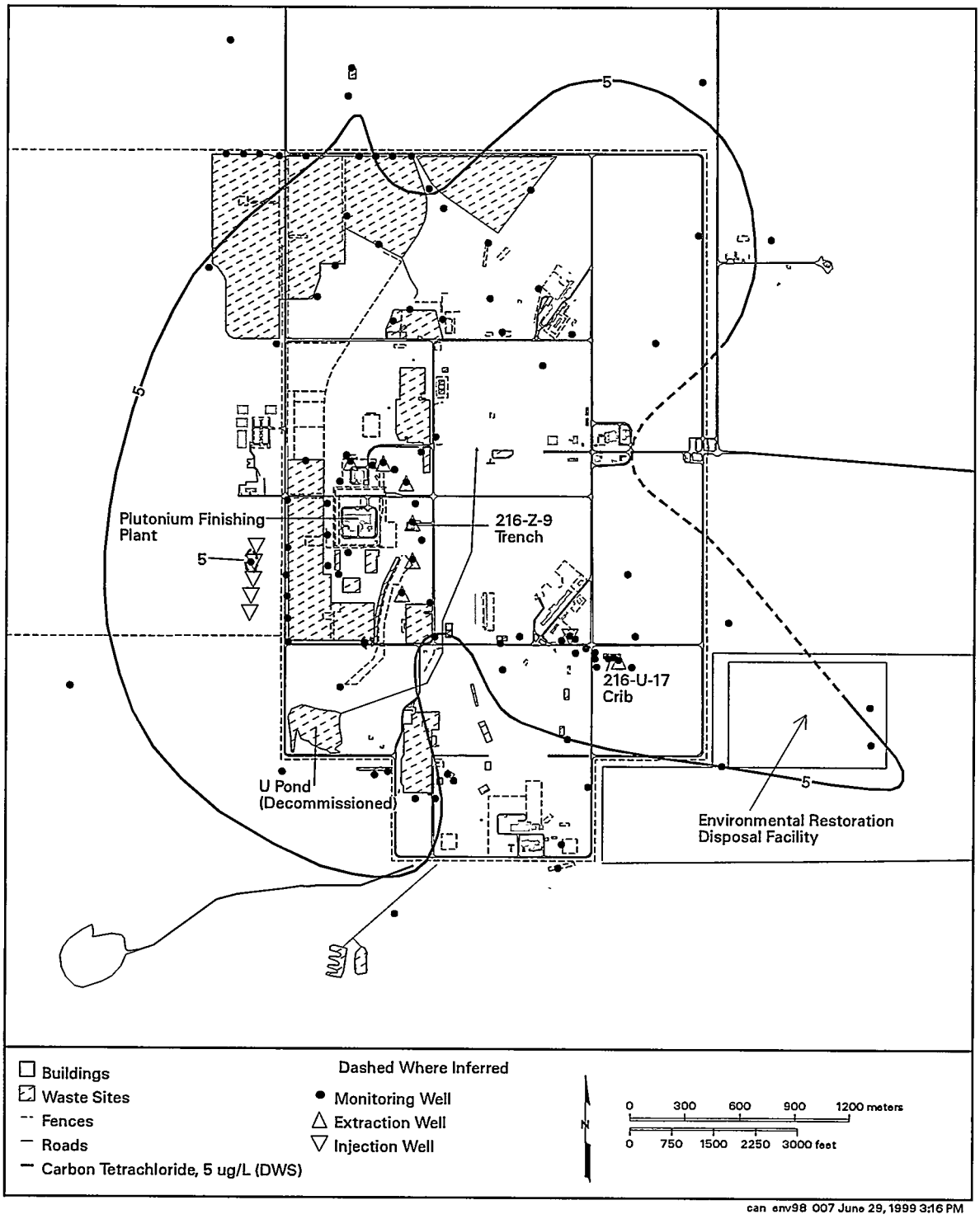
Chromium contamination has been found at several locations in the 200-West Area. Areas where concentrations exceeded the drinking water standard in 1998 include the T, TX, and TY Tank Farms and 216-S-10 Pond. Filtered samples from a new well monitoring the TX and TY Tank Farms showed a maximum concentration of 180 µg/L, the highest filtered chromium concentration in the 200-West Area. The highest concentration found in the vicinity of T Tank Farm was 172 µg/L. The highest concentration near the former 216-S-10 Pond was 175 µg/L.

Chromium in Other Areas. Filtered chromium concentrations above the drinking water standard have been known to occur downgradient of the 200-West Area (located southwest of the 200-East Area). However, the sampling frequency of wells in this area was changed from annual to every 3 yr in 1998 because historical trends showed that chromium concentrations were steady in this area. The maximum concentration in this area in 1997 was 226 µg/L. The extent of chromium contamination in this area is poorly defined, and the source has not been determined.

Carbon Tetrachloride. The carbon tetrachloride contamination that occurs above the 5-µg/L drinking water standard in much of the 200-West Area represents one of the most significant contaminant plumes at the Hanford Site (Figure 6.1.30). The plume covers an area that is >10 km^2 (4 mi^2). However, the overall carbon tetrachloride distribution has changed slowly since the plume was first identified in 1987.

The bulk of the contamination is believed to be from waste disposal operations associated with the Plutonium Finishing Plant in the west-central part of the 200-West Area. Carbon tetrachloride was used as the carrier solvent for tributyl phosphate in the final purification of plutonium. Carbon tetrachloride was also used in the same facility as a nonflammable thinning agent while machining plutonium. A minor source of carbon tetrachloride is a former waste disposal crib near T Plant. Carbon tetrachloride is immiscible in water but exhibits a relatively high solubility (805,000 µg/L at 20°C [68°F]). Carbon tetrachloride has been found to have a relatively high degree of mobility in groundwater. Mobilization above the water table can also occur through vapor transport.

Wells in the vicinity of the Plutonium Finishing Plant showed the highest concentrations in the plume, with levels exceeding the drinking water standard by more than two orders of magnitude. The maximum concentration was near 7,000 µg/L in one pump-and-treat extraction well just north of the plant. Pump-and-treat operations, which began in 1994, have influenced the distribution of carbon tetrachloride. The plume center continues to move in a northerly and easterly direction toward the extraction wells, as evidenced by increased concentrations in several extraction and monitoring wells (DOE/RL-99-02). The extraction wells are located north and east of the Plutonium Finishing Plant. Carbon tetrachloride concentrations in the vicinity of the injection wells southwest of the plant continue to decline as a result of injection of the treated water. As of September



can env98 007 June 29, 1999 3:16 PM

Figure 6.1.30. Average Carbon Tetrachloride Concentrations in the Unconfined Aquifer in the 200-West Area, 1998

1998, approximately 615 million L (162 million gal) of extracted groundwater have been treated, resulting in the removal of 2,099 kg (4,637 lb) of carbon tetrachloride (DOE/RL-99-02).

Near the 216-U-17 Crib in the southeastern part of the 200-West Area, the pump-and-treat system removed 13.8 kg (30.3 lb) of carbon tetrachloride from approximately 338 million L (89 million gal) of extracted groundwater as of September 1998 (DOE/RL-99-02).

The extent of carbon tetrachloride contamination in deeper parts of the aquifer is uncertain because of the limited amount of concentration data from depths below the water table. The limited amount of data indicates that the concentrations are highest at the top of the aquifer and decline with depth at most locations within the plume. In 1998, carbon tetrachloride was found at a level of 12 µg/L at a depth of ~58 m (190 ft) below the water table near the Plutonium Finishing Plant.

Changes in groundwater flow since decommissioning U Pond may be influencing the plume configuration and the concentrations at particular locations. Another potential influence is the continued spreading of carbon tetrachloride above the water table, in either the liquid or vapor phase. Free-phase, liquid, carbon tetrachloride above and possibly below the water table provides a continuing source of contamination. Therefore, lateral expansion of the carbon tetrachloride plume is expected to continue.

Chloroform. A chloroform plume appears to be associated with, but not exactly coincident with, the carbon tetrachloride plume in the 200-West Area (Figure 6.1.31). The highest chloroform concentrations were measured in the vicinity of the Plutonium Finishing Plant, where the maximum level was 120 µg/L. The drinking water standard for chloroform is 100 µg/L (total trihalomethanes), which is 20 times higher than that for carbon tetrachloride. The origin of chloroform is unknown, but is suspected to be a degradation product of carbon tetrachloride or an anaerobic degradation product associated with septic drain fields.

Trichloroethylene. A commonly used organic solvent, trichloroethylene has a drinking water standard of 5 µg/L. In 1998, trichloroethylene was detected at levels greater than the drinking water standard in some wells in the 100, 200, 300, and 600 Areas. The most widespread area of contamination occurred in the 200-West Area.

Trichloroethylene in the 100 Areas. Trichloroethylene was detected at levels greater than the drinking water standard in the southwestern corner of the 100-F Area and in the adjacent 600 Area. The maximum concentration detected in this area was 18 µg/L in the adjacent 600 Area. No specific sources of this contamination have been identified.

In the 100-K Area, two wells sampled contained trichloroethylene at levels above the drinking water standard, representing a localized area of contamination near the KW Reactor complex. The maximum concentration was 24 µg/L in monitoring well 199-K-106A.

Trichloroethylene in the 200 Areas. Trichloroethylene was detected at levels greater than the drinking water standard in several parts of the 200-West Area (Figure 6.1.32). The most significant area extends from the Plutonium Finishing Plant to the west of T Plant and past the northern boundary of the 200-West Area. The source of the contamination is presumably past disposal in these plant areas. The highest concentration was 23 µg/L northeast of the Plutonium Finishing Plant. A smaller, isolated area of contamination occurs downgradient of the U Plant cribs, where the maximum concentration was 15 µg/L.

Trichloroethylene in the 300 Area. Trichloroethylene was detected at one well in 1998 in the 300 Area at concentrations above the drinking water

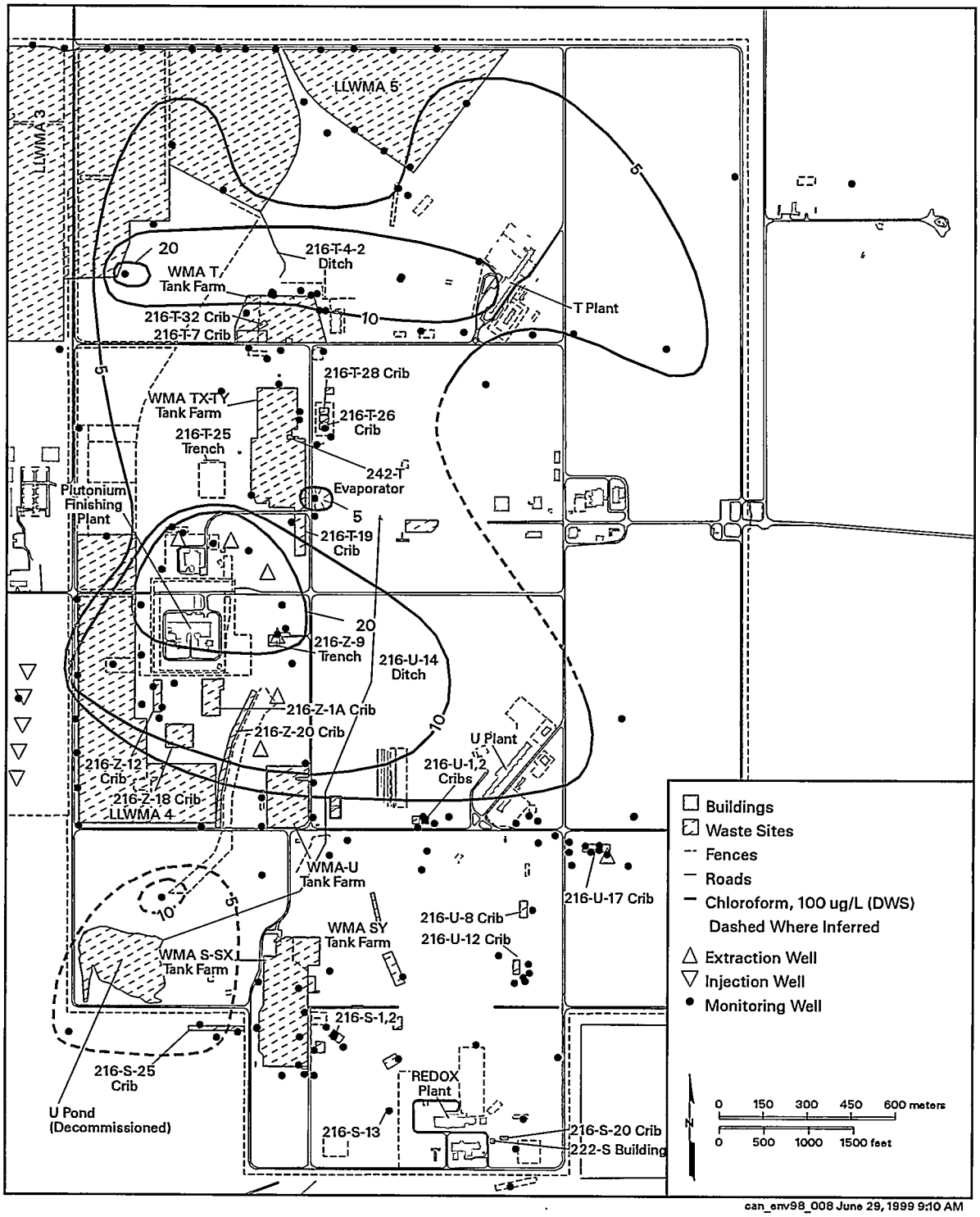


Figure 6.1.31. Average Chloroform Concentrations in the Unconfined Aquifer in the 200-West Area, 1998

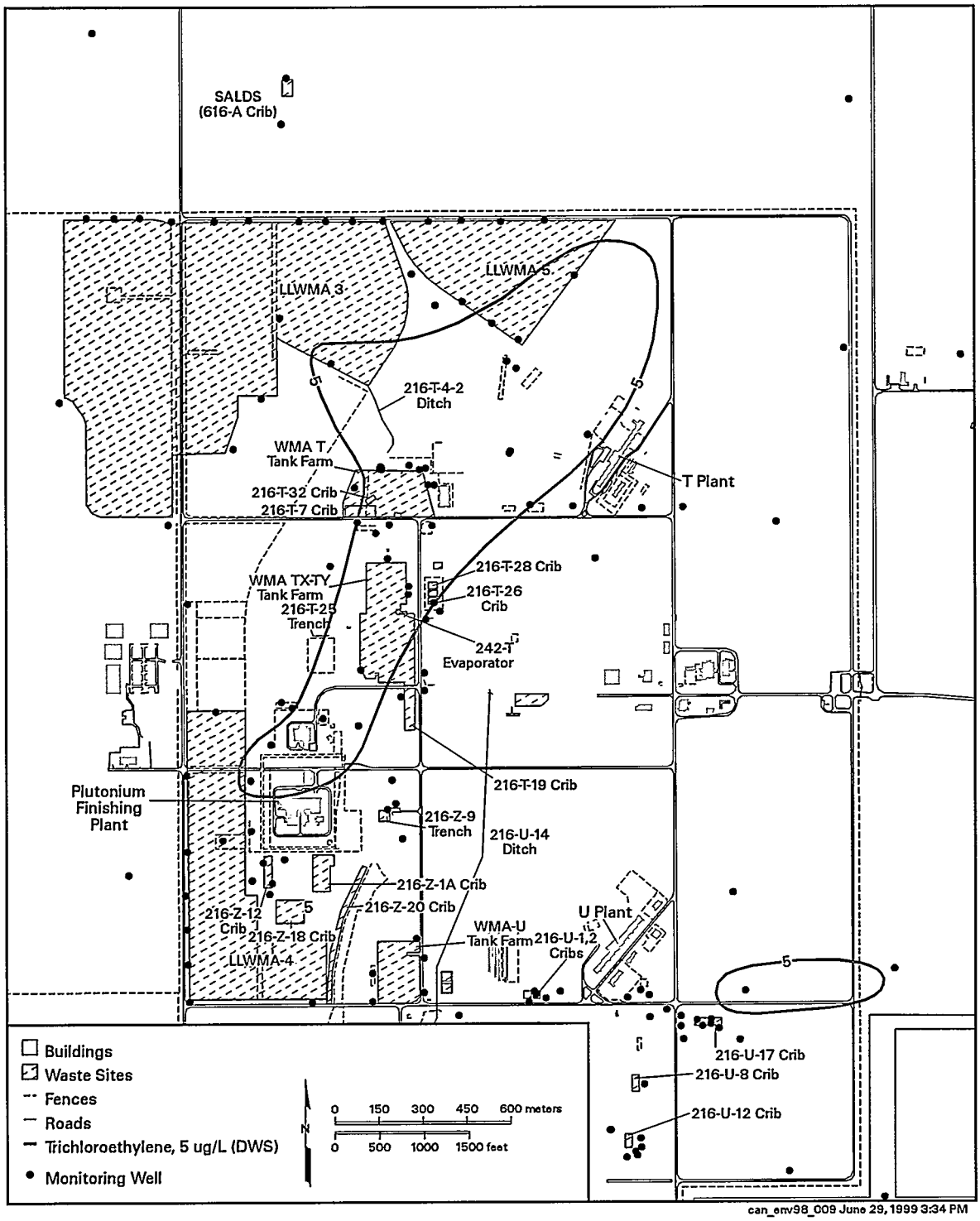


Figure 6.1.32. Average Trichloroethylene Concentrations in the Unconfined Aquifer in the 200-West Area, 1998

standard. The maximum concentration was 8 µg/L at well 399-1-16B. This well monitors the base of the unconfined aquifer downgradient of the former 316-5 process trenches.

Trichloroethylene in the 600 Area. Trichloroethylene was found at levels above the drinking water standard in a number of wells in the vicinity of the former Horn Rapids Landfill in the southern part of the site (Richland North Area). This contamination forms an elongated plume that extends from an area just south of the landfill to near the southwestern corner of the 300 Area and has an origin off the Hanford Site (Figure 6.1.33). The maximum contamination detected in this plume in 1998 was approximately 10 µg/L on the northeastern side of the landfill.

Tetrachloroethylene. Also referred to as perchloroethylene (or PCE), tetrachloroethylene was detected at levels above the 5-µg/L drinking water standard in the 300 Area during 1998. In the 300 Area, a new plume of tetrachloroethylene was discovered between the former process trenches and ponds and the Columbia River during 1998 (Figure 6.1.34). The maximum concentration detected was 38 µg/L near the southern end of the process trenches. However, by the end of 1998, concentrations decreased to levels near the drinking water standard. One possible source of the contamination was vadose zone residuals that were mobilized by the high-river levels in 1996 and 1997. Tetrachloroethylene was commonly used as a degreasing solvent.

cis-1,2-Dichloroethylene. Concentrations of cis-1,2-dichloroethylene, a biodegradation product of trichloroethylene, remain elevated in well 399-1-16B, located near the former process trenches and ponds in the 300 Area. This well is completed in the deeper part of the unconfined aquifer and is the only well on the site where this constituent is found at levels above the 70-µg/L drinking water standard. In 1998, a maximum of 180 µg/L was detected in this well.

Cyanide. Waste fractionation activities performed in the late 1950s used large quantities of sodium and nickel ferrocyanide to recover cesium-137. Large volumes of aqueous supernatant waste containing excess ferrocyanide were disposed to the ground in both the northern and southern portions of the 200-East Area. Smaller quantities were also disposed to former cribs in the 200-West Area. Procedures used to analyze for cyanide do not distinguish between ferrocyanide and free cyanide. Cyanide results reported here are, thus, normally assumed to be residual ferrocyanide associated with the discharges from the waste fractionation activities performed >30 yr ago. A chemical speciation study performed in 1988 indicated that approximately one-third of the cyanide in groundwater is present as free cyanide and the rest may be present as ferrocyanide (Section 4.1 in PNL-6886 and Section 3.2.2 in PNL-7120). The drinking water standard for cyanide is 200 µg/L.

The highest cyanide levels were detected in samples collected from wells in the northwestern part of the 200-East Area and in the 600 Area north of the 200-East Area. Only samples collected from one well near the inactive BY Cribs showed concentrations above the drinking water standard in 1998. The maximum concentration (347 µg/L) was a significant increase compared to levels in 1997 and correlates with cobalt-60 levels. Wells containing cyanide often contain several radionuclides, including cobalt-60. Although cobalt-60 is normally immobile in the subsurface, it appears to be chemically complexed by cyanide or ferrocyanide. The complexed chemical species is more soluble and more mobile in groundwater.

Fluoride. At this time, fluoride has a primary drinking water standard of 4 mg/L and a secondary standard of 2 mg/L. Secondary standards are based primarily on aesthetic rather than health considerations. Fluoride was detected above the primary drinking water standard at three wells near T Tank Farm in the 200-West Area in 1998. The new well

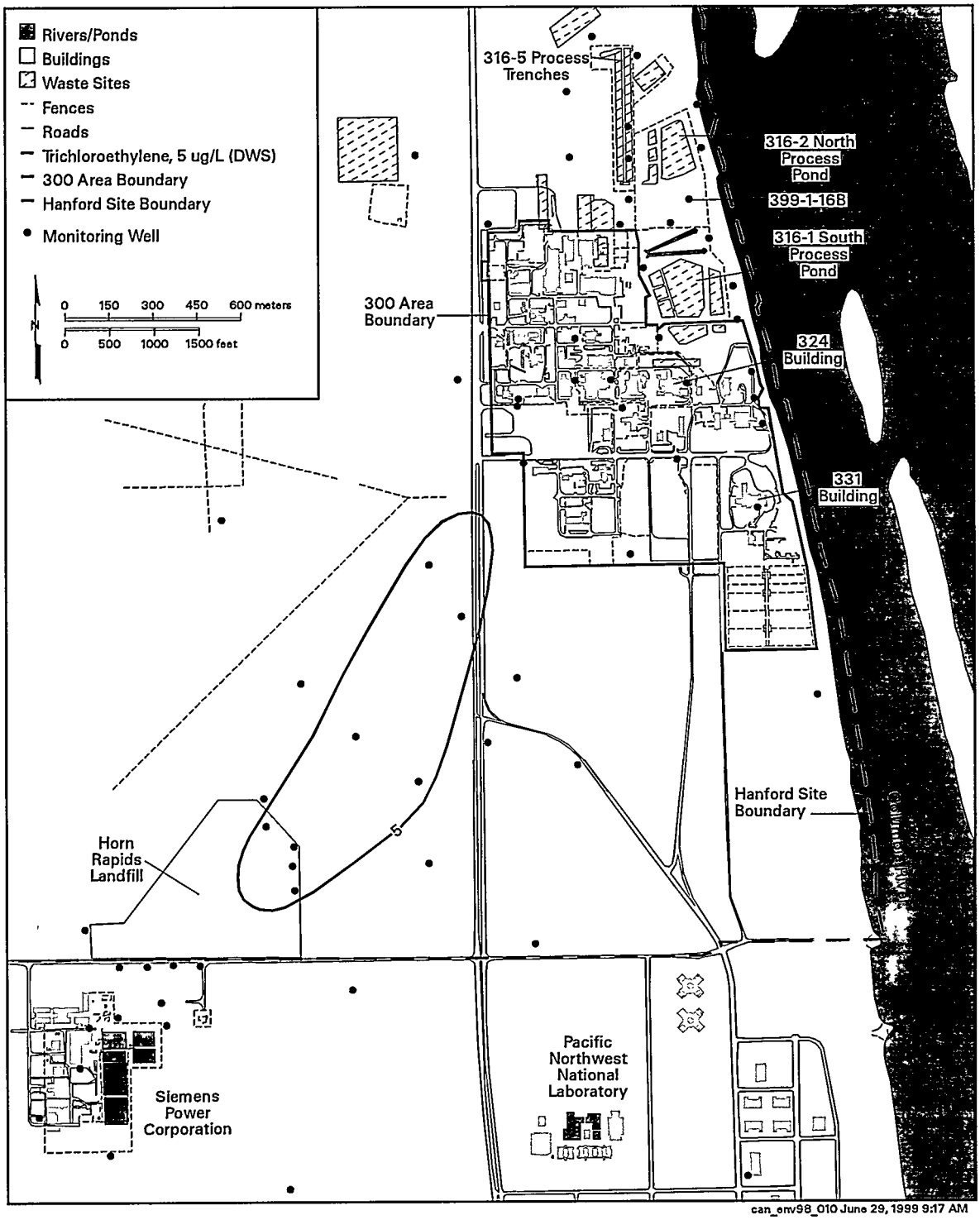


Figure 6.1.33. Average Trichloroethylene Concentrations in the Vicinity of the Former Horn Rapids Landfill and Richland North Area, 1998

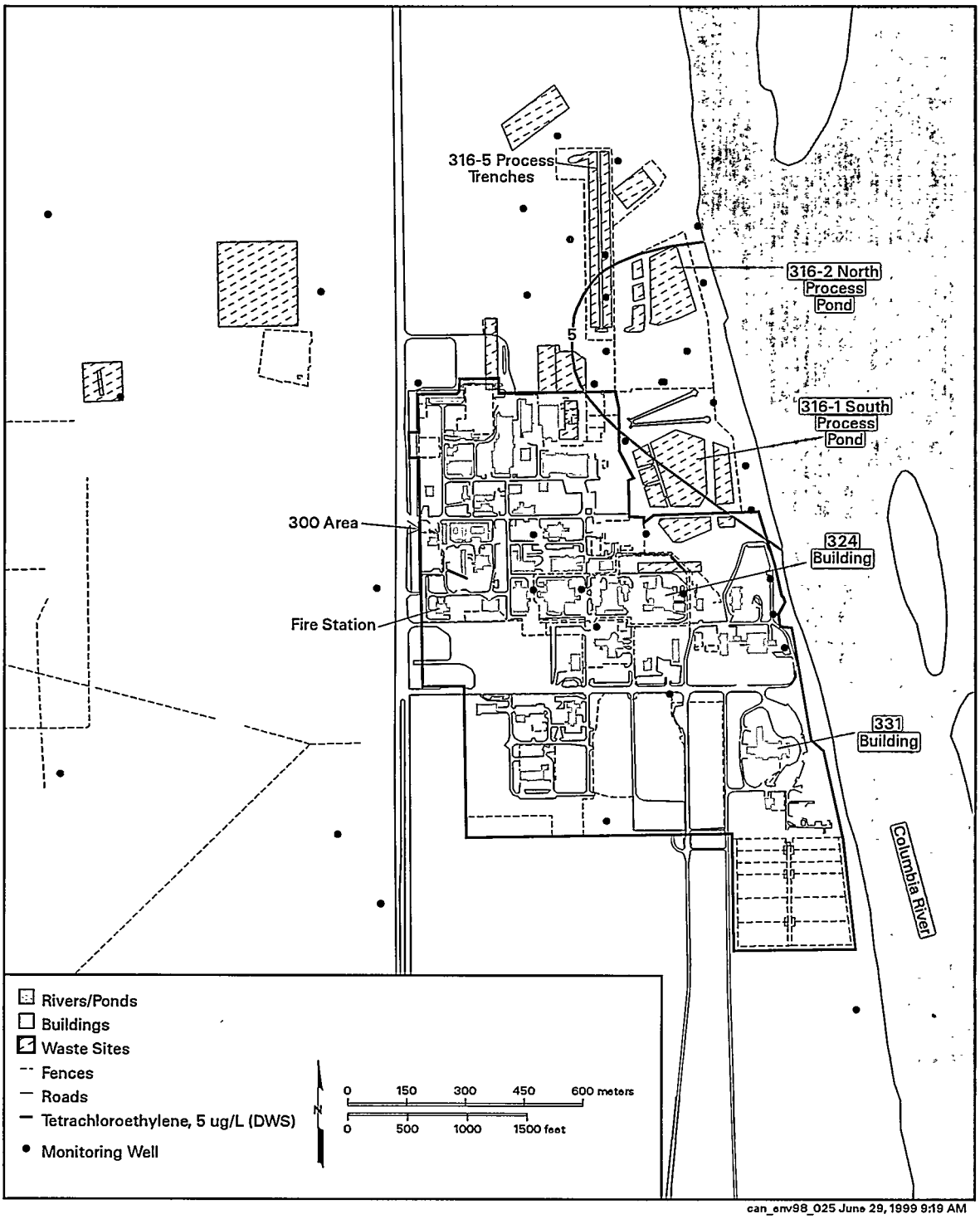


Figure 6.1.34. Average Tetrachloroethylene Concentrations in the 300 Area, 1998

(299-W10-24) showed a maximum fluoride concentration of 5 mg/L. A few wells near the T Tank Farm showed concentrations above the secondary standard. Aluminum fluoride nitrate used in the past 200-West Area processes is the probable source of the fluoride contamination.

6.1.6.3 Radiological and Chemical Monitoring Results for the Basalt-Confined Aquifer

Aquifers confined below the uppermost basalt layers show much less impact from Hanford Site contamination than the unconfined aquifer system within the overlying sediments. The minor contamination found in the basalt-confined aquifers may be attributed to several factors. These factors include areas where the confining layers of basalt have been eroded away, areas where disposal of large amounts of water resulted in downward gradients, and areas where wells penetrating to the confined aquifers provided pathways for contaminant migration. These factors produced intercommunication between the aquifers, meaning they permitted the flow of groundwater from the unconfined aquifer to the underlying confined aquifer, thereby increasing the potential to spread contamination. Because fewer wells are available to evaluate contamination in the confined aquifer, it is important to consider contamination in the confined aquifer even where the levels are well below drinking water standards. The distribution of tritium and other detected contaminants in the upper basalt-confined aquifer are shown in Figure 6.1.35.

Intercommunication between the unconfined and basalt-confined aquifers in the vicinity of the northern part of the 200-East Area has been identified previously in RHO-BWI-ST-5 and RHO-RE-ST-12 P. The hydrochemical and hydrogeologic conditions within the upper basalt-confined aquifer system and the potential for offsite migration of contaminants through confined aquifer pathways were evaluated in PNL-10817.

Several confined aquifer wells north and east of the 200-East Area that show evidence of intercommunication with the overlying unconfined aquifer were identified in PNL-10817. Intercommunication between the unconfined and confined aquifers in the area north and east of the 200-East Area has been attributed to erosion of the upper Saddle Mountains Basalt and downward vertical gradients that result from groundwater mounding associated with waste disposal. Groundwater chemical data from most confined aquifer wells in other areas of the Hanford Site do not exhibit evidence of contamination, with the exception of wells that were previously open to both the unconfined and confined aquifers, thus providing conduits for the downward transport of contamination.

Results of the 1995 sampling and analyses of groundwater from the upper basalt-confined aquifer indicated only a few areas of concern that warranted continued annual monitoring. Consequently, the number of wells sampled during 1998 was reduced to include only those with groundwater contamination or those downgradient from areas with historical indications of contamination. Prominent analytical results and trends arising from 1998 sampling are discussed below. The locations of wells used for monitoring confined aquifer groundwater chemistry were given in Figure 6.1.11.

Contamination has also been identified in the confined aquifer in the northern part of the 200-East Area and adjacent parts of the 600 Area. The highest levels of contamination detected in the confined aquifer in this vicinity were in well 299-E33-12. Contamination in this well is attributed to migration of high-salt waste down the borehole during construction when it was open to both the unconfined and confined aquifers (RHO-RE-ST-12 P). Contaminant concentrations continue to be elevated in this well. During 1998, technetium-99 was detected in well 299-E33-12 at 1,810 pCi/L, which is above the 900-pCi/L interim drinking water standard. Cobalt-60 was detected in this well (21.8 pCi/L) in 1998.

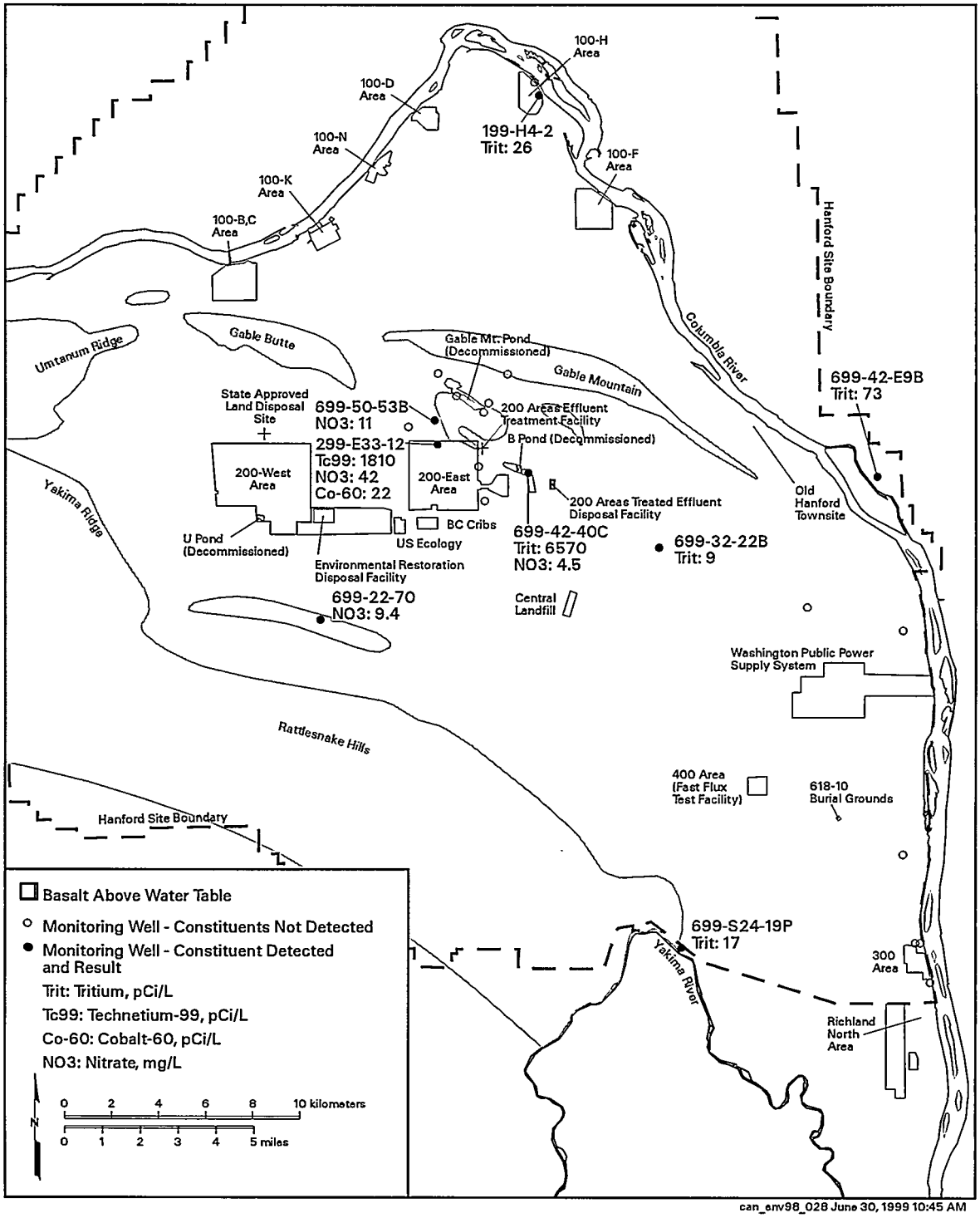


Figure 6.1.35. Tritium and Other Contaminants Detected in Confined Aquifer Wells, 1998

Well 699-42-40C monitors the confined aquifer adjacent to the former B Pond. Tritium in this well was 6,570 pCi/L, the highest level observed in the confined aquifer in 1998. Tritium in this well is believed to have originated from downward migration from the overlying, unconfined aquifer.

Wells are completed in the basalt-confined aquifer near the base of the Rattlesnake Hills in an area where pervasive downward flow from the unconfined aquifer recharges the upper portion of the confined aquifer (PNL-10817). Samples from one well contained up to 9.4 mg/L of nitrate in 1998, well below the 45-mg/L drinking water standard. Nitrate in the overlying unconfined aquifer in the Dry Creek Valley area and in wells near the base of the Rattlesnake Hills may result from agricultural sources to the south and west and is not believed to originate from sources on the Hanford Site.

6.1.7 RCRA Summary

More than 60 treatment, storage, and disposal units are recognized under the RCRA permit for the Hanford Site. Of these, 26 required groundwater monitoring during 1998. Locations of these groundwater monitoring sites were given in Figure 6.1.12. This section provides a summary of groundwater monitoring activities and results for these sites. Additional information, including RCRA groundwater monitoring and complete listings of radioactive and chemical constituents measured in monitoring wells from October 1997 through September 1998, is available in PNNL-12086. Any significant changes that occurred from October through December 1998 are noted below.

RCRA groundwater monitoring is conducted under one of three phases: 1) indicator parameter/detection, 2) groundwater quality assessment/compliance, or 3) corrective action. Initially, a detection program is developed to monitor the impact of facility operations on groundwater. During the indicator parameter/detection phase, groundwater parameters established for the particular site are measured in wells upgradient and downgradient from the site. Statistical tests are applied to the monitoring results to calculate "critical mean" values for each monitoring parameter. These values represent the background water quality for the site. Subsequent monitoring data are compared to the critical mean values to determine if there has been a statistically significant increase (or pH decrease) in the concentrations of key indicator parameters or dangerous waste constituents in the groundwater. The statistical methods used to calculate critical means and compare with monitoring data are described in Appendix B in PNNL-12086. If a statistically significant change from the "critical mean" is observed, then a groundwater quality assessment/compliance phase of monitoring and investigation is initiated. During this phase, groundwater monitoring is designed to determine if groundwater protection standards have been exceeded. If the source of the contaminants is determined to be the treatment, storage, and disposal unit and concentrations exceed maximum contaminant levels defined in the monitoring plan or permit, then the Washington State Department of Ecology may require corrective action to reduce the contaminant hazards to the public and environment. Groundwater monitoring during the corrective action phase is designed to assess the effectiveness of the corrective action. Table 2.2.2 in Section 2.2, "Compliance Status," listed the phase pertaining to each of the RCRA groundwater monitoring projects at the end of 1998.

6.1.7.1 100 Areas Facilities

120-D-1 Ponds. These ponds were constructed in 1977 for disposal of nonradioactive effluent derived from operating facilities in the 100-D,DR Area. This facility is located in the former 188-D Ash

Disposal Basin and includes settling and percolation ponds separated by a dike. Effluent to the ponds originated from two sources: the 183-D Filter Plant and the 189-D Building engineering testing laboratories. Some past discharges contained hydrochloric acid, sodium hydroxide, and sulfuric acid. Before 1986, the effluent may have had a >12.5 or <2.0 pH and, thus, may have been dangerous waste. There was also a potential for up to 2.3 kg (5 lb) of mercury to have been discharged to the ponds. Between 1986 and 1994, the effluent discharged to the ponds included chlorine and flocculating agents such as aluminum sulfate. Effluent discharge to the ponds ceased in 1994. Contaminated soils were removed from the ponds in 1996.

Recharge from the ponds diluted ambient groundwater, but did not degrade groundwater quality. In 1998, specific conductance, pH, total organic carbon, and total organic halide in downgradient wells continued to be below the background critical mean values. Mercury is the only listed waste that may have been discharged to these ponds but it has never been detected in any of the downgradient monitoring wells. The 100-D Ponds will be clean-closed when modification D of the RCRA permit is signed in 1999, and no further groundwater monitoring will be required. Until then, the site remains in indicator parameter monitoring.

183-H Solar Evaporation Basins. This facility, now remediated, consisted of four separate concrete basins surrounded by an earthen berm. Between 1973 and 1985, the basins were used to store liquid waste, primarily from nuclear fuel fabrication activities conducted in the 300 Area. Volume reduction occurred by solar evaporation. The waste was predominantly acid etch solution that had been neutralized with sodium hydroxide before being discharged into the basins. The solutions included chromic, hydrofluoric, nitric, and sulfuric acids and also contained various metallic and radioactive constituents. Groundwater in the vicinity of these basins is characterized by elevated levels of chromium, nitrate, technetium-99, and uranium. All of these constituents were present in waste discharged to the basins when they were in use.

The basins are subject to final-status monitoring. Concentration limits for chromium, nitrate, technetium-99, and uranium were exceeded in one or more downgradient wells in 1996 and 1997, and a corrective-action groundwater monitoring plan was released in 1997 (PNNL-11573). The monitoring plan was implemented in early 1998 after the corrective-action plan was incorporated into a revision of the RCRA permit. The monitoring plan takes into account the effects of a pump-and-treat system that began operation in 1997. Four wells are sampled annually for the constituents of concern to monitor concentration trends. Although the concentrations decreased several orders of magnitude in this area since the basins ceased operation, nitrate, chromium, and uranium remained above their respective drinking water standards in 1998.

1301-N and 1325-N Liquid Waste Disposal Facilities. These facilities contaminated groundwater with radionuclides, most notably strontium-90 and tritium, as discussed in Section 6.1.6.1, "Radiological Monitoring Results for the Unconfined Aquifer." A pump-and-treat system is active as a CERCLA interim action to reduce the amount of strontium-90 flowing into the river at the 100-N Area. RCRA monitoring focuses on the hazardous (nonradioactive) constituents discharged to the facilities.

The 1301-N facility was the primary liquid waste disposal site for N Reactor from 1963 until 1985. Discharges were primarily radioactive fission and activation products. Minor amounts of dangerous waste and other constituents may also have been discharged, including ammonium hydroxide, cadmium, diethylthiourea, lead, morpholine, phosphoric acid, and sodium dichromate. The facility consists of a concrete basin with an unlined, zigzagging extension trench, covered with concrete panels.

The 1325-N facility was constructed in 1983 and also received effluent from N Reactor. In 1985, discharge to 1301-N ceased, and all effluent was sent to 1325-N. All discharge to 1325-N ceased in late 1991. The facility consists of a concrete basin with an unlined extension trench, covered with concrete panels.

Total organic carbon (the indicator parameter) exceeded the critical mean value at 1301-N downgradient well 199-N-3 in September 1998. The well was resampled and the value was verified. However, no organic constituents of concern were identified in 1301-N waste or sediments (DOE/RL-96-39), and the contamination is believed to have originated at one of several petroleum waste sites nearby (DOE/RL-95-111). The Washington State Department of Ecology was notified of the exceedance and its probable cause, and the site remains in a detection monitoring program. No other indicator parameters exceeded critical mean values at the 1301-N or 1325-N facilities. Groundwater at these facilities is also analyzed for other constituents that were discharged to them, including cadmium, chromium, lead, nitrate, and phosphate. Cadmium, chromium, lead, and phosphate were not detected in groundwater at these facilities in significant concentrations; however, nitrate continued to be detected at levels greater than the EPA maximum contaminant level in 1998, but the sources are uncertain.

1324-N and 1324-NA Ponds. The 1324-N Pond was a treatment facility that was in service from May 1986 to November 1988. This facility is a double-lined pond that was used for neutralizing high- and low-pH waste from a demineralization plant. The 1324-NA Pond is unlined and was used for treating waste from August 1977 to May 1986 and for disposing of treated waste from May 1986 to August 1990. The effluent to both facilities contained sulfuric acid and sodium hydroxide, and the pH was occasionally high or low enough to classify the effluent as a dangerous waste.

Specific conductance measured in wells downgradient from these ponds remained higher than the background critical mean value in 1998. This indicator parameter is high because the 1324-NA Pond introduced nondangerous constituents (e.g., sodium, sulfate) to groundwater. Total organic carbon was detected above the background critical mean value in one downgradient well in September 1997, and the value was confirmed in January 1998. No organic contaminants were present in the waste discharged to the facility (DOE/RL-96-39), and the Washington State Department of Ecology agreed that a groundwater quality assessment is not required. The contamination is believed to have originated at one of several petroleum waste sites nearby. Downgradient measurements of pH and total organic halide were below critical mean values.

6.1.7.2 200 Areas Single-Shell Tank Farms

Single-shell tanks are located in the A, AX, B, BX, BY, C, S, SX, T, TX, TY, and U Tank Farms, which have been designated as parts of RCRA Waste Management Areas A-AX, B-BX-BY, C, S-SX, T, TX-TY, and U, respectively. Waste Management Areas A-AX, B-BX-BY, and C are located in the 200-East Area; Waste Management Areas S-SX, T, TX-TY, and U are in the 200-West Area. Each waste management area includes tanks and associated ancillary systems (e.g., pipelines). The single-shell tanks store a mixture of dangerous chemical and radioactive wastes generated by reprocessing fuel irradiated in Hanford Site reactors. The single-shell tanks received mixtures of organic and inorganic liquids that contain radionuclides, solvents, and metals that were originally discharged to the tanks as alkaline slurries. Subsequent waste management operations have combined waste streams from different processes. In many tanks, wastes have been concentrated by removing water through evaporation.

Waste Management Area A-AX. Critical mean values for pH, specific conductance, total

organic carbon, and total organic halide (the indicator parameters) were not exceeded during 1998. Iodine-129 exceeded the 1-pCi/L drinking water standard in the monitoring wells because of a plume extending through this area from other sources. Chromium, manganese, and nickel exceeded drinking water standards in one of the network wells, and may be related to corrosion of the well screen.

Waste Management Area B-BX-BY. The results of the first phase of a groundwater quality assessment program were published in 1998 (PNNL-11826). It was concluded that the waste management area was most likely the cause of the elevated specific conductance that had triggered the assessment.

There appear to be two centers of technetium-99 contamination near the waste management area. Levels continued to exceed the 900-pCi/L interim drinking water standard in 1998 in several wells. This contamination was discussed in Section 6.1.6.1, "Radiological Monitoring Results for the Unconfined Aquifer," and its distribution was shown in Figure 6.1.21.

Nitrate concentrations continued to rise across the waste management area and exceeded the 45-mg/L drinking water standard in most of the monitoring network (see Section 6.1.6.1, "Radiological Monitoring Results for the Unconfined Aquifer"). There are two local centers of nitrate contamination that approximately correspond with the technetium-99 distribution.

Uranium concentrations exceeded the 20-mg/L proposed drinking water standard in four wells, but its source is not known. In late 1997 and early 1998, two high, rapid spikes of uranium were observed in one well (299-E33-41). Similar spikes in technetium-99 were observed in this well in 1997.

One new monitoring well was installed in 1998 to support the assessment program.

Waste Management Area C. Critical mean values for pH, specific conductance, total organic carbon, and total organic halide (the indicator parameters) were not exceeded during 1998. Iodine-129 showed levels above the 1-pCi/L drinking water standard in the monitoring wells because of a plume extending through this area from other sources.

Waste Management Area S-SX. The results of the first phase of a groundwater quality assessment program were released in 1998 and showed that the S and SX Tank Farms contributed to groundwater contamination (PNNL-11810). A second phase assessment is being conducted to determine the nature, extent, and source(s) of groundwater contamination attributed to Waste Management Area S-SX.

Mobile contaminants from the waste management area include chromium, nitrate, and technetium-99. All of these constituents were highest in well 299-W22-46 in 1998. Lower, but sharply increasing, levels of contaminants were observed in well 299-W22-45. Past spills or leaks from transfer lines or diversion boxes are potential sources of this contamination.

Waste Management Areas T and TX-TY. The results of the first phase of assessment monitoring were released in 1998 (PNNL-11809). There is evidence that Waste Management Area T has contaminated groundwater in well 299-W11-27. The source of contamination at Waste management Area TX-TY could not be determined, but a source within the waste management area could not be ruled out, so assessment will continue.

Specific conductance in Waste Management Area T well 299-W11-27 has declined slowly since a peak in 1996. This pulse of specific conductance was caused by increases in calcium, magnesium, nitrate, and sulfate and was accompanied by increases in chromium, cobalt-60, technetium-99, and tritium. Technetium-99 is the major contaminant present, reaching a peak in 1997 (21,700 pCi/L) and declining in 1998 (average = 7,390 pCi/L). The contaminants

affecting groundwater quality in well 299-W11-27 represent a very narrow plume, indicating a nearby source.

Specific conductance in Waste Management Area TX-TY well 299-W10-17 remained elevated in 1998 and is principally a result of elevated nitrate and sodium. Gross beta, nitrate, and tritium exceeded their drinking water standards during the year and represent a regional contaminant plume. Specific conductance also was elevated in well 299-W14-12 in 1998. The high specific conductance is a result of elevated calcium, magnesium, nitrate, and sulfate and is distinctly different from the regional sodium/nitrate signature.

Monitoring wells for these waste management areas are rapidly going dry because of a declining water table. Two new wells were installed in 1998 at Waste Management Area T to replace those that were dry. Four new wells were drilled at Waste Management Area TX-TY.

Waste Management Area U. This waste management area is under a detection-level monitoring program. Three indicator parameters (pH, specific conductance, and total organic carbon) remained below their background critical mean values. Total organic halides exceeded the critical mean value in well 299-W19-31 as a result of carbon tetrachloride contamination flowing into the area from upgradient sources. The Washington State Department of Ecology was informed of the exceedance and its source, and the waste management area remains in a detection monitoring program.

Technetium-99 remained slightly elevated in downgradient wells. Levels are below the interim drinking water standard but higher than upgradient wells. The highest value was in well 299-W19-31, where the annual average was 320 pCi/L.

Two new wells were installed in 1998 to replace wells that are nearly dry because of the declining water table.

6.1.7.3 200 Areas Liquid Effluent Disposal Facilities

216-A-10, 216-A-36B, and 216-A-37-1 Cribs. These inactive cribs received liquid waste from the Plutonium-Uranium Extraction Plant. The waste stream at the 216-A-10 Crib was characteristically acidic and contained concentrated salts, hydrocarbon compounds, organic complexants, plutonium, uranium, and other radionuclides. The 216-A-36B Crib received ammonia scrubber distillate from nuclear fuel decladding operations, in which zirconium cladding was removed from irradiated fuel by boiling in a solution of ammonium fluoride and ammonium nitrate. Other waste stream constituents included tritium, cobalt-60, strontium-90, ruthenium-106, iodine-129, cesium-137, and uranium. The 216-A-37-1 Crib received process condensate from the 242-A Evaporator. The process condensate contained radionuclides, spent halogenated and nonhalogenated solvents, and ammonia. The radionuclides included cobalt-60, strontium-90, ruthenium-106, cesium-137, uranium, and plutonium.

These three cribs are monitored as a single waste management area under an assessment program because they have similar hydrogeology and waste constituents. The cribs have contributed to the large nitrate, iodine-129, and tritium plumes downgradient of the 200-East Area (see Section 6.1.6.1, "Radiological Monitoring Results for the Unconfined Aquifer"). These constituents remained above drinking water standards in 1998. Strontium-90 also exceeded the interim drinking water standard in well 299-E17-14, adjacent to the 216-A-36B crib, with an annual average of 16 pCi/L.

216-A-29 Ditch. This is an inactive earthen ditch approximately 2 km (1.2 mi) long that conveyed Plutonium-Uranium Extraction Plant chemical waste to the 216-B-3 Pond from 1955 to 1986. The ditch received effluents that contained dangerous

chemical and radioactive contaminants. Of primary concern for RCRA regulations were discharges of sodium hydroxide and sulfuric acid, which occurred daily as a result of ion-exchange regeneration at the Plutonium-Uranium Extraction Plant.

Assessment monitoring between 1990 and 1995 concluded that the ditch contaminated groundwater with the nondangerous constituents calcium, sodium, and sulfate, which contributed to elevated specific conductance. Because the contaminants are nondangerous, the site reverted to detection monitoring. Specific conductance subsequently declined, and in 1998, all indicator parameters were below the critical mean values.

216-B-3 Pond. This former pond consisted of a main pond and three expansion ponds (216-B-3A, 216-B-3B, and 216-B-3C). The main pond began operating in 1945 and the expansions were built in the 1980s. In 1994, the main pond ceased operating, and the waste streams were rerouted to the 216-B-3C Expansion Pond and the 200 Areas Treated Effluent Disposal Facility. The main pond was filled with clean soil, and the expansion ponds were clean-closed (i.e., deemed free of dangerous waste and no longer regulated under RCRA). In August 1997, waste streams received by the expansion pond were diverted to the 200 Areas Treated Effluent Disposal Facility, thus ending operation of the B Pond system. In the past, B Pond received liquid waste from B Plant and the Plutonium-Uranium Extraction Plant, consisting of chemical sewer waste, cooling water, and steam condensate. These waste streams contained aluminum nitrate, nitric acid, potassium hydroxide, sulfuric acid, tritium, and other acids. In its later years, B Pond received nondangerous, nonradioactive effluent primarily from the Plutonium-Uranium Extraction Plant and B Plant.

During 1998, B Pond was monitored under an interim-status detection program. Critical mean values of the indicator parameters were not exceeded. The only contaminants consistently detected in groundwater that could be attributed to B Pond operations were nitrate and tritium; however, these constituents have shown downward trends since monitoring began at B Pond.

216-B-63 Trench. This trench received liquid effluent from the B Plant chemical sewer from March 1970 to February 1992. The liquid effluent consisted of a mixture of steam condensate and raw water. Past releases to the trench also included sulfuric acid and sodium hydroxide solutions. Radioactive soils were dredged from the trench in August 1970, but no records exist of radioactive waste disposal to the trench.

Groundwater monitoring continues to show no evidence that dangerous nonradioactive constituents entered the groundwater from this trench. No indicator parameters (pH, specific conductance, total organic carbon, or total organic halide) were exceeded in 1998.

216-U-12 Crib. This crib received wastewater containing dangerous chemical wastes and radionuclides from April 1960 until February 1988. This facility has been in the groundwater quality assessment phase of monitoring since 1993. Site-specific waste indicators include gross alpha, gross beta, iodine-129, nitrate, technetium-99, and tritium. Iodine-129, nitrate, technetium-99, and tritium are detected consistently in groundwater. The findings of the first two phases of the assessment monitoring program indicate that the crib is a source of nitrate and technetium-99 detected in the downgradient wells (PNNL-11574). Nitrate concentrations downgradient of the crib are >10 times the average background value in the upgradient well.

One new well was installed in 1998 to replace a well that is nearly dry as a result of the declining water table.

216-S-10 Pond and Ditch. The facility consisted of an open, unlined ditch and an open, unlined percolation pond. The pond and ditch

received radioactive and dangerous chemical waste from the Reduction-Oxidation Plant from 1951 until 1985, when the pond and the lower part of the ditch were decommissioned and backfilled. The upper part of the ditch continued to receive nondangerous, unregulated wastewater from 1985 through 1991.

All indicator parameters (pH, specific conductance, total organic carbon, and total organic halide) were below their respective critical mean values in 1998.

Chromium continued to be elevated in well 299-W26-7, reaching 576 mg/L in December 1997 (there are no 1998 chromium data). This well is upgradient of the pond, but may have been affected by artificial recharge when the pond was active. The source of the chromium contamination is uncertain, but is possibly related to the pond or to earlier disposal to upgradient facilities.

6.1.7.4 200 Areas Low-Level Burial Grounds

The low-level burial grounds are divided into five low-level waste management areas in the 200 Areas (see Figure 6.1.12). However, Low-Level Waste Management Area 5 has not been monitored for groundwater since 1996 because the burial ground never received waste. The remaining low-level waste management areas are in the indicator parameter phase of RCRA groundwater monitoring.

Low-Level Waste Management Area 1. This waste management area consists of the 218-E-10 Burial Ground. Disposal activities began in 1960 and continue today. Materials placed in this facility are primarily failed equipment and mixed industrial waste from the Plutonium-Uranium Extraction Plant, B Plant, and N Reactor.

Specific conductance exceeded the critical mean value in one downgradient well in December 1998. The higher-conductivity groundwater is believed to have originated in other 200-East Area facilities. The Washington State Department of Ecology was notified of the exceedance and its probable source, and the waste management area remains in detection monitoring. No other indicator parameters exceeded background values, and there is no evidence of any contaminant contribution from this area.

Low-Level Waste Management Area 2. This waste management area includes all of the 218-E-12B Burial Ground, which has been in use since 1968. The waste consists primarily of miscellaneous dry waste and submarine reactor compartments. Parts of two trenches contain transuranic waste.

In 1998, specific conductance exceeded the critical mean established for this area as a result of increases in calcium, nitrate, and sulfate, which are not regulated constituents in groundwater. Because the increase occurred in an upgradient well, assessment monitoring is not required. Total organic halides exceeded the critical mean in a downgradient well in November 1998, but the high value is believed to be erroneous and is being investigated. Values for iodine-129 were above the 1-pCi/L drinking water standard in several wells along the southern boundary of this area. However, this is related to the widespread iodine-129 plume beneath the 200-East Area, and there is no evidence of groundwater contamination from this waste management area.

Low-Level Waste Management Area 3. The 218-W-3A, 218-W-3AE, and 218-W-5 burial grounds make up this area. The 218-W-3A Burial Ground began accepting waste in 1970 and received primarily ion-exchange resins and failed equipment (e.g., tanks, pumps, ovens, agitators, heaters, hoods, vehicles, accessories). The 218-W-3AE Burial Ground began operation in 1981 and contains low-level and mixed waste, including rags, paper, rubber gloves, tools, and industrial waste. The 218-W-5 Burial Ground first received waste in 1986, and contains low-level and low-level-mixed waste, including lead bricks and shielding.

Carbon tetrachloride and nitrate are consistently above their drinking water standards of 5 µg/L and 45 mg/L, respectively, in monitoring wells in this waste management area. However, the elevated values can be attributed to contaminant plumes originating to the south of the area. There appears to be no groundwater contamination directly attributable to this waste management area, and the critical mean values for indicator parameters were not exceeded in 1998.

Low-Level Waste Management Area 4. This area consists of the 218-W-4B and 218-W-4C Burial Grounds. The 218-W-4B Burial Ground first received waste in 1968 and contains mixed and retrievable transuranic waste in trenches and caissons. One caisson is believed to contain mixed waste. Wastes were first deposited in the 218-W-4C Burial Ground in 1978 and were classified as transuranic, mixed, or low-level and included contaminated soil, decommissioned equipment, and remote-handled transuranic waste.

Groundwater near this waste management area is being remediated as part of the 200-ZP-1 Operable Unit. Water is pumped from wells located east of this waste management area, treated, and injected into wells located west of the waste management area. Consequently, the direction of groundwater flow is now from west to east across the site. The groundwater monitoring network was revised in 1998 to reflect the current flow direction. Network modifications also were needed to accommodate declining water levels beneath the area. Statistical evaluation of the upgradient/downgradient comparison values has been suspended until the flow regime stabilizes following pump-and-treat activities. Semiannual sampling continues during this time to determine when stabilization occurs and to maintain continuity in the database.

6.1.7.5 Liquid Effluent Retention Facility

This facility consists of three, lined, surface impoundments (basins) located east of the 200-East Area and serves as temporary storage for condensate from the 242-A Evaporator. Constituents detected in the effluent stream from the 242-A Evaporator were acetone, aluminum, ammonium, 1-butanol, 2-butanone, tritium, strontium-90, ruthenium-106, and cesium-137.

The facility is subject to final-status monitoring. Until the final-status monitoring plan is approved by the regulators, the site continues to operate under the existing interim-status plan. The indicator parameters (pH, specific conductance, total organic carbon, and total organic halide) were not exceeded in 1998. However, in January 1999, specific conductance exceeded its critical mean in one downgradient well. Tritium, which is present in site effluent, is not elevated in downgradient wells, so the source of the high conductivity is not this facility. The Washington State Department of Ecology was notified of the exceedance, and the site remains in detection monitoring.

6.1.7.6 300 Area Process Trenches

The 316-5 Process Trenches are two unlined trenches that were used for the disposal of liquid wastes generated in the 300 Area, beginning in 1975, and received uranium and other radioactive and chemical constituents. From 1985 through 1991, the trenches received nondangerous effluent, and all discharges ceased in 1991.

The site is monitored under a final-status corrective-action program. Until the corrective-action plan is approved, the final-status compliance

monitoring program remains in effect. In 1998, monitoring continued to show elevated levels of uranium downgradient of the trenches. Trichloroethylene exceeded the drinking water standard in two deep downgradient wells, and cis-1,2-dichloroethylene exceeded the drinking water standard in one deep well. A plume of tetrachloroethylene appeared in 1998, with concentrations increasing and decreasing rapidly. The highest concentration was 38 mg/L in well 399-1-17A in July 1998. Levels declined rapidly and the concentration was only 3 mg/L in December 1998. Wells farther downgradient of the trenches reached peak concentrations somewhat later in the year. Although tetrachloroethylene was accidentally discharged to the trenches in 1982 and 1984, the trenches have not been used since 1994. Therefore, the 1998 plume was not due to a recent discharge. Furthermore, the sudden and wide lateral extent of the plume indicates it did not originate at a point source. The most likely source is residual vadose-zone contamination near the trenches that was mobilized by high-river levels in 1996 and 1997.

6.1.7.7 Nonradioactive Dangerous Waste Landfill

The former Nonradioactive Dangerous Waste Landfill (Central Landfill) in the 600 Area southeast of the 200-East Area received waste from 1975 through 1985 that included asbestos, miscellaneous laboratory waste, solvents, paints, sewage, sulfamic and other acids, batteries, battery acid, and mercury. The site is in the indicator parameter phase of groundwater monitoring. None of the indicator parameters (pH, specific conductance, total organic carbon, or total organic halide) exceeded critical mean values during 1998. Chlorinated hydrocarbons were detected in a few wells at concentrations below their respective drinking water standards. Some constituents (e.g., 1,1,1-trichloroethane, trichloroethylene) are thought to be the result of vadose zone vapor transport from the adjacent Solid Waste Landfill, while others (e.g., carbon tetrachloride, chloroform) may have originated in the Nonradioactive Dangerous Waste Landfill. Iodine-129, nitrate, and tritium contamination is also present in some wells, but is part of large plumes originating in the 200-East Area.

6.2 Vadose Zone Characterization and Monitoring

The vadose zone is the region in the subsurface between the ground surface and the top of the water table. In the Hanford 200 Areas, the vadose zone is >61 m (200 ft) thick. As a result of past Hanford Site operations, the vadose zone has become contaminated from spills, leaks, and intentional discharges. There are three programs/projects involved in vadose zone characterization and monitoring. This section provides descriptions of each and summarizes the 1998 results.

6.2.1 Tank Farms Vadose Zone Baseline Characterization Project

S. E. Kos and R. G. McCain

Contamination was released to the near-surface and subsurface environment at the Hanford Site single-shell tank farms as the result of tank leaks, spills of radioactive effluent on the ground surface, pipeline leaks, and airborne releases of particulate matter through tank ventilation and access ports.

RCRA specifies the requirements to identify sources of contamination and to determine the nature and extent of the contamination that has leaked from the single-shell tanks. In 1994, the Tank Farms Vadose Zone Baseline Characterization Project was initiated to perform a baseline characterization of the gamma-emitting contamination in the vadose zone under the tank farms and to satisfy RCRA requirements in a limited way. The technical plan for this baseline characterization is documented in P-GJPO-1786.

Under this project, approximately 800 preexisting monitoring boreholes surrounding the Hanford Site single-shell tanks are being logged with passive spectral gamma-ray logging methods. These methods were developed at the Hanford Site in the late 1980s and early 1990s to identify specific gamma-emitting radionuclides in the subsurface and to determine their concentrations.

Borehole logging is used for the initial characterization because it is an economical means of obtaining information about conditions in the subsurface, using existing boreholes, and it helps to identify the locations and sizes of the contamination plumes. For comprehensive characterizations or special investigations, follow-up drilling and sampling must be conducted to identify specific contaminants, to better define observed contaminant distributions, and to collect geologic samples as needed.

Once a baseline is established for a particular tank, that tank can be monitored over time for either short-term or long-term changes. Long-term monitoring over a 5- to 10-yr period can provide information on migration rates of gamma emitters that can be used to verify models used for predictive risk assessments. Short-term monitoring is useful for identifying recent changes in the vadose zone that result from current operations or tank leaks.

A plan view of a typical tank farm is presented in Figure 6.2.1. Each tank farm consists of a collection of between 2 and 18 underground waste storage tanks. Most of the tanks are surrounded by monitoring boreholes that provide access to the subsurface with

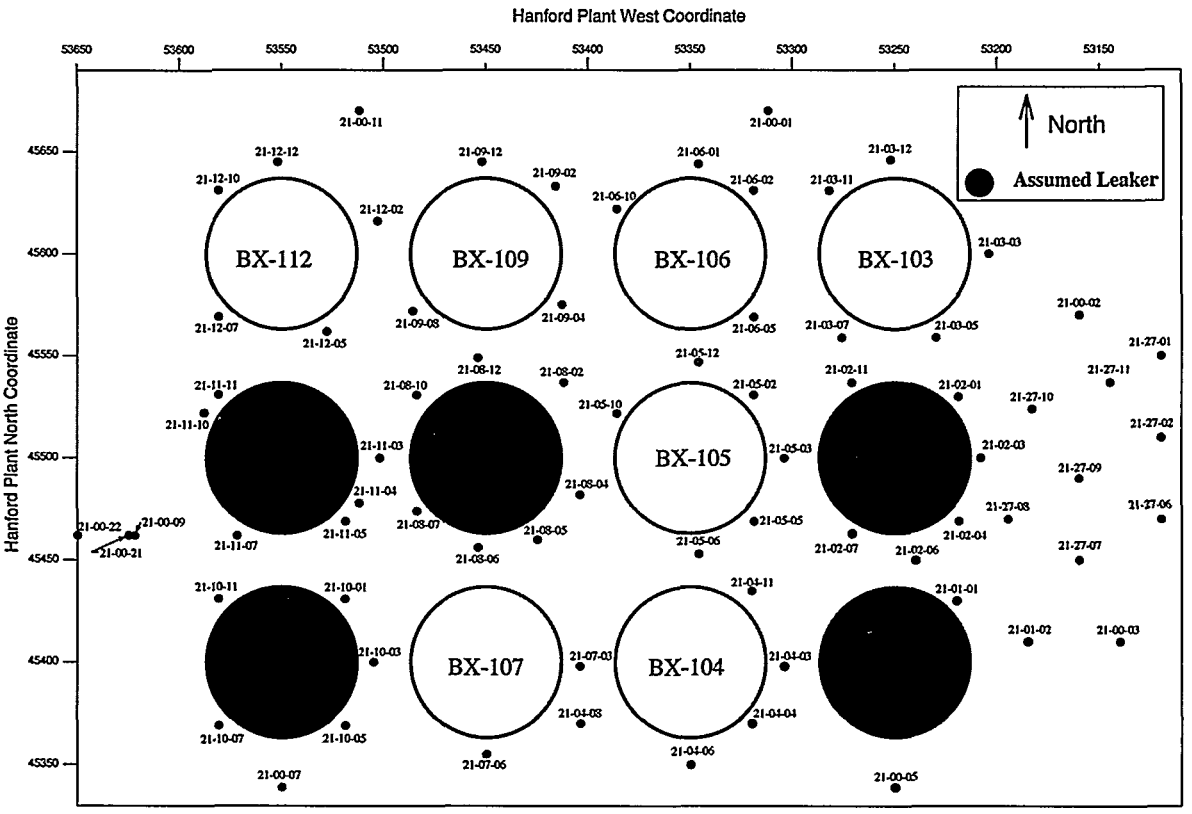


Figure 6.2.1. Plan View of BX Tank Farm with Monitoring Boreholes

geophysical logging probes. There are 12 single-shell tank farms at Hanford that contain a total of 149 tanks.

The baseline characterization project involves logging the boreholes surrounding the single-shell tanks and analyzing the data to produce logs of the radionuclide concentrations. Figure 6.2.2 presents an example of a radionuclide concentration log. The logs for all of the boreholes surrounding a tank are interpreted and reported in a tank summary data report for each tank. The reports also provide summaries of the tank histories and any other tank-specific information.

After completion of a summary data report for each tank, a more comprehensive tank farm report is prepared. Each tank farm report provides a correlation of the contamination across the farm and includes computer-generated, three-dimensional visualizations of the contamination. Correlations between boreholes help to determine contamination sources and define the three-dimensional contamination distributions. The visualizations are based strictly on an empirical geostatistical correlation of the data and are used to help identify the general location and distribution of the contamination so that more complete analyses can be assembled to develop more realistic and quantitative contamination distribution models. The visualizations are an effective means of identifying regions in specific tank farms where additional characterization is necessary.

6.2.1.1 Data Collection and Analysis

All data acquisition is accomplished with spectral gamma-ray logging systems that are automated

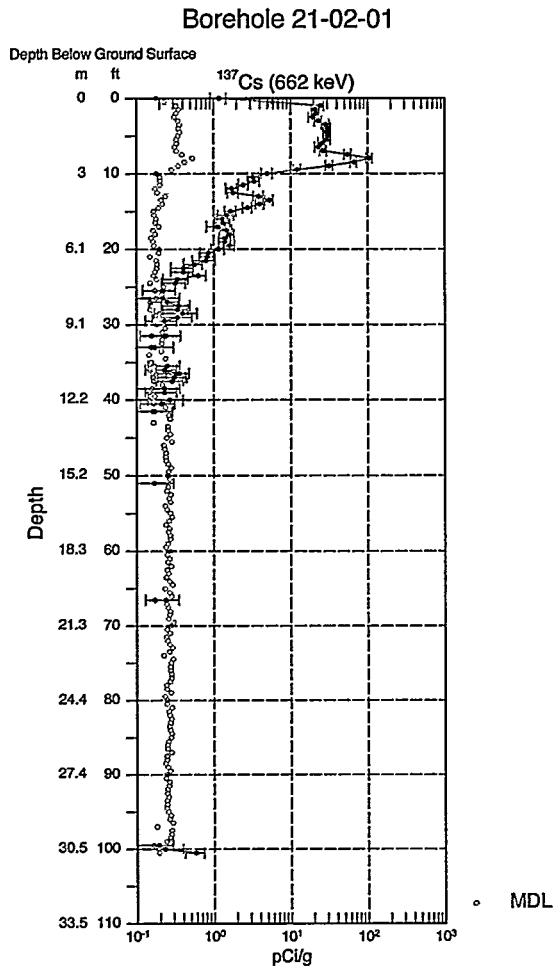


Figure 6.2.2. Example of a Radionuclide Concentration Log (MDL = minimum detection level)

and configured to deliver a germanium detector down a borehole. Data acquisition operations are specified by logging procedures provided in MAC-VZCP-1.7.10-1 (Rev. 2) and governed by quality assurance procedures specified in a project management plan MAC-VZCP-1.7.2 (Rev. 1). All data are managed as quality records governed by the current revision of the Hanford Tank Farms Vadose Zone Working File Index, which is used in conjunction with Section 3.0, "Records Management," of the *General Administrative Procedures Manual* (MAC-1000).

The spectral gamma-ray logging system equipment was calibrated by conducting a comprehensive baseline calibration and biannual field calibrations as specified in a calibration plan (MAC-VZCP-1.7.3, Rev. 1). The baseline calibration was conducted using borehole model standards constructed at the DOE Grand Junction Office specifically for borehole logging. The results of the calibration are reported in GJPO-HAN-1. Biannual field calibrations were conducted using borehole calibration models installed at the Hanford Site, and the results were reported in biannual calibration reports. The results of the fifth and most current recalibration report are presented in GJO-98-41-TAR, GJO-HAN-20. Based on the observed stability of the logging system from the biannual recalibrations, a

decision was made in 1998 to revise the calibration frequency from biannually to annually.

Data analysis involves identifying the specific isotopes detected in the gamma-ray spectra and then calculating the concentrations of those isotopes. Once the isotope concentrations are determined, the data are collated into isotope-specific logs of the radionuclide concentration versus depth, and the data are plotted as logs. Logs of man-made and naturally occurring radionuclides are produced routinely. Details of the data analysis process are documented in MAC-VZCP-1.7.9 (Rev. 1).

Data are interpreted by reviewing all of the spectral gamma logs from a single borehole and correlating the data with information on the geology, tank history, and historical gross gamma-ray logs. The intent of the individual borehole interpretations is to quantify contamination plumes, identify potential contamination sources, and relate contamination distribution patterns to the geology or tanks.

6.2.1.2 Activities for 1998

Baseline Logging, Tank Summary Data Reports, and Tank Farm Reports. During 1998, spectral gamma data were acquired from 79 boreholes surrounding tanks in the B and T Tank Farms in the 200-East and 200-West Area, respectively.

Tank summary data reports were completed for 25 tanks in the A, B, BX, C, and T Tank Farms. The tank summary data reports that were completed are tanks A-101 through A-106; tanks B-101 and B-103; tank BX-101 and tanks BX-103 through BX-112; tanks C-222 and C-112; and tanks T-108, T-109, T-111, and T-112. The borehole log plots and interpretation of results are presented in each of the tank summary data reports (GJ-HAN-93 through GJ-HAN-112, GJ-HAN-114, and GJ-HAN-121 through GJ-HAN-124).

During 1998, tank farm reports were prepared for the BX, C, and S Tank Farms (GJO-98-40-TAR, GJO-HAN-19; GJO-98-39-TAR, GJO-HAN-18; and GJO-97-31-TAR, GJO-HAN-17, respectively). Much of the preparation of the A Tank Farm Report was conducted in 1998, and the report was published in 1999 (GJO-98-64-TAR, GJO-HAN-23). The results of the A Tank Farm vadose zone characterization will be reported in next year's environmental report.

Enhancements to Spectral Shape Factor Analysis. At the recommendation of the independent SX Tank Farm expert panel, activities were conducted in 1998 to enhance the applicability of shape factor analysis. Shape factor analysis is a data analysis method that provides insights into the distribution of gamma-emitting radionuclides relative to the detector based on the ratio of count rates in various portions of the gamma-ray spectrum (GJO-96-13-TAR, GJO-HAN-7; GJO-97-25-TAR, GJO-HAN-15). To provide these insights, spectral shape factor analysis takes advantage of 1) the spectral gamma-ray logging system's ability to record the specific energies of detected gamma rays and 2) the Compton downscattering caused by the interaction of gamma rays with matter between the gamma-ray source and the detector. The enhancement activities conducted in 1998 were based on a combination of computer and physical modeling to simulate the effects of various contaminants.

The computer modeling expanded on work previously performed (GJO-97-25-TAR, GJO-HAN-15) and modeled three types of cesium-137 distributions that had not been performed previously. The three types of distributions modeled were 1) cesium-137 distributed uniformly in a cylindrical configuration of various diameters around a central borehole coincident with the cylinder's axis; 2) a cesium-137 source distributed uniformly in a thick, horizontal tabular zone; and 3) a cesium-137 source distributed uniformly in a thin, horizontal tabular zone. The results of the modeling are provided in GJO-99-80-TAR, GJO-HAN-24.

The physical modeling activities also expanded on previous work (GJO-97-25-TAR, GJO-HAN-15). The physical modeling was performed using a sand-filled tank with a central, steel-cased borehole (15-cm [6-in.] diameter). Tubes were provided in the sand-filled tank at various radii from the central borehole to allow the placement of cobalt-60 and cesium-137 point sources. The borehole was logged with the point sources located at various distances from the borehole to examine the effect of source distance on the shape factor analysis results. Examination of the data from the physical modeling is ongoing, and the results are scheduled to be reported in next year's environmental report.

Reassessment of Vadose Zone Contamination at Tank SX-104. In late 1997, moisture measurements acquired from the liquid observation well in tank SX-104 indicated a possible decrease in the tank's liquid level. At the request of DOE, Richland Operations Office, MACTEC-ERS relogged the boreholes surrounding tank SX-104 to identify regions of increased gamma-ray activity that would indicate increasing contaminant concentration in the sediments surrounding the boreholes. The boreholes were relogged with a spectral gamma logging system in January 1998, and the data were compared to those acquired during the baseline logging conducted between April and June 1995. Each borehole was also logged with a neutron-neutron logging system to evaluate the moisture content in the sediments surrounding tank SX-104.

The results of the 1998 relogging of the SX-104 monitoring boreholes indicated there was no increase or other changes in the concentrations and distributions of contaminants observed in the baseline logging. The moisture data showed variations in volumetric moisture content that were related to soil properties and not to specific contamination intervals that were detected in the boreholes. Consequently, there was no evidence from the log data acquired in 1998 in the SX-104 boreholes that indicated the tank had leaked. The results of the 1998 spectral gamma and neutron-neutron logging and comparisons between the 1998 and the baseline data are presented in GJO-98-48-TAR, GJO-HAN-21.

SX Tank Farm Borehole 41-09-39 Extension. Borehole 41-09-39 was installed to evaluate deep cesium-137 contamination that was detected around tank SX-109 during the initial spectral gamma logging in the SX Tank Farm in 1995. The borehole was terminated at a depth of 40 m (130 ft), and log data collected during installation were analyzed. The results were reported in GJO-97-4-TAR, GJO-HAN-9. The borehole was deepened in the fall of 1997, and the spectral gamma-ray system was used to log borehole 41-09-39 periodically during extension activities. The purposes of the logging were to estimate gamma-emitting radionuclide concentrations and to assess whether contamination was being dragged down during drilling operations. The spectral gamma-ray logging system was operated in both the spectral and total gamma modes during these logging operations.

Drag down relates to the contamination, generally cesium-137, that adheres to the outside of the casing and is carried down as the casing is advanced (i.e., the casing becomes contaminated as it passes through a contaminated zone). The drag-down contamination is later detected by the spectral gamma logging system, and every effort is made to identify and eliminate the drag-down data from the interpretation.

The spectral data from certain depths showed contaminant concentration changes from one log run to the next (Figure 6.2.3). On the basis of these data, and corroboration by the results of a spectral shape factor analysis process where applicable, it was shown that drag-down contamination was occurring during the deepening of borehole 41-09-39. Because of this drag-down contamination, it was not possible to determine to what depth contamination plumes exist. If an actual contaminant plume exists in the interval from approximately 40 to 49 m (133 to

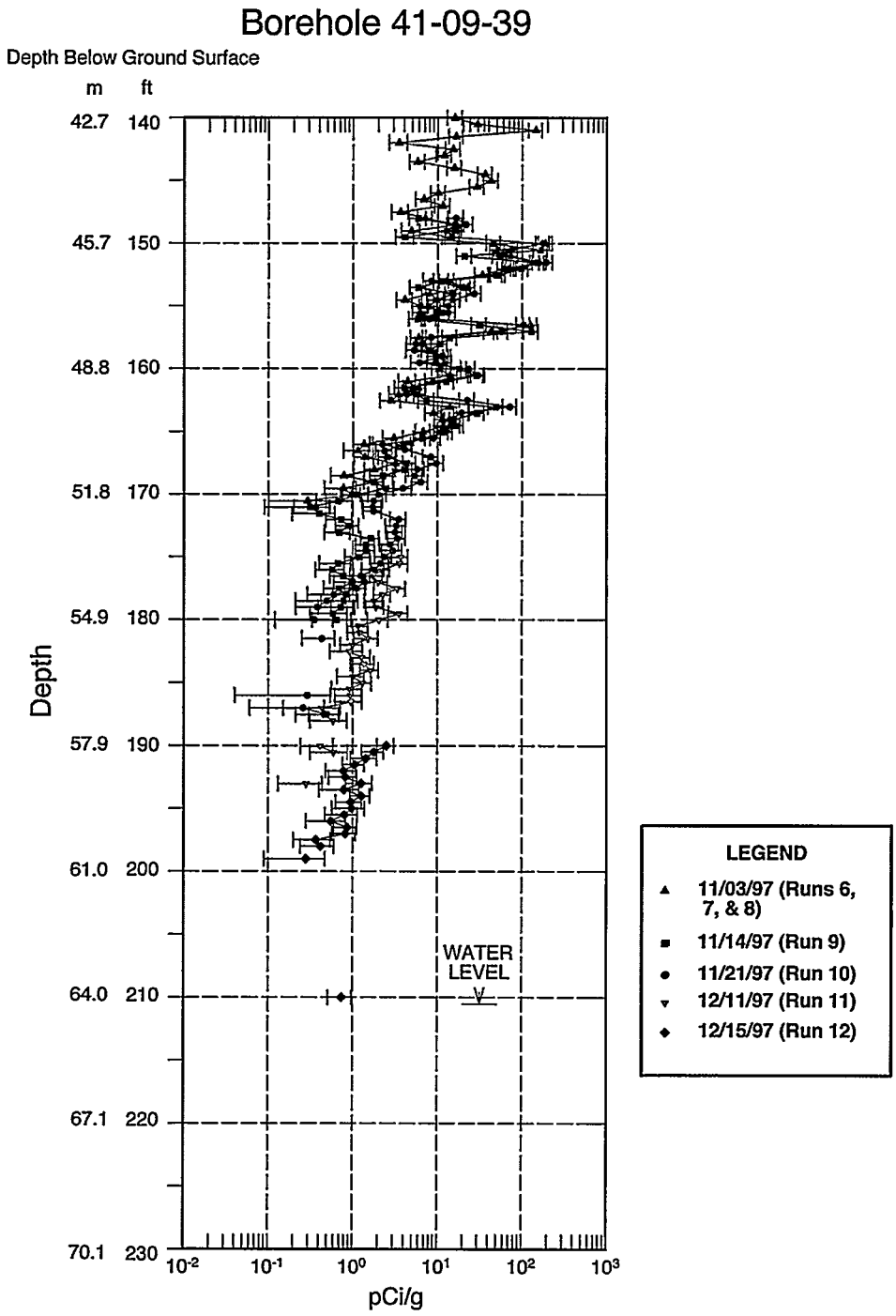


Figure 6.2.3. Comparison of Cesium-137 Concentrations from Log Runs 6 through 12 in Borehole 41-09-39, 200-West Area

160 ft), it could be masked by a false plume caused by contamination dragged down from higher in the borehole. Below approximately 49 m (160 ft), no zones of highly elevated activity were detected during the first log run in those intervals, suggesting that the existence of contaminant plumes in those intervals is very unlikely. On the basis of a comparison of the driller's logs and the gamma logs, it was postulated that the one mechanism of the drag down was that contamination had been smeared on the inside of the outer borehole casing and was being knocked loose and collected at the bottom of the borehole during drilling, logging, and sampling activities.

In addition to the spectral and total gamma logging, neutron-neutron moisture log data were collected at the conclusion of borehole drilling. Increases in moisture content identified in the neutron-neutron moisture log data correlated to water additions during drilling.

BX Tank Farm Vadose Zone Characterization. Details of the results of the spectral gamma logging in boreholes surrounding tank BX-102, where most of the vadose zone contamination in the BX Tank Farm was found, were presented in PNNL-11795 (Section 6.2.3.4). Some of the information discussed in that report are presented again in this section, along with the information for the rest of the tank farm, to provide a complete description of the BX Tank Farm vadose zone contamination.

The 74 existing boreholes surrounding the 12 single-shell tanks in the BX Tank Farm were logged with the spectral gamma logging system from May to August 1997. Figure 6.2.1 is a plan view of the BX Tank Farm, showing the locations of the monitoring boreholes. The final tank summary data report for the BX Tank Farm was completed in May 1998, and the BX Tank Farm report (GJO-98-40-TAR, GJO-HAN-19) was completed in August 1998.

Cobalt-60, antimony-125, cesium-137, europium-152, europium-154, uranium-235, and uranium-238 were the major gamma-emitting contaminants detected in the BX Tank Farm vadose zone. Occurrence of these radionuclides was detected around and below all tanks that are designated as leakers (BX-101, -102, -108, -110, and -111); however, the vadose zone contamination in the tank farm was not limited to these tanks. Figure 6.2.4 shows the vadose zone contamination at the BX Tank Farm that was detected with spectral gamma logging. The contamination shown in the figure is limited to the depth extent of the existing monitoring boreholes.

Cesium-137 was detected at ground surface throughout most of the BX Tank Farm area, and most of this contamination is associated with surface spill and/or piping leaks. This contamination decreased below the detection limits of the logging equipment at depths of approximately 3 m (10 ft).

The majority of the contamination in the BX Tank Farm was detected in its eastern area, where cobalt-60, antimony-125, cesium-137, europium-152, europium-154, uranium-235, and uranium-238 were detected throughout the 46-m (150-ft) depths of the monitoring boreholes (the majority of the monitoring boreholes surrounding the tanks are 30 m [100 ft] deep). This contamination is associated with leakage from tanks BX-101 and -102, which are designated as leakers, and the plumes originating from these tanks have commingled to create a complex distribution of contamination in this region of the tank farm. Because the monitoring boreholes surrounding tanks BX-101 and -102 are only 30 m (100 ft) deep, the presence of these radionuclides below the tanks, as well as the westward extent of the contaminant plumes, could not be determined.

Monitoring of groundwater in the well network surrounding the B, BX, and BY Tank Farms indicates contamination of groundwater has occurred. Remobilization of waste leaked from tanks BX-101 and -102 has been identified as the source of contamination in monitoring well 299-E33-41, which is located approximately 46 m (150 ft) northeast of

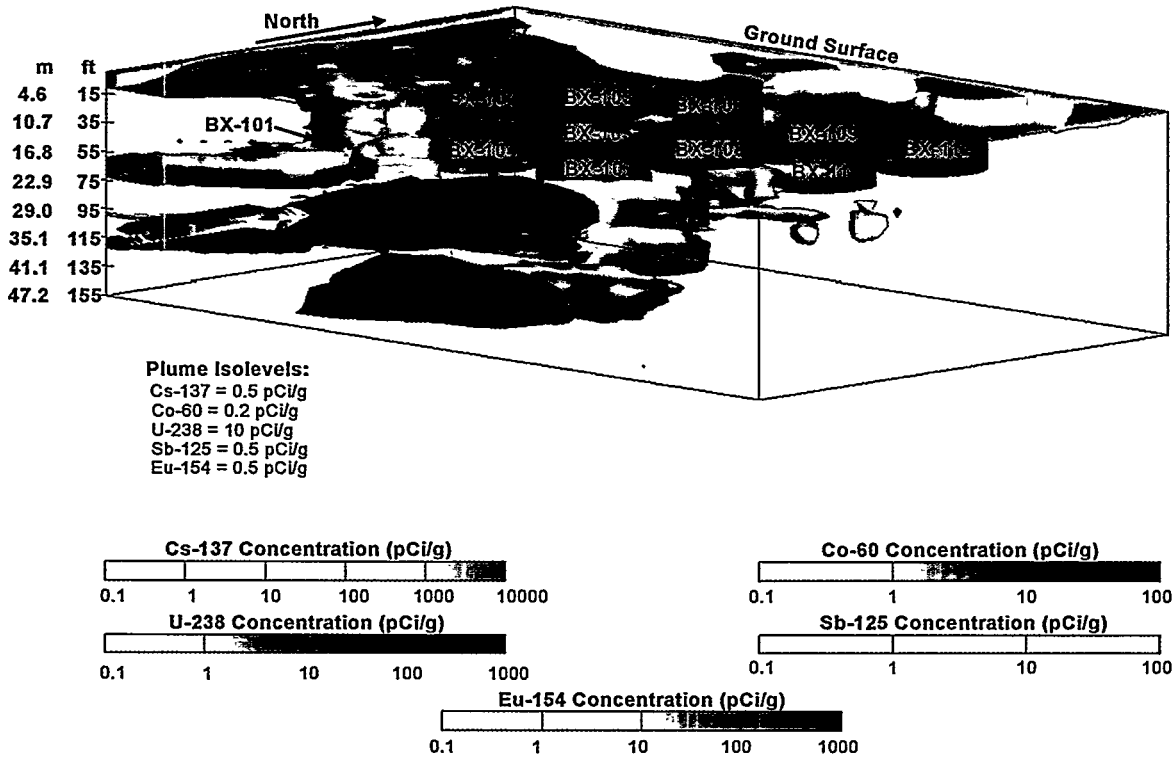


Figure 6.2.4. Vadose Zone Contamination at the BX Tank Farm, 200-East Area

tank BX-102 (PNNL 11826). Man-made uranium was detected in sediments at the depth of groundwater (which is approximately 78 m [255 ft]) and at the capillary fringe in this well.

An isolated plume of antimony-125, cesium-137, uranium-235, and uranium-238 occurs along the side of tank BX-106, which is designated as sound. The isolated nature of this plume and its spatial position relative to the tank location suggest that tank BX-106 may have leaked.

A thick accumulation of cesium-137 contamination occurs along the southern side of tank BX-107 and in the area between tanks BX-107 and -110 (see Figure 6.2.4). Several boreholes in this area have high-cesium-137 concentrations along most of their lengths. There are no documented spills and/or leaks for this area of the BX Tank Farm to account for the contamination that was detected with the spectral gamma logging systems.

C Tank Farm Vadose Zone Characterization. The 70 existing boreholes surrounding the 12 single-shell tanks in the C Tank Farm, 200-East Area, were logged with the spectral gamma logging system from January to April 1997. The final tank summary data report was completed in January 1998, and the C Tank Farm report (GJO-98-39-TAR, GJO-HAN-18) was completed in July 1998.

Cobalt-60 and cesium-137 were the major radionuclides detected in the vadose zone at the C Tank Farm; europium-152, europium-154, and uranium-235 were also detected, but their occurrences were limited to thin zones or single encounters near ground surface. Three-dimensional visualizations were created only for the cobalt-60 and cesium-137

distributions, and the plumes of these radionuclides are shown in Figure 6.2.5. The contamination detected in the C Tank Farm is limited to the depths of the existing C Tank Farm monitoring boreholes.

The majority of the contamination detected by the spectral gamma logging in the C Tank Farm cannot be directly associated to documented leaks from tanks or subsurface pipelines. The contamination distributions in some cases appear to indicate that tanks designated as sound (C-104, -105, -106, -107, and -108) may, in fact, have leaked. Conversely, there was minimal evidence of contamination detected in boreholes surrounding tanks that are designated as leakers (C-110 and -111). Contamination leaking from these tanks may not have migrated laterally to the extent to reach the vadose zone penetrated by the monitoring boreholes.

The contamination detected beneath tanks C-104, -105, and -106 may have resulted from leakage from cascade lines between these tanks as a result of overfilling tank C-105 or possible leakage from the tank itself. A 91-cm (36-in.) liquid-level drop in tank C-105 between 1963 and 1967 may be indicative of tank leakage. An investigation of this liquid-level drop identified evaporation as the cause; however, there was no positive support to this conclusion.

An extensive plume of cobalt-60 and cesium-137 was detected in boreholes between and around tanks C-108 and -109, which are designated as sound. This contamination may have resulted from leaks from tanks C-108 and/or -109, from a leak in the cascade line between these tanks, or from a leak over the dome of either tank. The leak over the dome may

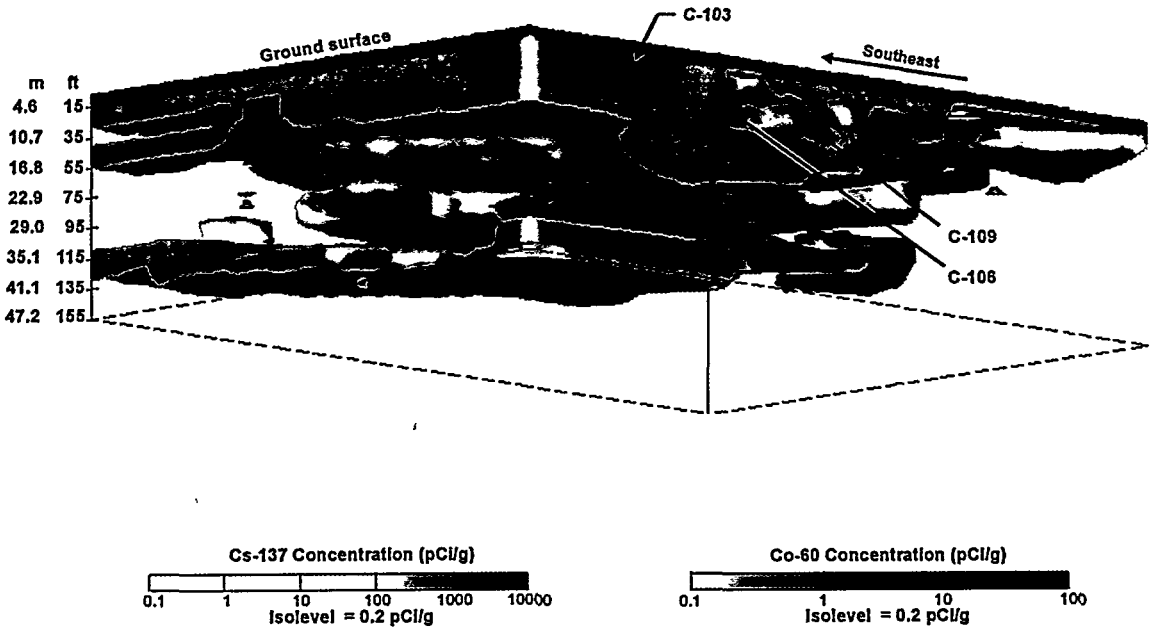


Figure 6.2.5. Vadose Zone Contamination at the C Tank Farm, 200-East Area

have migrated downward along the tank sides and may have accumulated at the interface of the backfill materials and undisturbed Hanford formation sediments. The source(s) of this contamination was not positively identified.

Tanks C-201, -202, -203, and -204 are designated as leakers. There are no monitoring boreholes around these tanks; therefore, the vadose zone in this region of the C Tank Farm cannot be characterized. The contamination from the relatively small volume of leakage (6,624 L [1,750 gal]) from these tanks is probably minimal.

There is no indication from published groundwater monitoring data that waste from tanks in the C Tank Farm has reached groundwater.

S Tank Farm Vadose Zone Characterization. The 68 existing boreholes surrounding the 12 single-shell tanks in the S Tank Farm, 200-West Area, were logged with the spectral gamma logging system from May to June 1996. The final tank summary data report was completed in August 1997, and the S Tank Farm report (GJO-97-31-TAR, GJO-HAN-17) was completed in February 1998.

Cobalt-60 and cesium-137 were the major radionuclides detected in the S Tank Farm vadose zone monitoring boreholes. Europium-154 was detected in one borehole in a thin interval near ground surface. Because of the limited occurrence of cobalt-60 contamination relative to the distribution of cesium-137, three-dimensional visualizations of only the cesium-137 contamination were prepared. Figure 6.2.6 shows the cesium-137 contamination in the S Tank Farm that was detected with spectral gamma logging; the characterization of the S Tank Farm vadose zone contamination is limited to the depths of the tank monitoring boreholes.

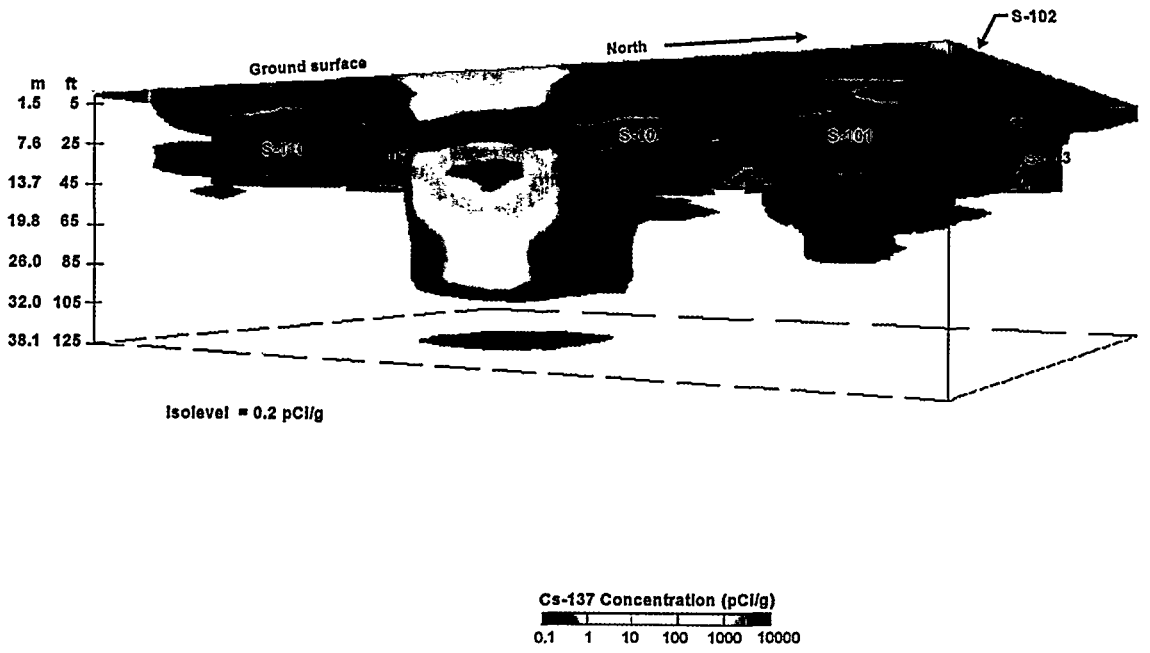


Figure 6.2.6. Vadose Zone Contamination at the S Tank Farm, 200-West Area

Two major regions of contamination were detected in the S Tank Farm: one beneath and to the east of tank S-104 and the other around tanks S-101, -102, and -103. Cesium-137 contamination beneath tank S-104 resulted from leakage from that tank and extends to a depth of approximately 29 m (95 ft) (approximately 17 m [55 ft] beneath the tank base).

Cobalt-60 and cesium-137 contamination was detected around tanks S-101, -102, and -103. This plume of contamination resulted from a large surface spill that occurred in this region of the tank farm in 1973. The surface spill appears to have migrated through the backfill materials, cascaded over tank domes, and collected at the base of the tank farm excavation to depths of approximately 22 m (73 ft).

Data indicate that contaminants may be entering the groundwater beneath the S Tank Farm; however, a positive source of the contamination could not be determined from this initial vadose zone characterization. Waste disposal facilities adjacent to the S Tank Farm, as well as the S Tank Farm itself, may be sources of the groundwater contamination (WHC-SD-EN-AP-191).

6.2.2 Vadose Zone Monitoring at Waste Disposal Facilities

D. G. Horton, R. J. Serne, and V. J. Rohay

Radioactive and hazardous waste in the soil column from past intentional liquid waste disposals, accidental spills, and leachate from solid waste burial grounds at the Hanford Site are potential sources of groundwater contamination. Subsurface source characterization and vadose zone monitoring, using spectral gamma logging and soil-gas monitoring were conducted during 1998. Also in 1998, physical, chemical, and hydraulic properties were measured from samples obtained from characterization boreholes at the Immobilized Low-Activity Waste site in the 200-East Area, which is the site for activities associated with retrieval and processing of tank waste, to support performance assessment modeling; at the borehole 41-09-39 extension site in the 200-West Area, to support SX Tank Farm remediation/closure; and at the 216-B-2-2 ditch in the 200-East Area to support 200 Areas soils remediation. Further, soil-vapor monitoring in the 200-West Area continued in 1998, and the summary of those activities is provided in this section.

6.2.2.1 Subsurface Characterization and Vadose Zone Monitoring

During 1998, in situ spectral gamma logging was performed by Waste Management Federal Services, Inc., Northwest Operations in support of Pacific Northwest National Laboratory RCRA groundwater monitoring in 21 boreholes (Figure 6.2.7) at the 216-Z-1A Tile Field, 216-Z-9 Trench, and 216-Z-12 Crib, all associated with the Plutonium Finishing Plant in the 200-West Area. These facilities were logged to determine whether recent movement of transuranic radionuclides had occurred beneath the facilities as a result, in part, of infiltration of precipitation. The surface of the 216-Z-1A facility is approximately 2 m (6.6 ft) below the surrounding grade and is covered with gravel. Thus, infiltration at this facility could be expected to be enhanced.

Spectral Gamma Logging Results. All borehole logs and a full discussion of the logging results at the 216-Z-1A Tile Field, 216-Z-9 Trench, and 216-Z-12 Crib can be found in PNNL-11978.

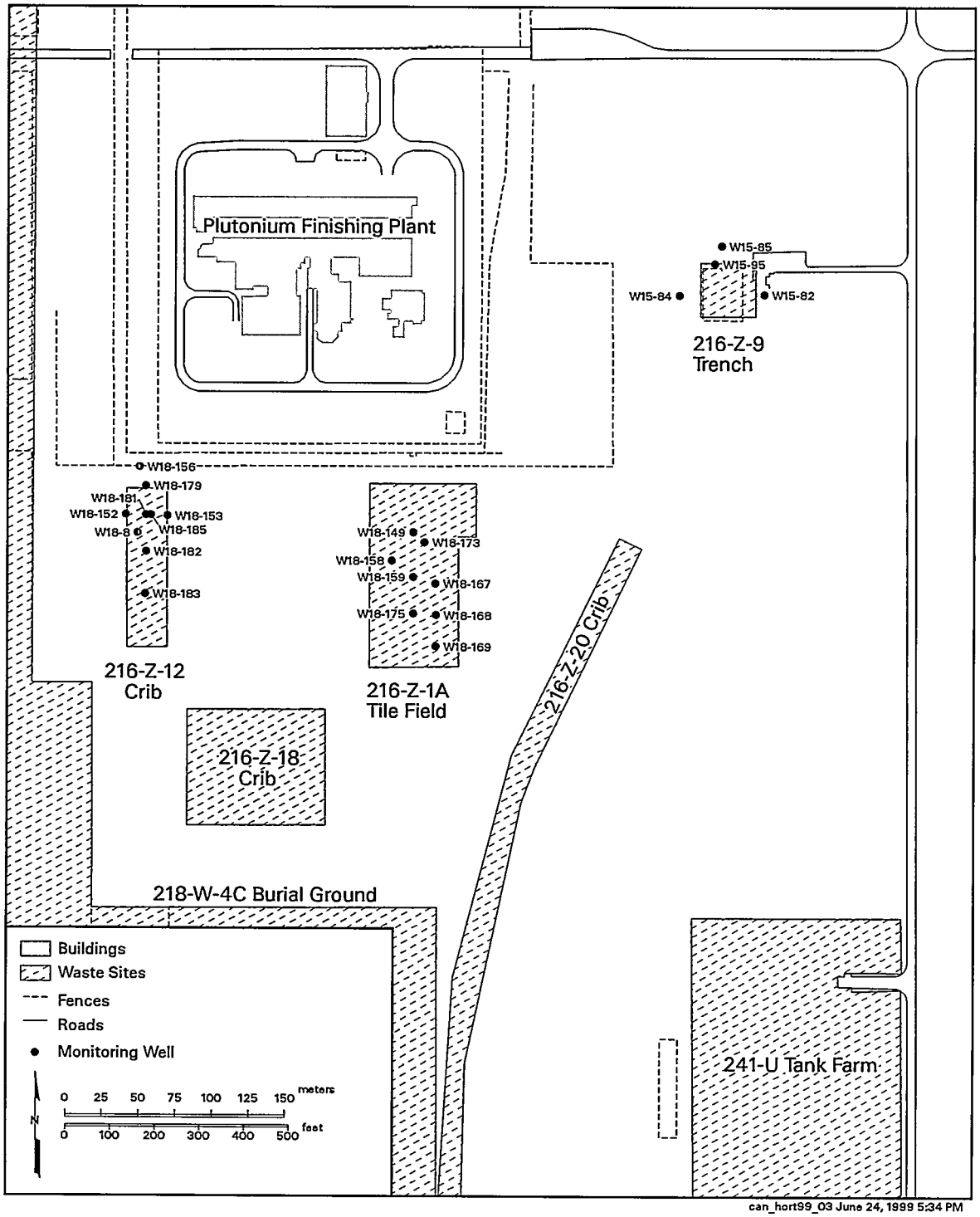


Figure 6.2.7. Location of Boreholes Logged at the 216-Z-1A Tile Field, 216-Z-9 Trench, and 216-Z-12 Crib, 200-West Area

The discussion below summarizes those results. All depths referred to in this section are relative to ground surface.

Cesium-137, protactinium-233, plutonium-239, and americium-241 were identified in the logs from the tile field and the crib. The maximum activities found at the tile field were in borehole 299-W18-159, which is located along the centerline/central distributor pipe of the tile field (cesium-137, 23 pCi/g at 3.3 m [10.8 ft]; protactinium-233, 63 pCi/g at 16.5 m [54.1 ft]; plutonium-239, 25,000,000 pCi/g at 3.3 m [10.8 ft]; americium-241, 2,500,000 pCi/g at 4.3 m [14.1 ft]). The distributor pipes are at the approximate 4.6-m (15-ft) depth (RHO-ST-17). This high-activity, shallow zone has been attributed to particulate plutonium dioxide that was filtered out of the liquid effluent by the sediments. Grab samples obtained in 1979 during drilling of borehole 299-W18-159 were found to contain a maximum of 1,500,000 pCi/g plutonium-239,240 at 4 m (13.1 ft) (RHO-ST-17). The difference between the maximum activities found from the 1979 laboratory results and the 1998 logging results probably reflects differences in the two analytical methods, coupled with the potential for discrete particulate plutonium dioxide at the level of the distributor pipe.

The deepest depth at which contamination was found at the 216-Z-1A Tile Field was approximately 30 m (98.4 ft) in borehole 299-W18-175, which is located along the centerline/central distributor pipe, where protactinium-233 was ~21 pCi/g, plutonium-239 was near 28,000 pCi/g, and americium-241 was near 80,000 pCi/g. Significant activities (≥100,000 pCi/g) of plutonium-239 were found as deep as 16 m (52.3 ft) in one borehole and approximately 14 m (46 ft) in another. Significant activities (≥100,000 pCi/g) of americium-241 were found as deep as 15 to 18 m (49 to 59 ft) in two boreholes. Whereas the shallow, high-activity zone can be attributed, in part, to particulate plutonium dioxide that was filtered out of the effluent by the sediments, the deeper, more widely distributed zones of contamination probably resulted from dissolved transuranics in aqueous and/or organic phases.

The only man-made radionuclide identified at the 216-Z-9 Trench was cesium-137, at <1 pCi/g near the surface in borehole 299-W15-95. However, only four wells were logged, and radionuclide contamination almost certainly exists beneath the trench.

At the 216-Z-12 Crib, boreholes 299-W18-179, -181, -182, and -185 showed the highest activities of man-made radionuclides. The maximum plutonium-239 activity was 3,000,000 pCi/g at 7 m (22.9 ft) in borehole 299-W18-181. The maximum americium-241 activity was 2,100,000 pCi/g at 7 m (22.9 ft) in borehole 299-W18-182. The maximum cesium-137 activity was 900 pCi/g at 5.8 m (19 ft) in borehole 299-W18-179. The distributor pipe is ~5.2 m (17 ft) below ground surface at this facility. The deepest contamination was found ~10 to 11 m (32.8 to 36 ft) at borehole 299-W18-181, where plutonium-239 was ~110,000 pCi/g, americium-241 was ~40,000 pCi/g, and cesium-137 was ~6 pCi/g. These boreholes all lie along the central distributor pipe near the headend of the crib. Protactinium-233 was the only man-made radionuclide found in boreholes near the crib boundary.

Comparisons of log data collected in 1998 with past logging event data suggest that some changes have occurred in radionuclide activity around two boreholes in the 216-Z-1A Tile Field and around one borehole in the 216-Z-12 Crib.

In borehole 299-W18-159 at the 216-Z-1A Tile Field, there was an apparent decrease in protactinium-233 activity to approximately one-third of 1991 values between 13.4 and 15 m (43.9 to 49.2 ft), with no apparent change above or below that zone. This suggests a lateral, not a vertical, change in protactinium-233 activity. Also, between 13 and 16 m (42.6 and 52.5 ft), cesium-137 activity decreased by a factor of approximately three, compared to the 1991 log.

In borehole 299-W18-175 at the 216-Z-1A Tile Field, a 51% increase in protactinium-233 activity was found between 6 and 16 m (19.7 and 52.5 ft) and a 22% increase between 28 and 29 m (91.9 and 95.1 ft), compared to activities from a 1993 log. Also in this borehole, there was an increase in the intensity of the americium-241 60-keV photopeak but no change in the intensity of the americium-241 208-keV photopeak at the 12.5-m depth, which compared with the 1993 log data. This suggests either a decrease in the casing thickness, such as from corrosion, leading to less attenuation of the less-energetic photon, or small amounts of americium-241 inside the borehole casing.

Only borehole 299-W18-179 at the 216-Z-12 Crib suggested that there were changes in subsurface distribution of radionuclides at that facility. Protactinium-233 showed an apparent 16% increase, and plutonium-239 showed an apparent 123% increase over the 4.6- to 5.5-m (15- to 18-ft) depth interval since the last logging in 1993. This depth is within the crib backfill material.

There is significance to the occurrence and the changes in protactinium-233 activity found in the three boreholes. Protactinium-233 has a 27-d half-life, so its occurrence must be supported by a long-lived parent isotope. Alpha decay of neptunium-237, with a half-life of 2.2 million years, is the most probable parent for protactinium-233. One probable origin for the neptunium-237 is alpha decay of americium-241, which was a significant contaminant in the waste stream sent to the Plutonium Finishing Plant cribs. A second possible origin for neptunium-237 is uranium-238 (n,2n) uranium-237, which beta decays to neptunium-237. Regardless of the origin of the neptunium-237, it is considered to be rather mobile in oxidizing environments (see PNL-10379, SUP. 1). Thus, the changes in activity of protactinium-233 probably reflect movement of neptunium-237, and the distribution of protactinium-233 can be considered a surrogate for neptunium-237.

Finally, the 1998 logging found large amounts of transuranics around boreholes 299-W18-149 and -159 that produced a large neutron flux, resulting in activation of elements in the soil column and in the borehole casing. This phenomenon was not investigated further.

Migration of Transuranics. The mobility of transuranics that are complexed with organic molecules in acidic waste streams discharged to past-practice disposal facilities near the Plutonium Finishing Plant were discussed in Section 4.4.5 of PNNL-11793 and by Johnson and Hodges (1997). The mechanism suggested by Johnson and Hodges might account for the distribution of high-activity transuranics to the 20- to 30-m (65.6- to 98.4-ft) depth in the 216-Z-1A Tile Field as found in earlier soil-column characterizations (RHO-ST-17). It is also suggested that transuranics could be adsorbed by the soil column after degradation of the organic complexing agents, resulting in stabilization of the contaminants. Alternatively, other soil-chemical reactions may have occurred (RHO-ST-17, NUREG/CR-6124).

In 1993, a logging team produced prompt fission neutron logs of four boreholes at the 216-Z-1A Tile Field and one each at the 216-Z-9 Trench and 216-Z-12 Crib. The prompt fission neutron tool measures undifferentiated, fissionable isotopes (primarily uranium-235, plutonium-239, and plutonium-241). The results of the prompt fission neutron logging were not published, but a draft report states that all the boreholes at the 216-Z-1A Tile Field and one borehole at the 216-Z-12 Crib showed large activities of fissionable isotopes. Two of the boreholes at the tile field had been logged previously with the prompt fission neutron tool in 1978 and again in 1984. The distribution of contaminants, as seen from the 1993 log, agreed well with the previous logs, indicating that fissionable radionuclides, including plutonium, had not moved substantially over the span of 15 yr at the two boreholes. The general

conclusion is that transuranics were relatively mobile at the time of discharge to the tile field but have been fairly stable since.

The 1998 logging found that the subsurface distribution of plutonium had changed around only one borehole at the 216-Z-12 Crib. "Particulate" plutonium, with discrete 2- to 24-micron particle sizes (>79 wt% plutonium dioxide) at and immediately below the distribution pipe at the 216-Z-1A Tile Field was documented in Price and Ames (1976). Although it is possible that particulate plutonium has been remobilized at the 5-m (16.4-ft) depth at the crib, further investigation is needed to determine both the nature and the reasons for plutonium remobilization.

Comparing the distribution of transuranics beneath the 216-Z-1A Tile Field and the 216-Z-12 Crib shows a much deeper penetration of transuranics beneath the tile field. This agrees with past characterizations at the two facilities (RHO-ST-17, RHO-ST-44) and can be explained by the processes described in Section 4.4.5 of PNNL-11793 or in Johnson and Hodges (1997). Unlike the acidic, organics-containing waste stream disposed to the tile field, the waste stream sent to the crib was neutral to basic and contained little organic-complexing agents (though sufficient carbon tetrachloride was found beneath the crib to include it in the vapor-extraction project). The initial mobility of transuranics is expected to be greater in the former waste stream than in the latter. After the disposal occurred, both the acidic and organic complexes are expected to have diminished via soil pH neutralization and biodegradation processes, and transuranics, especially americium and plutonium, would be expected to adsorb strongly to the sediments. There has been no obvious increased americium or plutonium migration deeper into the sediment profile at these facilities, but the protactinium-233 distribution may be interpreted as showing some migration of neptunium-237.

6.2.2.2 Immobilized Low-Activity Waste Site

The Tank Waste Remediation System program is focusing on resolving tank safety issues, planning for waste retrieval, developing waste pretreatment and treatment facilities, and evaluating waste storage and disposal needs for single-shell tank wastes. Vitrification and onsite disposal of low-activity waste from single-shell tanks are embodied in the strategy described in the Hanford Site federal facility agreement and consent order (commonly known as the Tri-Party Agreement; Ecology et al. 1989). The pretreatment and immobilization operations for both the low-activity and high-level wastes have been contracted to private organizations. The current plan is to dispose of immobilized, low-activity, tank waste in new facilities in the south-central part of the 200-East Area and in four existing vaults (unused, reinforced concrete structures remaining at the former Grout Treatment Facility) along the eastern side of the 200-East Area (DOE/RL-97-69).

Boreholes 299-E17-21, B8501, and B8502 were drilled in April 1998 at the southwestern corner of the Immobilized Low-Activity Waste disposal site (Figure 6.2.8) in support of the performance assessment activities for the disposal options. The boreholes were drilled using an air-lift, driven-casing method, and continuous soil samples were collected through the vadose zone. A complete description of the drilling project is presented in PNNL-11957.

Geologic logging of the drill cores showed that the vadose zone beneath the southwestern portion of the Immobilized Low-Activity Waste disposal site consists of the upper few meters (feet) of Ringold Formation Unit E gravels overlain by the Hanford formation (PNNL-11957). The careful drilling and near-continuous core recovery allowed geologists to identify for the first time three paleosols (layers) in a single borehole (299-E17-21). The three paleosols represent significant time intervals when soil development took place and are interpreted to be the tops

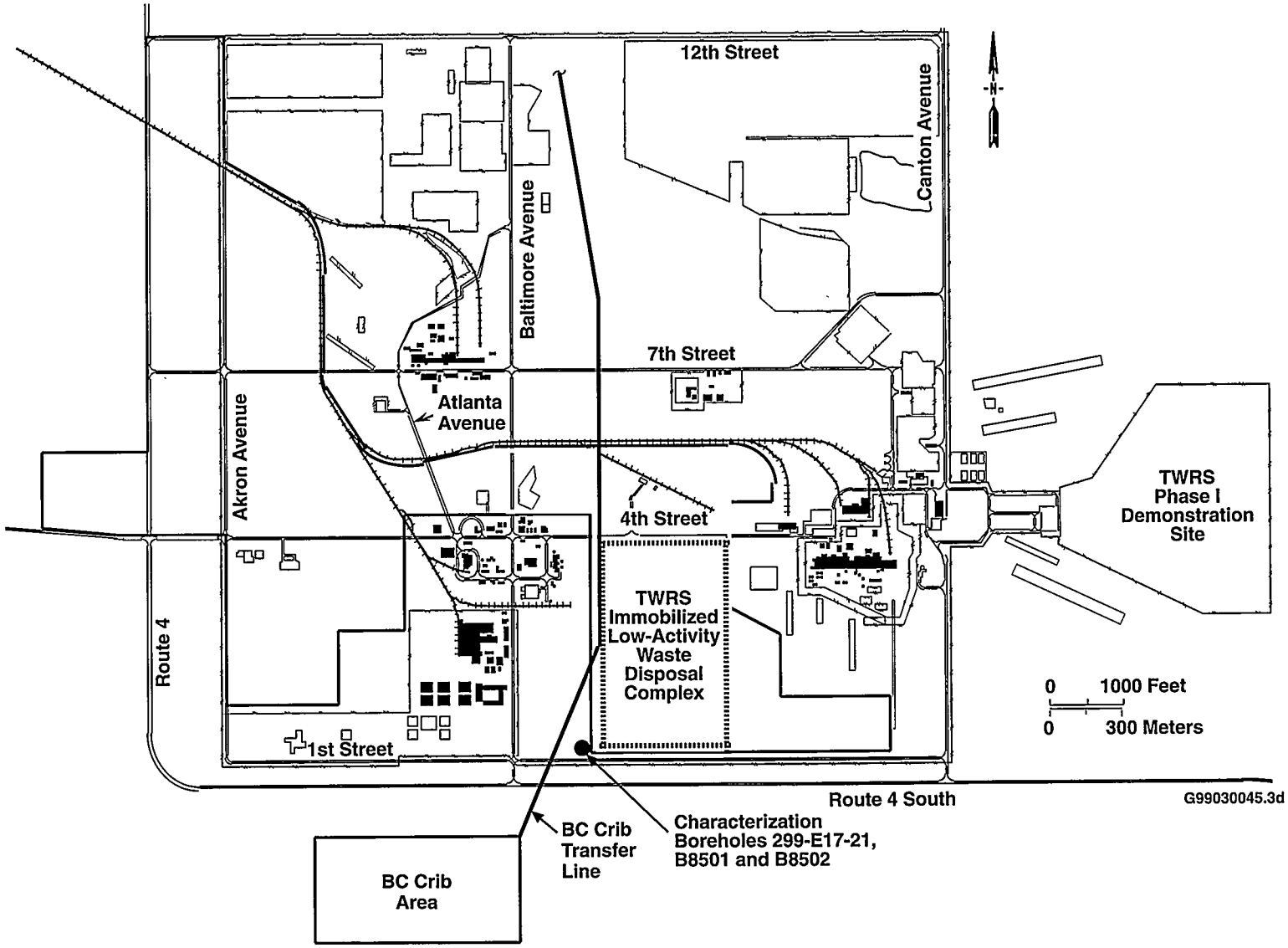


Figure 6.2.8. Locations of the Immobilized Low-Activity Waste Site and Characterization Boreholes 299-E17-21, B8501, and B8502, 200-East Area

of three Missoula flood deposits. The three flood events have been mapped at the Hanford Site (Reidel and Fecht 1994a, 1994b) but they have not been encountered in a single borehole. The detailed stratigraphy from the borehole sets a good background for the subsequent chemical transport, physical properties, and estimation of recharge tests.

All three boreholes were logged with a high-purity germanium detector to determine whether man-made, gamma-emitting radionuclides were present and to provide analyses of naturally occurring isotopes for stratigraphic purposes. No man-made radionuclides were identified. The boreholes were also logged with a neutron probe to determine moisture content. The moisture logging showed higher moisture content in the upper part of the borehole, consistent with higher-than-normal precipitation over the past several years. Comparison of the neutron probe moisture data with the stratigraphy indicated good agreement between high-moisture zones and fine-grained stratigraphic units.

Twenty intact cores from borehole 299-E17-21 were analyzed for physical and hydraulic properties. The 20 cores are from the Hanford formation sandy sequence. The cores were found to be fairly uniform as were the data generated, reflecting the high percentage of medium to fine sand. The variability among the hydrologic and physical data collected was within the range reported by WHC-EP-0883 for sediments of the 200 Areas. This increases confidence that existing data sets are representative of the range of physical and hydrologic properties present in the uncontaminated portions of the 200 Areas and may be representative of many of the contaminated portions of the 200 Areas. The data represent the most complete set of physical properties (i.e., particle size, particle density, bulk density, porosity) and hydrologic properties (i.e., saturated and unsaturated hydraulic conductivity, water retention) measured on undisturbed cores (split-spoon samples) at the Hanford Site.

In two samples, thin zones were observed with finer texture and lower hydraulic conductivities than were seen in the other 18 samples. These two thin zones could impact flow and contaminant transport by increasing lateral spreading. These observations, in concert with others, will be used to formulate a vadose zone conceptual model for the Immobilized Low-Activity Waste disposal site. Additional boreholes are planned in future years to help verify whether the two, thin, fine-textured layers are continuous across the disposal site. An unexpected feature found during coring activities was a relatively thick, open-framework, gravel sequence below 76.2 m (250 ft). No physical or hydrologic data are available for this sequence. Plans are in place to gather samples that are as undisturbed as possible during the future drilling activities.

Specific Distribution Coefficient Data. Radionuclide distribution coefficients (K_d) are a measure of the ratio of the amount of radionuclide adsorbed onto soil or rock and the amount remaining in solution (i.e., groundwater). K_ds are usually obtained by contacting soil with groundwater that has been spiked with a known amount of a specific radionuclide. The quantity of radionuclide adsorbed on the soil and the quantity remaining in the water are then measured. The higher the K_d, the greater the amount of contaminant on the soil relative to the amount remaining in the groundwater.

Radionuclide K_d measurements for cesium, iodine, selenium, strontium, technetium, and uranium were made on 20 samples from borehole 299-E17-21. Results of the measurements are summarized below. A more complete description of the tests is given in PNNL-12086 (Section 4.4). The results of the testing serve as input to performance assessment modeling of the Immobilized Low-Activity Waste Site.

Two sets of K_d values were calculated: conservative and best estimate. The conservative and best estimates of K_d values are given in Table 6.2.1,

Table 6.2.1. Conservative and Best Estimates of Distribution Coefficient (K_d) Values of Units 1, 2, and 3[a,b] at Borehole 299-E17-21, 200-East Area

	Units 3 and 2 K_d, mL/g		Unit 1 K_d, mL/g	
Radionuclide	Conservative[c]	Best[d]	Conservative[c]	Best[d]
Cesium	1,370	2,050 ± 440	1,370	2,050 ± 440
Iodine	0	0 ± 0	0	0.1 ± 0.1
Selenium	3.8	6.7 ± 1.9	3.8	6.7 ± 1.9
Strontium	12.0	14.3 ± 1.6	12.0	16.5 ± 1.9
Technetium	0	0 ± 0	0	0 ± 0
Uranium	0.5	0.6 ± 0.1	0.5	0.6 ± 0.1

(a) Different K_d values were assigned to each unit when statistical analyses determined that they differed at the 5% level of confidence. Otherwise, the same K_d values were assigned for all three units.
(b) Units represent depths within the Hanford formation: unit 3, 1.5 to 17.7 m (5 to 58 ft); unit 2, 17.7 to 49.7 m (58 to 163 ft); and unit 1, 49.7 to 75.3 m (163 to 247 ft).
(c) Conservative estimates were based on the minimum value.
(d) Best estimates were based on the median ± standard deviation.

assuming that performance assessment modeling will divide the Hanford formation into three geologic units separated by the paleosols described above, and in Table 6.2.2, assuming that the Hanford formation will be treated as a single modeling unit. Which of these two conceptual models will ultimately be used in future performance assessments will depend on these as well as other characterization data. Presumably, if significant differences in other parameter values such as hydraulic conductivity are observed among the three units, then it may be decided that introducing the added complexity of three units is warranted. Otherwise, the most conservative estimate of the combined units may be used for the performance assessment.

Overall, the estimates appearing in Tables 6.2.1 and 6.2.2 are consistent with those used for past performance assessments, with some notable exceptions. The older, conservative values for cesium, selenium, and strontium used in past calculations were 100, 0, and 5 mL/g, respectively, and were appreciably more conservative than necessary. The new K_d estimates for technetium and uranium in Tables 6.2.1 and 6.2.2 are approximately the same as those used for past calculations. The iodine K_d value from this new work is appreciably less than that used in the most recent performance assessment (3 mL/g) (DOE/RL-97-69), which was based on a literature review of K_d values measured using generic Hanford Site sediments (PNL-10379, SUP. 1). The cause for the new, measured, lower, iodine K_d values is not known, though the sediments used in this study clearly had appreciably lower amounts of fine-grained material than the previously used Hanford Site sediments. These differences in values underscore the importance of basing K_d estimates for the more-mobile major dose contributors on measurements using site-specific sediments.

Ideally, all K_d experiments should be conducted using site-specific sediments because the science of

Table 6.2.2. Conservative and Best Estimates of Distribution Coefficient (K_d) Values for the Hanford Formation at Borehole 299-E17-21, 200-East Area

Radionuclide	Conservative K_d Value,[a] mL/g	Best K_d Value,[b] mL/g
Cesium	1,370	2,030 ± 597
Iodine	0	0 ± 0
Selenium	3.8	6.7 ± 1.9
Strontium	12.0	14.3 ± 1.6
Technetium	0	0 ± 0
Uranium	0.5	0.6 ± 0.1

(a) Conservative K_d value estimates are based on the lowest value for each radionuclide (except uranium, which used the second-lowest measured K_d value.
(b) Best K_d value estimates are the median ± standard deviation from the 20 samples studied.

geochemistry is not yet advanced enough to permit estimating the geochemical behavior of a radionuclide in one sediment based on its behavior in another. However, site-specific sediments are generally expensive to collect, and the volume of material available usually is limited. The newly determined iodine K_d data suggest that the most technically defensible way to quantify radionuclide sorption is through experiments conducted with site-specific sediments and pore water or waste leachate, but the new results for the other contaminants studied are quite similar to past results using generic Hanford Site sediments not proximal to the proposed Immobilized Low-Activity Waste disposal complex.

6.2.2.3 Borehole 41-09-39 Extension to Groundwater

Borehole 41-09-39 was drilled in 1996 in the SX Tank Farm, 200-West Area, to a depth of 40 m (131 ft) in response to the determination that cesium-137 might reside in the soil column at depths >30.4 m (100 ft). Closed-end casing was driven to ascertain whether the contamination was an artifact of transport down the outside of an adjacent borehole or was disseminated in the soil formation. Geophysical logging of this borehole in late 1996 confirmed that cesium-137 dissemination within the formation was plausible and that contamination was still present at a depth of 40 m (131 ft).

Concern was raised that if relatively immobile cesium-137 was present at that depth, then more-mobile, long-lived, tank-waste constituents such as technetium-99 might be at or near the water table at approximately 64 m (210 ft). In response to a recommendation of the independent expert panel brought together to address these early findings (DOE/RL-97-49), borehole 41-09-39 was extended to groundwater in 1998 and samples were collected for laboratory analysis of tank waste components.

The closed-end casing was removed by milling with a rotary drilling machine, and the borehole was extended by sequentially driving a split-spoon sampler into the formation ahead of the drill casing, then cleaning the bore to the depth sampled, driving the drill casing to that depth, and finally cleaning out the drill casing again. This process was then repeated for

subsequent samples. Geologic conditions resulted in excessive friction against the drill pipe, effectively stopping progress. The drill casing was removed from the bore, and the drill shoe was replaced to over-ream the hole, reducing friction and allowing the casing to be advanced. The over-reaming drill shoe created a small annular space that may have contributed to drag down of contamination.

Sediment samples were collected in a near-continuous manner throughout the vadose zone, except where geologic conditions required use of a drilling method that resulted in unrepresentative samples. All sediment returned to the surface was preserved for potential analysis. Samples from seven selected locations within the borehole were analyzed for radionuclides, chemical constituents, cation-exchange capacity, and particle-size distribution.

Periodic geophysical logging of the borehole was used to indicate the occurrence of contaminant drag down and to provide additional data used to select sample locations. Gamma logging techniques were used throughout the drilling effort. On completion of the borehole, a neutron-neutron moisture log was run. Geophysical logging indicated that some contaminated material was following the casing as it was advanced. It should be noted that the indicated contaminant levels were low.

Screening analyses of the samples showed that the upper portion of the split-spoon sampler often exhibited low levels of contamination while the lower portion did not. The regularity of this occurrence resulted in its being interpreted as cross-contamination, either from material dragged along the outside of the casing or from material smeared along the inside of the casing that was deposited as the drill tools and samplers were inserted or extracted from the bore. Samples from the upper split-spoon sleeves were excluded from analysis when there was evidence of such possible cross-contamination.

Detailed geochemical analyses of the seven samples from this borehole showed that tank waste constituents are predominantly held within or above the Plio-Pleistocene sediments. Nonradiological constituents (calcium, nitrate, sodium) point to the leading edge of tank waste components being at a depth of approximately 47 m (154 ft) in borehole 41-09-39. This leading edge may be from natural percolation or drag down; however, the determination of which process is most likely cannot be made at this time.

Analyses for cesium-137, the radionuclide originally recognized as being deeper than expected in the vadose zone, were conducted on all samples via gamma energy analysis. Cesium-137 activity in the soils of the extended borehole was highest in the Plio-Pleistocene sediments at the 40-m (131-ft) depth. Activity dropped off rapidly and was at or below detection levels from 48.8 m (160 ft) to the water table at 64.3 m (210 ft).

Distribution of technetium-99, the most mobile of the long-lived radionuclides found in tank wastes, was sporadic, with most occurrences above the method detection level being above the Plio-Pleistocene unit. A single, deep occurrence was noted at 56.3 m (185 ft); this is the location postulated to be the highest level reached by groundwater during operation of U Pond (now decommissioned) located west of the SX Tank Farm. It is possible that technetium-99 was brought to this sediment sample by horizontal migration from disposal facilities outside the tank farm boundaries. If the technetium source was the SX tanks, it would have been expected that near-continual detection would have been noted throughout the shallower sediments. Figure 6.2.9 shows the distribution of cesium-137, technetium-99, and water extractable nitrate concentrations in the vadose zone sediments from borehole 41-09-39.

K_d tests were run on sediment samples for both technetium-99 and cesium-137. These tests showed that cesium-137 is strongly bound to the fine-grained sediments. The tests for technetium-99 showed positive K_d values, but the uncertainty associated with those values was significant.

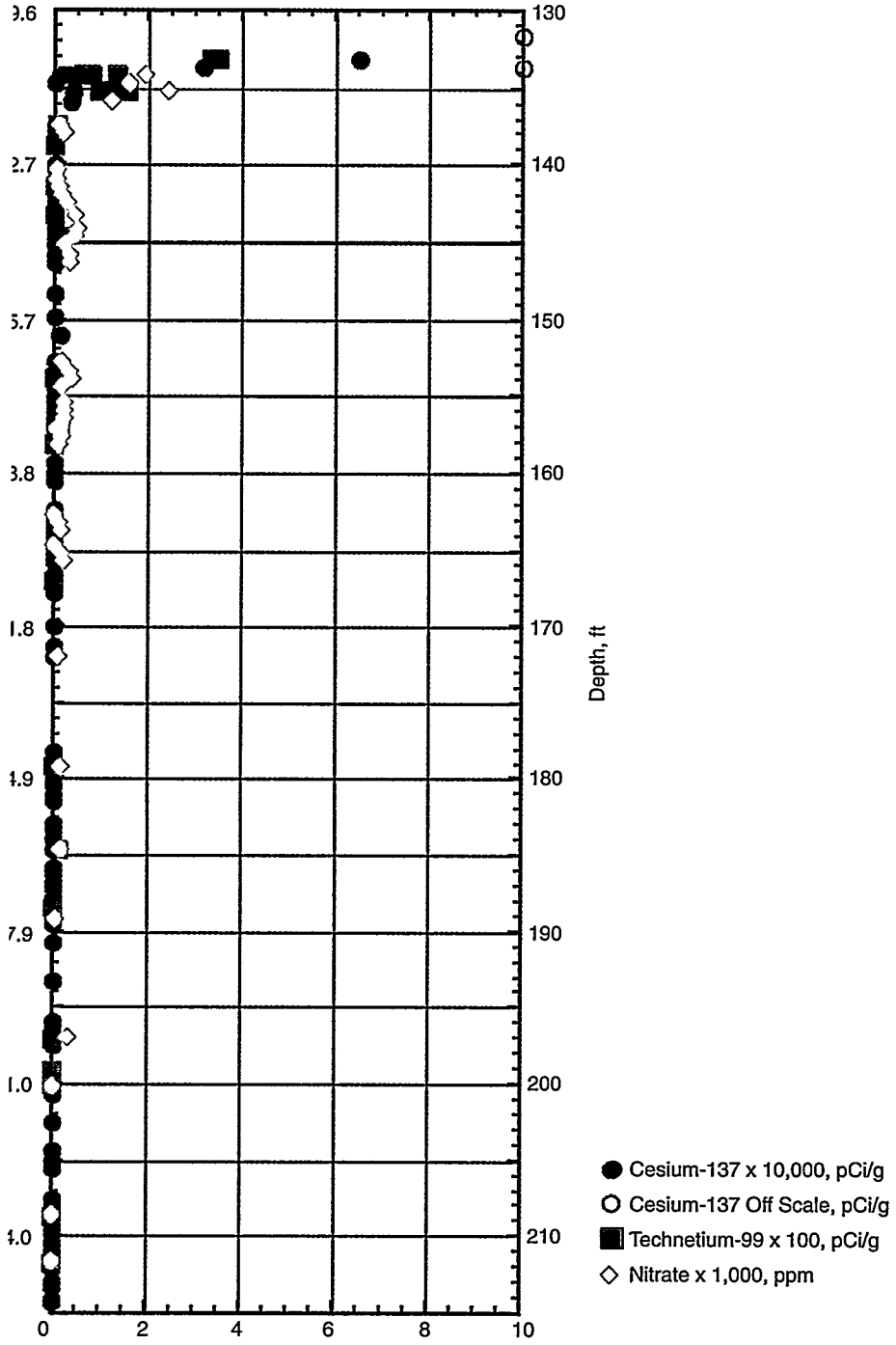


Figure 6.2.9. Distribution of Technetium-99 and Cesium-137 in the Vadose Zone Sediments from Depth and the Water Extractable Nitrate Concentrations from Borehole 41-09-39, SX Tank Farm, 200-West Area

Groundwater samples were collected from 0.02, 0.6, and 3 m (0.06, 2, and 10 ft) below the water table. Analyses of these samples showed technetium-99 and tritium activities indicative of an upgradient source. Analytical results for chromium were consistently below the method detection limit. These analyses indicate that groundwater contamination at this specific location is due to non-tank farm sources. More sampling of vadose zone sediments under the SX Tank Farm at additional locations is needed to determine whether the contaminants in downgradient monitoring wells may have originated from the single-shell tanks or from non-tank-related liquid discharge facilities nearby.

The results of the investigation of the borehole 41-09-39 extension point to a need to ascertain the disposition and distribution of the mobile, long-lived, waste constituents in the vadose zone. Complete details of the borehole extension findings can be found in HNF-2855. The geochemistry of tank wastes and the possible interactions of mobile species with sediments of the vadose zone are major gaps in the Hanford Site vadose zone information base for addressing tank remediation/closure.

6.2.2.4 200 Areas Assessment

A characterization borehole (299-E33-333) was drilled through the 216-B-2-2 Ditch, 200-East Area, (Figure 6.2.10) to groundwater during late December 1997 and early January 1998. This ditch was selected for characterization based on the criteria in DOE/RL-96-81, which identified this ditch as a representative site for the 200-CW-1 Gable Mountain Pond/B Pond and Ditches Cooling Water Group (formerly the 200-BP-11 Operable Unit). The 216-B-2-2 Ditch was selected as a representative site because 1) it was operationally typical of a ditch and contains a representative inventory of contaminants; 2) it is expected to contain typical to higher levels of contamination at the headend of the ditch system; and 3) it lies in the middle of the 216-B-2 Ditch system, providing composite data for all three 216-B-2 ditches at depth. The 216-B-2-2 Ditch received 49,700,000 L (13,100,000 gal) of effluent containing 147 Ci of strontium-90 as the major contaminant (DOE/RL-96-81). The purpose of drilling the borehole was to refine the preliminary physical conceptual models of contaminant distribution and hydrogeology, to assess the nature and extent of subsurface contaminants, and to support remedial action/closure decisions for the 200-CW-1 group (BHI-01052). The characterization activities, sampling and analysis plan, and data quality objectives are described in the description of work (BHI-01052). The characterization results are found in the borehole summary report (BHI-01177).

Characterization borehole 299-E33-333 was drilled at the influent end of the 216-B-2-2 Ditch because it was the location considered the most likely to have the highest concentration of contaminants along the ditch. The borehole was extended to a depth of 77.4 m (254 ft), which is below the water table, to investigate the extent of contamination throughout the vadose zone. The borehole was drilled using cable-tool techniques and was abandoned following characterization. Soil samples for chemical and radiological analyses and/or physical property testing were collected at 13 depths using a split-spoon sampler.

Geophysical surveys of borehole 299-E33-333 included both spectral gamma logging and neutron-neutron logging (BHI-01177). Spectral gamma logging was conducted to characterize the vertical profile of gamma-emitting radionuclides in the vadose zone. Neutron-neutron logging was conducted to characterize the vertical profile of the moisture content of the vadose zone.

Volatile organic analyses were conducted on all chemical samples, with the exception of the uppermost sample from 1.2 to 1.8 m (4 to 6 ft) below ground surface, which had insufficient sample volume. Three target volatile organic contaminants (acetone, methylene chloride, toluene) were detected at

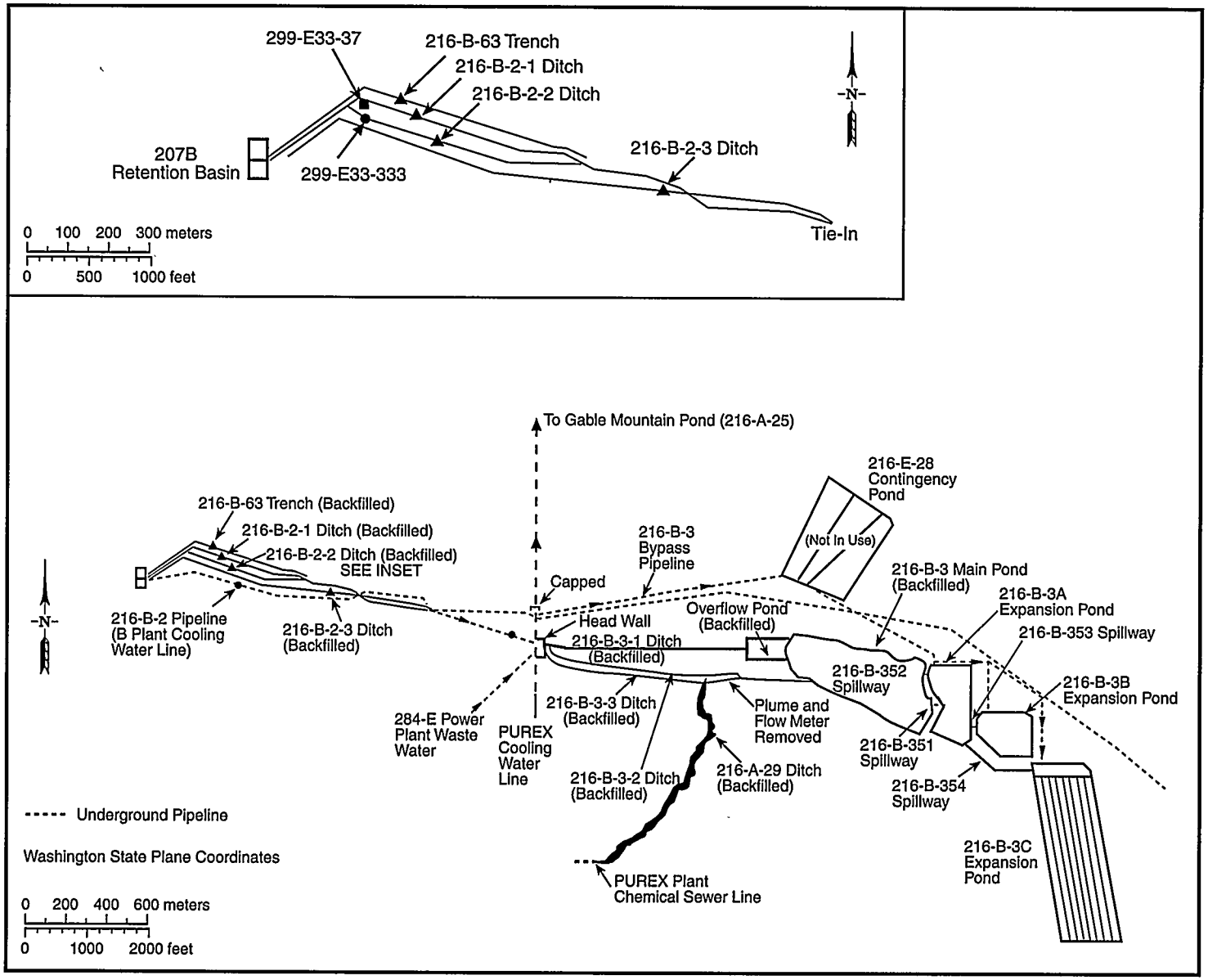


Figure 6.2.10. Location of the 216-B-2 Ditch System, 200-East Area

concentrations below the limit of quantification. One nontarget volatile organic (total xylenes) was detected at 8 µg/kg in the 45.7- to 46.5-m (150- to 152.5-ft) interval.

Semivolatile organic analyses were conducted on all chemical samples. The only polychlorinated biphenyl detected was aroclor-1260, which was found in the 2.4- to 4.7-m (8- to 15.5-ft) interval, with a maximum concentration of 9,200 µg/kg between 2.4- and 3.2-m (8 and 10.5 ft). Two nontarget semivolatile organic contaminants (butyl benzyl phthalate, di-n-octyphthalate) were detected at concentrations below the limit of quantification.

Chemical analyses for ammonia, cyanide, nitrate, nitrite, and sulfate were conducted on all samples, with one exception: cyanide was not analyzed in the uppermost sample from 1.2 to 1.8 m (4 to 6 ft) because a sufficient sample volume was not available. Cyanide was not detected in any sample. The maximum ammonia, nitrate, nitrite, and sulfate concentrations were 0.553, 35.8, 0.38, and 43.3 mg/kg, respectively, and all were detected in the 1.2- to 3.2-m (4- to 10.5-ft) interval. Ammonia and elevated nitrate were detected in only the uppermost sample from 1.2 to 1.8 m (4 to 6 ft).

Inorganic (metal) analyses were conducted on all chemical samples. For 12 of the 17 target metals detected, the maximum concentration was found in the 2.4- to 4.7-m (7.9- to 15.4-ft) interval. Cadmium and tin were the only 2 of the 17 target metals not detected in any samples.

Radiochemical analyses were conducted on all samples for both man-made and naturally occurring radionuclides. The primary man-made radionuclides detected were strontium-90, cesium-137, and europium-154 at maximum activities of 4,710, 100, and 1.29 pCi/g, respectively. The activities were one to two orders of magnitude higher in the intervals from 2.4 to 3.0 and 4.0 to 4.6 m (8 to 10 and 13 to 15 ft) than in the intervening sample interval from 3.2 to 4.0 m (10 to 13 ft). No man-made radionuclides were detected below 4.6 m (15 ft).

Cobalt-60, cesium-137, and europium-154 were detected in borehole 299-E33-333 by spectral gamma-ray logging methods. Cesium-137 was detected from the ground surface to a depth of 0.7 m (2.3 ft) and at depths between 1.8 and 3.3 m (6 and 11 ft). The maximum cesium-137 activity was approximately 400 pCi/g measured at 2.7 m (8.8 ft). Analysis of the data indicates that, within the zone of highest cesium-137 activity, the contamination is uniformly distributed in the formation as a thin, 0.15- to 0.3-m-thick (0.5- to 1-ft) layer (BHI-01177). Cobalt-60 was detected at the ground surface and at a depth of 0.15 m (0.5 ft). The maximum cobalt-60 activity was approximately 0.15 pCi/g. Europium-154 was detected at three points at depths between 2.6 and 2.9 m (8.5 and 9.5 ft) within the interval of highest cesium-137 activity. The maximum europium-154 activity was 2.0 pCi/g. The spectral gamma logging and sediment radiochemical analyses agree, except that the spectral gamma logging estimates the maximum cesium-137 activity at 400 versus 100 pCi/g for the laboratory analyses. Strontium-90, a beta emitter, was not detectable using the spectral gamma logging instrument.

For both data sets, man-made radionuclides are found within the upper 4.6 m (15 ft) of the soil column. One zone of high activity was found at a depth of 2.4 to 3.2 m (7.9 to 10.5 ft) in both data sets. The laboratory analytical data also indicated a zone of high activity from 4.0 to 4.6 m (13.1 to 15.1 ft). The distribution of man-made radionuclides underlying the 216-B-2-2 Ditch is consistent with the conceptual model developed for the 200-CW-1 group (DOE/RL-96-81). The conceptual model for this group is that the highest activity of the primary contaminants of concern (e.g., strontium-90) will be directly underlying the headend of the ditch. Furthermore, according to the conceptual model, most of the contaminants were expected to be within the

uppermost gravel unit, which at this site extends to a depth of 9.1 m (29.8 ft). The data indicate that, in fact, the radionuclide contamination does not extend below 4.6 m (15.1 ft).

6.2.2.5 Soil-Vapor Monitoring

Soil-vapor extraction is being used to remove the carbon tetrachloride from the vadose zone as part of the 200-West Area expedited response action being conducted by Bechtel Hanford, Inc. This section summarizes 1998 activities. For a more complete description of 1998 activities, see Section 4.5 of PNNL-12086. For descriptions of past work, see BHI-00720 (Rev. 2) and Section 4.4 in PNNL-11793.

To track the effectiveness of the remediation effort, measurements of soil-vapor concentrations of chlorinated hydrocarbons were made at the inlet to the soil-vapor-extraction system, at individual, on-line (i.e., operating), extraction wells, and at individual, off-line (i.e., standby), wells and probes throughout the soil-vapor-extraction sites during 1998. One soil-vapor-extraction system was operated from April through September 1998. Soil-vapor monitoring at off-line wells and probes was conducted from October 1997 through September 1998.

Soil-vapor samples were collected from approximately 25 off-line wells and probes once per month. Soil-vapor samples were analyzed primarily to monitor for carbon tetrachloride; however, the samples collected from off-line wells and probes were also analyzed for chloroform, methylene chloride, methyl ethyl ketone, and water vapor.

In 1998, 46 drilled wells were available for on-line extraction or monitoring (BHI-00720, Rev. 2) (Figure 6.2.11). Thirteen of these wells were drilled during 1992 and 1993 and were completed as vapor-extraction wells with stainless-steel casing and screens; one well was drilled at a 45-degree incline. Thirty-three wells, drilled between 1954 and 1978 and completed with carbon steel casing, were adapted for vapor extraction by perforating the well casing using mechanical or jet perforators. Of the 46 wells, 17 have two, separated open intervals in the well. The soil-vapor-extraction system extracts simultaneously from multiple wells open either above and/or below the Plio-Pleistocene unit. The mix of on-line wells is adjusted periodically to optimize contaminant removal.

There are 125 subsurface monitoring probes at >2 m (6.6 ft) below ground surface. A cone penetrometer was used to install 11 extraction, or monitoring, wells (denoted by + on Figure 6.2.11) and 104 subsurface monitoring probes at 33 locations (denoted by D on Figure 6.2.11). Up to five monitoring probes were installed per location at various depths. The deepest monitoring probe installed at the vapor-extraction sites is 36 m (118 ft) below ground surface. Ten stainless-steel tubes were strapped to the outside of the casing of 4 of the 13 wells during installation to enable monitoring above and below the screened intervals.

There are up to 73 shallow, soil-vapor probes at depths ranging from 1.2 to 1.8 m (4 to 6 ft) (Figure 6.2.12). The network was installed between 1991 and 1995. Some of the probes have since been destroyed, primarily as a result of other near-surface construction activities or prolonged exposure to weather conditions.

Based on the results of the 1997 rebound study (BHI-01105) and the declining rate of carbon tetrachloride removal during continuous extraction operations (BHI-00720, Rev. 2), the operating strategy for 1998 was modified. Rather than operating all three soil-vapor-extraction systems continuously, only the 14.2-m^3/min (500-ft^3/min) system was used for carbon tetrachloride removal during 1998. The 14.2-m^3/min (500-ft^3/min) system was modified so that it could be moved between the well fields surrounding the 216-Z-1A Tile Field, 216-Z-9 Trench, 216-Z-12 Crib, and 216-Z-18 Crib. The 28.3- and

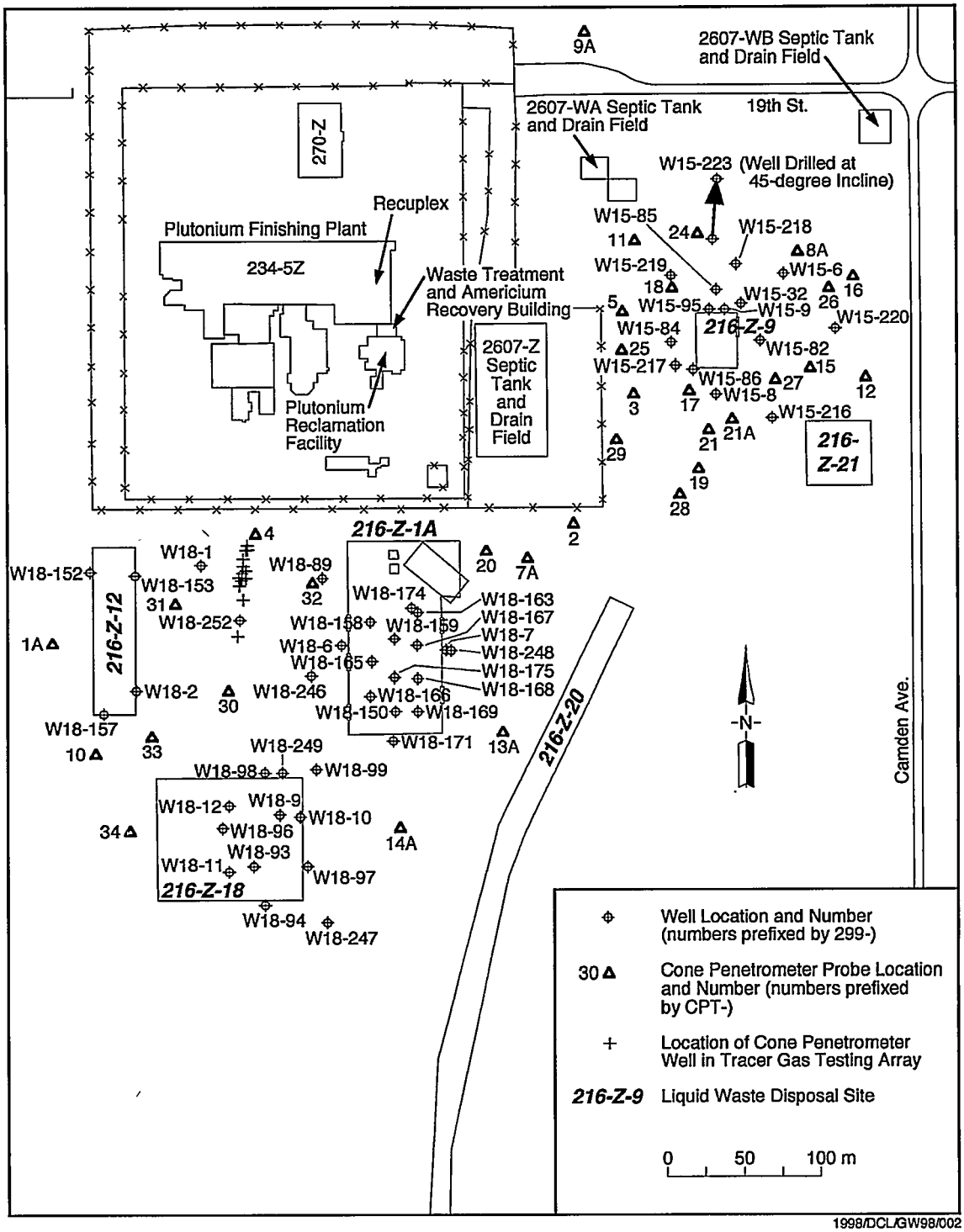


Figure 6.2.11. Location of Wells and Deep Soil-Vapor Monitoring Probes at the Carbon Tetrachloride Vapor-Extraction Site, 200-West Area

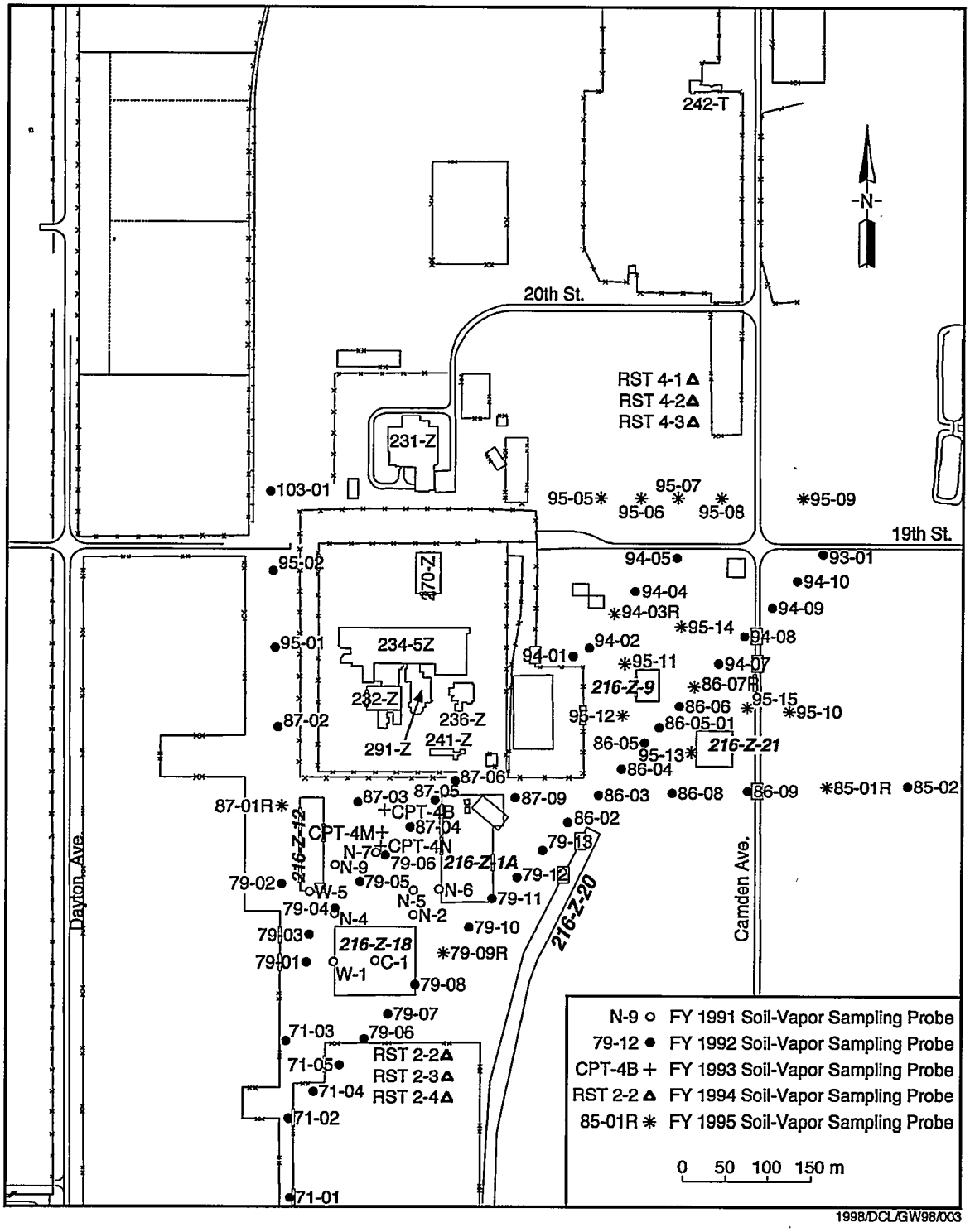


Figure 6.2.12. Locations of Shallow Soil-Vapor Monitoring Probes at the Carbon Tetrachloride Vapor-Extraction Site, 200-West Area

42.5-m^3/min (1,000- and 1,500-ft^3/min) soil-vapor-extraction systems were maintained in standby mode during 1998.

The 14.2-m^3/min (500-ft^3/min) soil-vapor-extraction system was operated from March 30 through June 30, 1998 at the combined 216-Z-1A/-12/-18 well field and from July 7 through September 30, 1998 at the 216-Z-9 well field. The system was shut down for the winter (October 1, 1997 through March 29, 1998).

For the 6 mo that the system was shut down, the rebound in carbon tetrachloride concentrations was monitored at 25 wells and probes at both well fields. For the 3 mo that the system was operated at 216-Z-1A/-12/-18, carbon tetrachloride concentrations were monitored at 25 wells and probes primarily at the 216-Z-9 well field; for the 3 mo that the system was operated at the 216-Z-9 well field, carbon tetrachloride concentrations were monitored at 25 wells and probes primarily at the 216-Z-1A/-12/-18 well field.

Soil-Vapor Remediation. Soil-vapor extraction to remove carbon tetrachloride from the vadose zone resumed on March 30, 1998 at the 216-Z-1A/-12/-18 well field, using the 14.2-m^3/min (500-ft^3/min) system, which is on the northern side of the 216-Z-18 Crib. Fifteen extraction wells distributed throughout the well field were selected to optimize both protection of groundwater and mass removal of contaminant. Initial characterization of the 15 on-line wells indicated that the system was extracting soil vapor effectively from only the closest wells and that the applied vacuum at the distant wells was insufficient to produce flow. Tests showed that the system could, however, extract soil vapor effectively from isolated, distant wells. Therefore, the mix of on-line extraction wells was periodically switched among one set of seven relatively nearby wells and various sets of four relatively distant wells. Each set included wells open near the groundwater and wells open near the less-permeable Plio-Pleistocene unit. As a result, the system was extracting from wells primarily associated with the 216-Z-18 Crib for the first 7 wk (March 30 through May 17) and from wells primarily associated with the 216-Z-1A Tile Field for the following 6 wk (May 18 through June 30). Comparison of the changes in inlet concentrations to the changes in the sets of on-line wells indicated that the higher concentrations observed from May 18 through June 30 tended to be associated with the 216-Z-1A wells (Figure 6.2.13).

Soil-vapor extraction to remove carbon tetrachloride from the vadose zone resumed on July 7, 1998 at the 216-Z-9 well field, using the 14.2-m^3/min (500-ft^3/min) system. Initial on-line wells were selected close to the 216-Z-9 Trench. As extraction continued, wells farther away from the trench were brought on line. Each selection of on-line wells included those with openings near the groundwater and those with openings near the less-permeable Plio-Pleistocene unit. The daily mass-removal rate increased significantly twice during the 3 mo of extraction as a result of changes in extraction wells: two additional wells were brought on line on July 29, 1998 (the mass-removal rate increased, despite a continued decline in concentrations, because the flow rate increased [see Figure 6.2.13]); and the mix of on-line wells was changed again on September 1, 1998 (the mass-removal rate increased, despite a constant flow rate, because the inlet concentrations increased [see Figure 6.2.13]).

During a total of 178 d of soil-vapor extraction in 1998, 777 kg (1,700 lb) of carbon tetrachloride were removed from the vadose zone. Of this total, 254 kg (560 lb) were removed from the 216-Z-1A/-12/-18 well field during 91 d of operation and 523 kg (1,150 lb) were removed from the 216-Z-9 well field during 86 d of operation.

As of September 1998, approximately 75,000 kg (165,000 lb) of carbon tetrachloride had been removed from the subsurface since extraction operations started in 1992 (Table 6.2.3). Since initiation, the extraction systems are estimated to

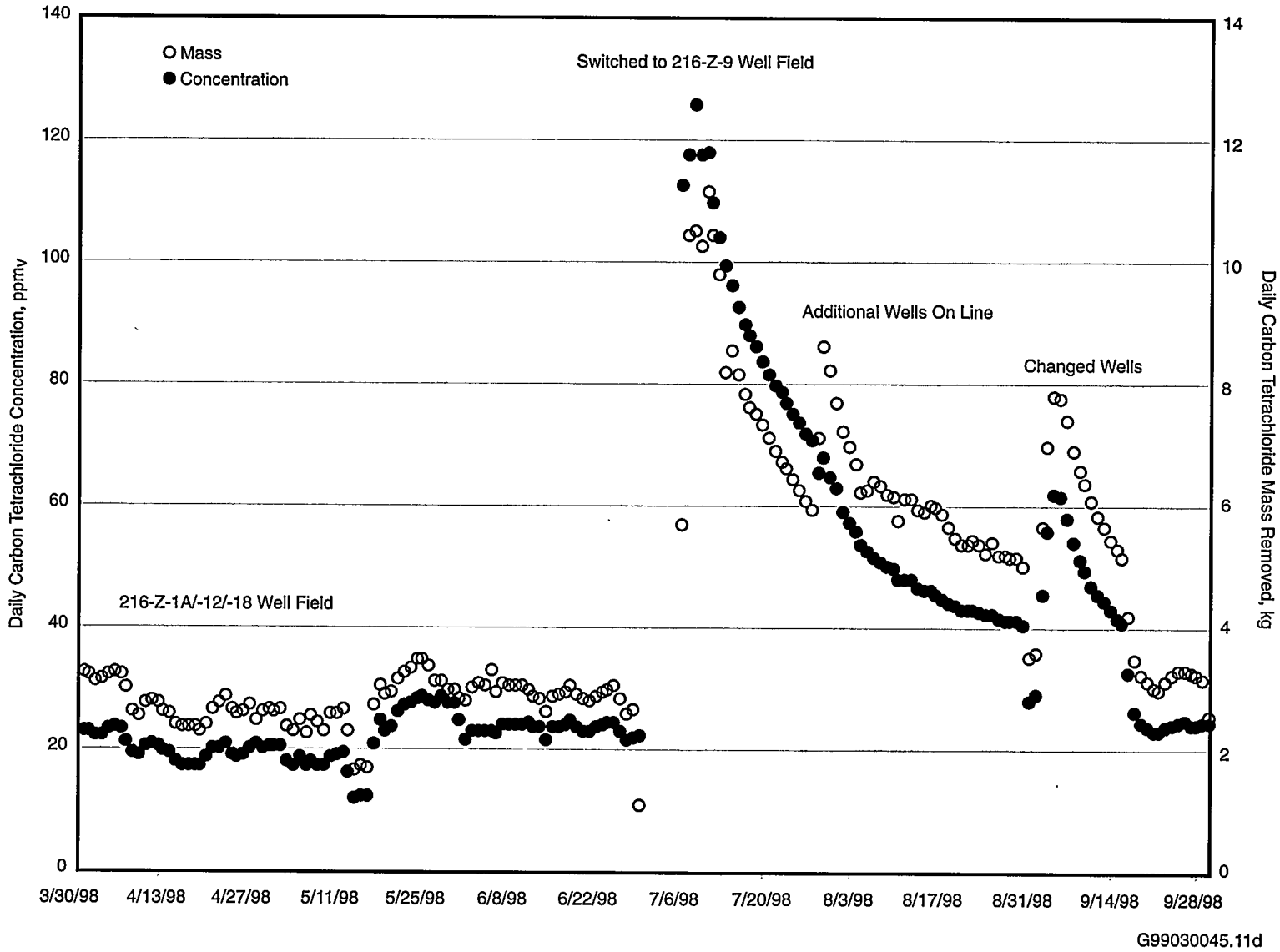


Figure 6.2.13. Time-Series Concentration of Carbon Tetrachloride in Soil Vapor Extracted from the 216-Z-1A/-12/-18 Well Fields, 200-West Area

Table 6.2.3. Carbon Tetrachloride Inventory in Primary Disposal Sites, 200-West Area

Well Field	Estimated Mass Discharged, 1955 to 1973,[a] kg (lb)	Estimated Mass Lost to Atmosphere, 1955 to 1990,[b] kg (lb)	Mass Removed Using Soil-Vapor Extraction, 1992 to 1998, [c] kg (lb)
216-Z-1A	270,000 (595,000)	56,700 (125,000)	22,983[d] (50,500)
216-Z-18	170,000 (375,000)	35,700 (78,700)	
216-Z-9	130,000 to 480,000 (287,000 to 1,060,000)	27,300 to 100,800 (60,200 to 222,000)	52,507 (115,500)
Total	570,000 to 920,000 (1,260,000 to 2,030,000)	119,700 to 196,800 (264,000 to 434,000)	75,490 (166,000)

(a) Based on DOE/RL-91-32 (Draft B).
(b) Based on WHC-SD-EN-TI-101.
(c) Based on BHI-00720 (Rev. 2).
(d) Includes mass removed from 216-Z-18 well field; reported as a combined value because the well fields overlap.

have removed 7% of the residual mass at the 216-Z-1A/-12/-18 well field and 22% of the mass at the 216-Z-9 well field. This estimate assumes that all of the mass that has not been lost to the atmosphere (21% of the original inventory) or dissolved in groundwater (2% of the original inventory) is still available in the vadose zone as "residual" mass (BHI-00720, Rev. 2; WHC-SD-EN-TI-101).

Soil-Vapor Monitoring. During October 1997 through March 1998, soil-vapor concentrations were monitored near the groundwater and near the ground surface to assess whether nonoperation of the soil-vapor-extraction system was allowing carbon tetrachloride to migrate out of the vadose zone. The maximum concentration detected between 1.5 and 4.5 m (5 and 15 ft) below ground surface was 1 ppm (by volume); the maximum concentration detected between 7.6 and 18.3 m (25 and 60 ft) was 43 ppm (by volume). Near the groundwater, at depths ranging from 56.0 to 63.4 m (184 to 208 ft), maximum concentrations ranged from 14.6 to 31.3 ppm (by volume). These results, after 6 mo of rebound, are similar to those obtained during the 8-mo rebound study conducted in 1997 (BHI-01105).

During April through June 1998, soil-vapor monitoring was continued at the shallow and deep locations at the 216-Z-9 well field. Monitoring locations were added near the less-permeable Plio-Pleistocene unit at 216-Z-9 to provide an indication of concentrations that could be expected during restart of soil-vapor extraction in July 1998. Concentrations detected in the near-surface and near-groundwater zones during these additional 3 mo of rebound were similar to those observed during the previous 6 mo. Nearer the Plio-Pleistocene layer, at depths ranging from 18.3 and 36.0 m (60 and 118 ft), maximum concentrations ranged from 0 to 630 ppm (by volume). The highest concentration was detected in well 299-W15-217 (35.1 m [115 ft] deep), the well at which the highest concentration was detected during the 1997 rebound study. These results were obtained after 9 mo of rebound and are similar to

those obtained during the 8-mo rebound study conducted in 1997 (BHI-01105).

During July through September 1998, soil-vapor monitoring was resumed at the 216-Z-1A and -18 sites. Monitoring was conducted in the near-surface, near-Plio-Pleistocene, and near-groundwater zones. The maximum concentration detected was 143 ppm (by volume) in well 299-W18-158L (37.5 m [123 ft] deep) in the 216-Z-1A Tile Field. This result was obtained after only 3 mo of rebound.

Samples were collected initially from well 299-W15-217 at the wellhead before the downhole sampling tube was installed to evaluate the effect of an installed sampling tube. In March and April, these wellhead samples contained 65 and 25 ppm (by volume) of carbon tetrachloride, respectively. Samples collected in May and June, using the downhole sampling tube, contained 630 and 504 ppm (by volume) of carbon tetrachloride, respectively. Other wells sampled without the sampling tube had anomalously low to nondetectable carbon tetrachloride concentrations.

Because carbon tetrachloride concentrations did not increase significantly at the shallow probes monitored in 1998, temporarily suspending operation of the soil-vapor-extraction system for 6 to 9 mo appears to have caused minimal, detectable, vertical transport of carbon tetrachloride through the soil surface to the atmosphere. Because carbon tetrachloride concentrations did not increase significantly near the water table during this time, temporarily suspending operation of the soil-vapor-extraction system appears to have had no negative impact on groundwater quality.

Carbon Tetrachloride Migration. A schematic representation, or conceptual model, of the subsurface behavior of carbon tetrachloride beneath the 216-Z-9 Trench is shown in Figure 6.2.14. A numerical model was developed (BHI-00459) to simulate the primary transport processes shown in Figure 6.2.14, using local stratigraphy and published parameters for the source term and soil properties. Results of initial simulations suggested that over two-thirds of the discharged carbon tetrachloride would have been retained in the soil column and that a dense, nonaqueous-phase liquid would continue to drain slowly through the vadose zone into the underlying aquifer for years into the future. Although additional modeling is needed to assess the influence of effective porosity and groundwater velocity, the modeling results support the liquid-phase transport concept illustrated on the model in Figure 6.2.14. The vapor-phase results were less definitive but suggested that vapor-phase transport is secondary to dense, nonaqueous-phase liquid transport as a groundwater contamination pathway.

Field measurements of carbon tetrachloride vapor concentrations are not completely consistent with numerical modeling results. Soil-vapor monitoring of rebound carbon tetrachloride concentrations conducted in 1997 and 1998 within the vadose zone at the 216-Z-9 Trench did not exceed 60 ppm (by volume). Vapor-extraction concentrations >12,000 ppm (by volume) of carbon tetrachloride are needed to indicate that the soil near the extraction well is saturated with nonaqueous-phase liquid. The low, measured, vapor concentrations indicate less nonaqueous-phase liquid remaining in the vadose zone below the Plio-Pleistocene unit than predicted; however, these measurements were not taken directly under the 216-Z-9 Trench or at depth-discrete, narrow zones above the water table. Although carbon tetrachloride volatilizing from a residual, nonaqueous-phase, liquid source may have been diluted by the time the vapor reached the sampling locations, the data suggest that soil-vapor extraction may have removed much of the remaining source in the area of the 216-Z-9 Trench and that the continuing groundwater source may now be within the aquifer (BHI-01105).

Vertical and areal distribution of dissolved carbon tetrachloride in groundwater is consistent with a dense, nonaqueous-phase, liquid transport mechanism for transport of carbon tetrachloride to groundwater. Maps and profiles of carbon tetrachloride

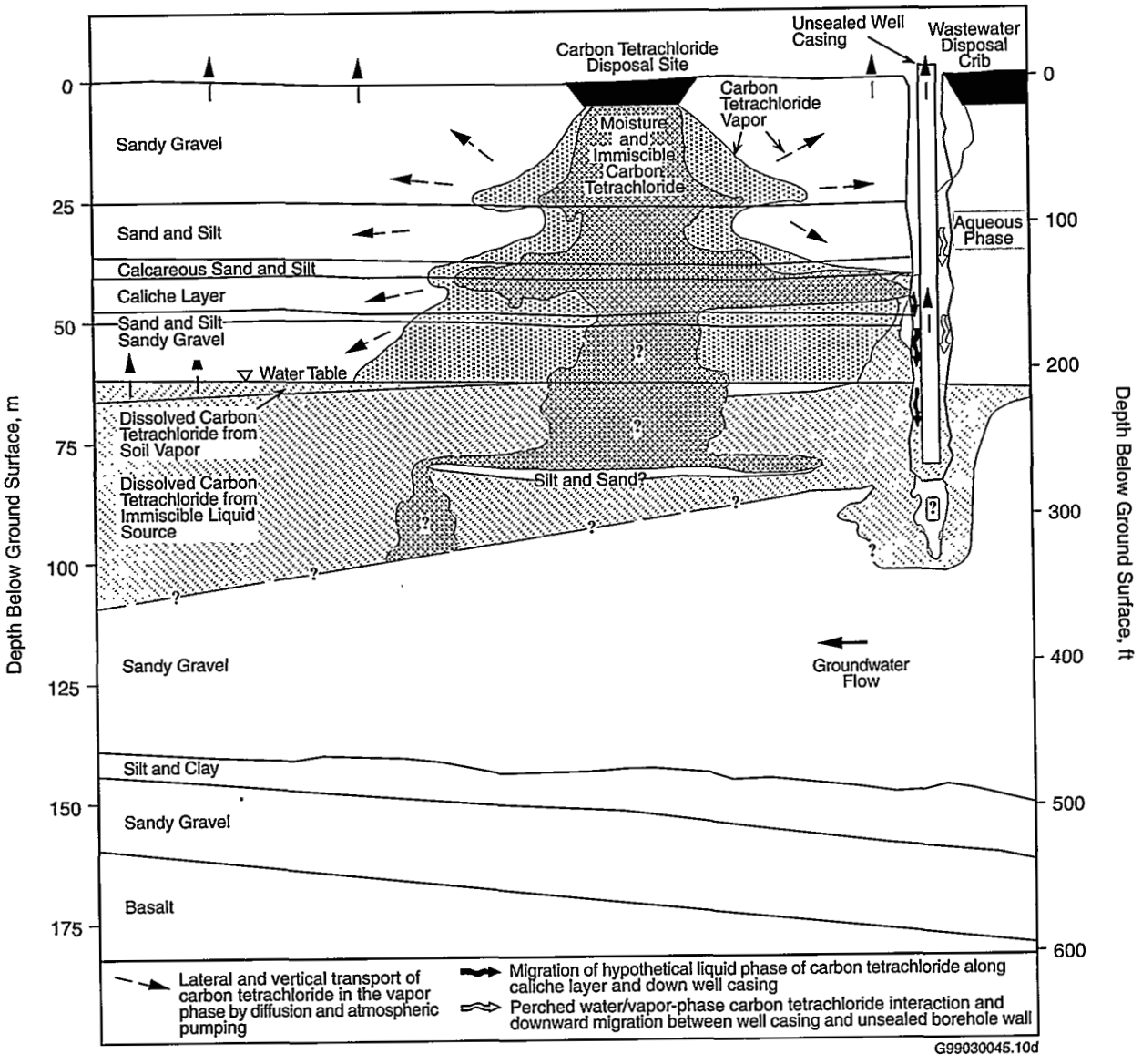


Figure 6.2.14. Conceptual Model of Carbon Tetrachloride and Wastewater Migration Beneath 216-Z-9 Trench, 200-West Area

distribution in groundwater suggest there is a continuing groundwater source that produces somewhat uniform carbon tetrachloride concentrations with depth in the aquifer. A dense, nonaqueous-phase liquid that drained from the vadose zone into the aquifer and is slowly dissolving could produce such a pattern. An alternative explanation for the depth-distribution pattern is that a secondary source of water passing near or through an area containing a dense, nonaqueous-phase liquid and soil-vapor carbon tetrachloride could absorb this slightly soluble, chlorinated hydrocarbon and carry it into the aquifer under saturated flow conditions.

The continuing presence of relatively high, dissolved, carbon tetrachloride concentrations in groundwater in the immediate vicinity of the 216-Z-9 Trench, 35 yr after termination of disposal operations, suggests that a dense, nonaqueous-phase liquid is

slowly dissolving within the aquifer. Although this liquid phase may be slowly draining from the vadose zone to groundwater, the soil-vapor concentrations monitored deep within the vadose zone during 1997 and 1998 suggest that soil-vapor-extraction remediation may have removed much of the vadose-zone source and that the continuing groundwater source resides within the aquifer. Carbon tetrachloride concentrations in the soil vapor and underlying groundwater do not appear to be in equilibrium, and the expected direction of carbon tetrachloride migration is from the groundwater to the vadose zone (BHI-01105).

Carbon tetrachloride rebound concentrations indicate that in many areas much of the readily accessible mass has been removed during soil-vapor-extraction operations and that the supply of additional carbon tetrachloride is limited by desorption and/or diffusion from contaminant sources (e.g., lower-permeability zones such as the lower Hanford formation silt and/or Plio-Pleistocene unit). Under these conditions, the removal rate of the additional carbon tetrachloride using soil-vapor extraction is controlled by the desorption and diffusion rates of the contaminant.

6.2.3 Historical Gross Gamma-Ray Log-Time Series

R. R. Randall, D. A. Myers, D. G. Horton

The single-shell tank farm borehole logging surveillance program was established as one of several methods used to identify leaking tanks and operated until 1994. In 1975, borehole logging within this program was upgraded to a digital system. Under the upgraded program, gross gamma-ray logs were captured in digital form and reviewed to identify large leaks of radioactive liquid from the underground tanks. In 1998, Waste Management Federal Services, Inc., Northwest Operations and Three Rivers Scientific reanalyzed the January 1975 through 1993/1994 gross gamma-ray logs to look for mobile changes in subsurface contamination not found under the original program. During 1998, the tank data for the BX, BY, SX, and TY Tank Farms were reanalyzed. The results of these analyses were available in 1998, but only those for the SX Tank Farm were published (WMNW/TRS-ES-VZMA-002). The remaining results are scheduled to be published in 1999.

This section summarizes the methods of analysis and the general observations for the borehole data analyzed during 1998. A more-complete description of this work is found in PNNL-12086 (Section 4.3) and in WMNW/TRS-ES-VZMA-002.

The strategy for analysis of the surveillance log data was to preserve as much of the raw data as possible by limiting the amount of processing. All historical log surveys for one borehole were analyzed as a group for each radioactive zone in a well, allowing statements to be made about the stability of any given contaminated interval.

Integral to the analysis of the gross gamma-ray data was the use of information provided by the spectral gamma logging system (DOE/ID/12584-268, GJPO-HAN-4). The spectral gamma logging system employs a high-resolution germanium detector to obtain data that lead to the identity and depth of radionuclides. Knowledge of the isotopes present in the subsurface was invaluable in the interpretation of the tank farm surveillance logs. By integrating the spectral gamma logging data with historical surveillance data, the behavior of radionuclides in the vadose zone over time was examined. The analysis performed on the gross gamma-ray data makes evident the usefulness of the historical data for the purpose of evaluating the presence of gamma-emitting radionuclides in the vadose zone beneath the tank farms.

Data were represented graphically to illustrate trends in subsurface contamination. Figure 6.2.15 shows an example analysis for borehole 41-00-08 in the SX Tank Farm, 200 West Area. The plot shows gamma-ray data by depth over the period for which data were available. The log profiles in Figure 6.2.15 represent quarterly logging events selected from more frequently collected data for most years between 1975 and 1994. Between 1980 and 1984, log data were collected approximately once per year. This example illustrates zones of anthropogenic gamma-ray activity at 20.7 and 23.8 m (68 and 78 ft). The activity at 23.8 m (78 ft) is first identifiable around 1985 and increases with survey date from that time to the end of data collection in 1993. The zone at 20.7 m (68 ft) is a clear case of lateral contaminant migration into the region surrounding the borehole.

The analysis of the 98 SX Tank Farm boreholes indicates that 45 were free of identifiable contamination, 31 exhibited zones of contamination interpreted to have been stable over the period of records analyzed, 9 exhibited zones that are interpreted to have increasing activity at the end of the period of records analyzed, and 13 exhibited zones of contamination that could not be readily interpreted. A total of 37,210 records were analyzed.

The analysis of the 74 BX Tank Farm boreholes indicates that 25 were free of identifiable contamination, 27 exhibited zones of contamination interpreted to have been stable over the period of the records analyzed, 8 exhibited zones interpreted to have been increasing at the end of the record period, 8 had contamination interpreted to be from tank

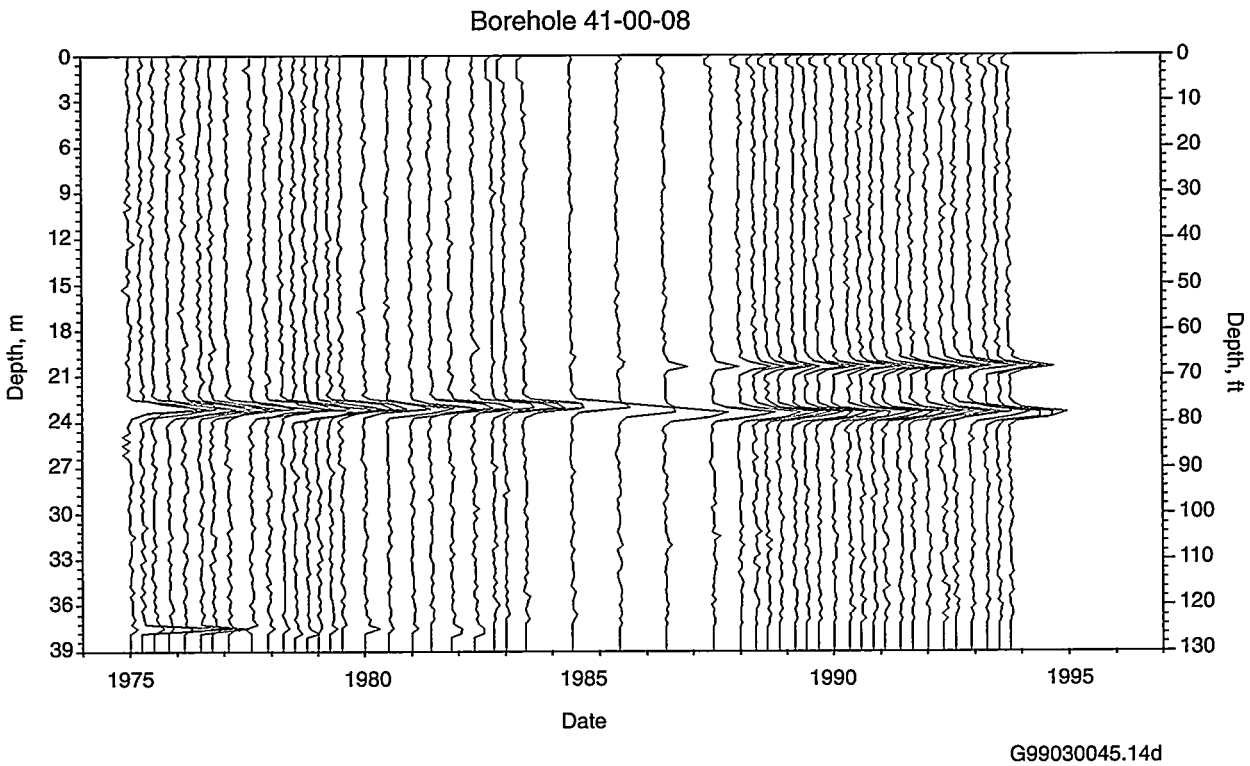


Figure 6.2.15. Example Analysis of Historical Gross Gamma-Ray Logs from Borehole 41-00-08 in the SX Tank Farm

farm activities such as waste transfers, and 6 exhibited zones of contamination that could not be readily interpreted. A total of 20,021 records were analyzed.

The analysis of the 71 BY Tank Farm boreholes indicates that 5 were free of identifiable contamination, 8 were interpreted to be stable at the end of the period of record analyzed, 10 were interpreted to be unstable or increasing at the end of the record period, 43 had contamination interpreted to be from tank farm activities such as waste transfers, and 4 exhibited zones of contamination that could not be readily interpreted. There was one borehole for which there were no available data. A total of 30,882 records were analyzed.

Boreholes may exhibit one or more characteristics, so the above summations reflect the most conservative status.

The results of these analyses show that detailed examination of historical gross gamma-ray logs can reveal changes in subsurface contamination at the tank farms that was not previously identified.

6.3 References

40 CFR 141. U.S. Environmental Protection Agency. "National Primary Drinking Water Regulations; Radionuclides; Proposed Rule." *Code of Federal Regulations.*

40 CFR 265. U.S. Environmental Protection Agency. "Interim Status Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities." *Code of Federal Regulations.*

40 CFR 300. U.S. Environmental Protection Agency. "National Oil and Hazardous Substances Pollution Contingency Plan." *Code of Federal Regulations.*

BHI-00184. 1995. *Miocene- to Pliocene-Aged Suprabasalt Sediments of the Hanford Site, South-Central Washington.* K. A. Lindsey, Bechtel Hanford, Inc., Richland, Washington.

BHI-00459. 1996. *Numerical Analysis of Carbon Tetrachloride Movement in the Saturated and Unsaturated Zones in the 200 West Area, Hanford Site.* M. G. Piepho, Bechtel Hanford, Inc., Richland, Washington.

BHI-00720, Rev. 2. 1998. *Performance Evaluation Report for Soil Vapor Extraction Operations at the Carbon Tetrachloride Site, February 1992 – September 1997.* V. J. Rohay, Bechtel Hanford, Inc., Richland, Washington.

BHI-01052. 1997. *Description of Work for a Vadose Zone Characterization Borehole at the 216-B-2-2 Ditch.* J. M. Faurote and C. D. Wittreich, Bechtel Hanford, Inc., Richland, Washington.

BHI-01105. 1997. *Rebound Study Report for the Carbon Tetrachloride Soil Vapor Extraction Site, Fiscal Year 1997.* V. J. Rohay, Bechtel Hanford, Inc., Richland, Washington.

BHI-01126. 1997. *Fiscal Year 1997 Annual Report for the 100-NR-2, 200-UP-1, and 200-ZP-1 Pump and Treat Operations and Operable Units.* J. V. Borghese, R. E. Peterson, L. C. Swanson, and P. B. Tolley, CH2M Hill Hanford, Inc. for Bechtel Hanford, Inc., Richland, Washington.

BHI-01177. 1998. *Borehole Summary Report for the 216-B-2-2 Ditch.* V. J. Rohay and D. C. Weekes, Bechtel Hanford, Inc., Richland, Washington.

BMI/ONWI-660. 1987. *Coupled Fluid, Energy, and Solute Transport (CFEST) Model: Formulation and User's Manual.* S. K. Gupta, C. R. Cole, C. T. Kincaid, and A. M. Monti, Battelle Memorial Institute, Columbus, Ohio.

BNWL-90. 1965. *Evaluation of Radiological Conditions in the Vicinity of Hanford for 1964.* R. H. Wilson (ed.), Pacific Northwest Laboratory, Richland, Washington.

BNWL-1970. 1976. *Environmental Monitoring Report on Radiological Status of the Ground Water Beneath the Hanford Site, January-December 1974.* J. R. Raymond, D. A. Myers, J. J. Fix, V. L. McGhan, and P. M. Schrotke, Pacific Northwest Laboratory, Richland, Washington.

Comprehensive Environmental Response, Compensation, and Liability Act. 1980. Public Law 96-150, as amended, 94 Stat. 2767, 42 USC 9601 et seq.

DOE - Also see U.S. Department of Energy.

DOE/EIS-0119F. 1992. *Decommissioning of Eight Surplus Production Reactors at the Hanford Site, Richland, Washington, Final Environmental Impact Statement.* U.S. Department of Energy, Washington, D.C.

DOE/ID/12584-268, GJPO-HAN-4. 1996. *Vadose Zone Characterization Project at the Hanford Tank Farms, SX Tank Farm Report.* U.S. Department of Energy, Albuquerque Operations Office and Grand Junction Office for Richland Operations Office, Richland, Washington.

DOE Order 5400.1. "General Environmental Protection Program."

DOE Order 5400.5. "Radiation Protection of the Public and the Environment."

DOE/RL-89-12, Rev. 2. 1995. *Hanford Site Ground-Water Protection Management Plan.* D. B. Barnett, J. S. Schmid, S. S. Lowe, W. L. Allen, N. A. Ballantyne, C. H. Dohrer, M. J. Hartman, F. N. Hodges, D. G. Horton, V. G. Johnson, K. J. Lueck, D. J. Ortiz, A. J. Knepp, B. H. Ford, S. P. Hope, D. K. Tyler, R. D. Hildebrand, D. E. Olson, R. E. Peterson, G. L. Kasza, D. A. Myers, S. P. Luttrell, P. D. Thorne, and K. R. Moser. U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-91-32, Draft B. 1991. *Expedited Response Action Proposal (EE/CA & EA) for 200 West Area Carbon Tetrachloride Plume, Appendix* B. V. J. Rohay and V. G. Johnson for U.S. Department of Energy, Richland Field Office, Richland, Washington.

DOE/RL-91-50, Rev. 2. 1997. *Environmental Monitoring Plan, United States Department of Energy Richland Operations Office.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-95-110. 1996. *N-Springs Expedited Response Action Performance Evaluation Report.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-95-111. 1998. *Corrective Measures Study for the 100-NR-1 and 100-NR-2 Operable Units.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-96-39. 1998. *100-NR-1 Treatment, Storage, and Disposal Units Corrective Measure Study/ Closure Plan.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE-RL-96-81. 1997. *Waste Site Grouping for 200 Areas Soil Investigation.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-96-102. 1998. *Proposed Plan for Interim Remedial Actions at the 100-NR-1 Source Sites Operable Unit and the 100-NR-2 Groundwater Operable Unit.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE-RL-97-49. 1997. *TWRS Vadose Zone Contamination Issue Expert Panel Status Report.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE-RL-97-69. 1998. *Hanford Immobilized Low-Activity Tank Waste Performance Assessment.* F. M. Mann, R. J. Puigh, P. D. Rittmann, N. W. Kline, J. A. Voogd, Y. Chen, C. R. Eiholzer, C. T. Kincaid, B. P. McGrail, A. H. Lu, G. F. Williamson, N. R. Grown, and P. E. LaMont. U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-97-96. 1998. *100-KR-4 and 100-HR-3 Operable Units Interim Action Performance Evaluation Report.* Prepared by CH2M Hill Hanford, Inc. for Bechtel Hanford, Inc., U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-98-48, Draft C. 1998. *Groundwater/Vadose Zone Integration Project Specification.* Prepared by Bechtel Hanford, Inc. for the U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-98-56. 1999. *Groundwater/Vadose Zone Integration Project, Project Management Plan.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-99-02. 1999. *Fiscal Year 1998 Annual Summary Report for the 200-UP-1, 200-ZP-1, and 100-NR-2 Pump-and-Treat Operations and Operable Units.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-99-13. 1999. *Annual Summary Report, February to December 1998, for the 100-HR-3 and 100-KR-4 Pump-and-Treat Operations and Operable*

Units. U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RW-0164. 1988. *Consultation Draft, Site Characterization Plan, Reference Repository Location, Hanford Site, Washington*. U.S. Department of Energy, Richland Operations Office, Richland, Washington, 2 vols.

Ecology - See Washington State Department of Ecology.

EPA 822-R-96-001. 1996. *Drinking Water Regulations and Health Advisories*. U.S. Environmental Protection Agency, Office of Water, Washington, D.C.

ES-SSPM-001. 1998. *Sampling Services Procedures Manual*. Waste Management Federal Services, Inc., Northwest Operations, Richland, Washington.

Gee, G. W., M. J. Fayer, M. L. Rockhold, and M. D. Campbell. 1992. "Variations in Recharge at the Hanford Site." *Northwest Science* 66(4):237.

GJ-HAN-93. 1998. *Hanford Tank Farms Vadose Zone, Tank Summary Data Report for Tank C-111*. Prepared by MACTEC-ERS for U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

GJ-HAN-94. 1998. *Hanford Tank Farms Vadose Zone, Tank Summary Data Report for Tank C-112*. Prepared by MACTEC-ERS for U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

GJ-HAN-95. 1998. *Hanford Tank Farms Vadose Zone, Tank Summary Data Report for Tank BX-101*. Prepared by MACTEC-ERS for U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

GJ-HAN-96. 1998. *Hanford Tank Farms Vadose Zone, Tank Summary Data Report for Tank BX-103*. Prepared by MACTEC-ERS for U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

GJ-HAN-97. 1998. *Hanford Tank Farms Vadose Zone, Tank Summary Data Report for Tank BX-104*. Prepared by MACTEC-ERS for U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

GJ-HAN-98. 1998. *Hanford Tank Farms Vadose Zone, Tank Summary Data Report for Tank BX-105*. Prepared by MACTEC-ERS for U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

GJ-HAN-99. 1998. *Hanford Tank Farms Vadose Zone, Tank Summary Data Report for Tank BX-106*. Prepared by MACTEC-ERS for U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

GJ-HAN-100. 1998. *Hanford Tank Farms Vadose Zone, Tank Summary Data Report for Tank BX-107*. Prepared by MACTEC-ERS for U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

GJ-HAN-101. 1998. *Hanford Tank Farms Vadose Zone, Tank Summary Data Report for Tank BX-108*. Prepared by MACTEC-ERS for U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

GJ-HAN-102. 1998. *Hanford Tank Farms Vadose Zone, Tank Summary Data Report for Tank BX-109*. Prepared by MACTEC-ERS for U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

GJ-HAN-103. 1998. *Hanford Tank Farms Vadose Zone, Tank Summary Data Report for Tank BX-110*. Prepared by MACTEC-ERS for U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

GJ-HAN-104. 1998. *Hanford Tank Farms Vadose Zone, Tank Summary Data Report for Tank BX-111*. Prepared by MACTEC-ERS for U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

GJ-HAN-105. 1998. *Hanford Tank Farms Vadose Zone, Tank Summary Data Report for Tank BX-112.* Prepared by MACTEC-ERS for U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

GJ-HAN-106. 1998. *Hanford Tank Farms Vadose Zone, Tank Summary Data Report for Tank A-101.* Prepared by MACTEC-ERS for U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

GJ-HAN-107. 1998. *Hanford Tank Farms Vadose Zone, Tank Summary Data Report for Tank A-102.* Prepared by MACTEC-ERS for U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

GJ-HAN-108. 1998. *Hanford Tank Farms Vadose Zone, Tank Summary Data Report for Tank A-103.* Prepared by MACTEC-ERS for U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

GJ-HAN-109. 1998. *Hanford Tank Farms Vadose Zone, Tank Summary Data Report for Tank A-104.* Prepared by MACTEC-ERS for U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

GJ-HAN-110. 1998. *Hanford Tank Farms Vadose Zone, Tank Summary Data Report for Tank A-105.* Prepared by MACTEC-ERS for U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

GJ-HAN-111. 1998. *Hanford Tank Farms Vadose Zone, Tank Summary Data Report for Tank A-106.* Prepared by MACTEC-ERS for U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

GJ-HAN-112. 1998. *Hanford Tank Farms Vadose Zone, Tank Summary Data Report for Tank B-101.* Prepared by MACTEC-ERS for U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

GJ-HAN-114. 1998. *Hanford Tank Farms Vadose Zone, Tank Summary Data Report for Tank B-103.* Prepared by MACTEC-ERS for U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

GJ-HAN-121. 1998. *Hanford Tank Farms Vadose Zone, Tank Summary Data Report for Tank T-108.* Prepared by MACTEC-ERS for U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

GJ-HAN-122. 1998. *Hanford Tank Farms Vadose Zone, Tank Summary Data Report for Tank T-109.* Prepared by MACTEC-ERS for U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

GJ-HAN-123. 1998. *Hanford Tank Farms Vadose Zone, Tank Summary Data Report for Tank T-111.* Prepared by MACTEC-ERS for U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

GJ-HAN-124. 1998. *Hanford Tank Farms Vadose Zone, Tank Summary Data Report for Tank T-112.* Prepared by MACTEC-ERS for U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

GJO-96-13-TAR, GJO-HAN-7. 1997. *Spectrum Shape-Analysis Technique Applied to the Hanford Tank Farms Spectral Gamma Logs.* R. D. Wilson, MACTEC-ERS for U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

GJO-97-4-TAR, GJO-HAN-9. 1997. *Vadose Zone Characterization Project at the Hanford Tank Farms, Assessment of Log Data for Borehole 41-09-39 and Correlation With Borehole 41-09-04 in the SX Tank Farm.* MACTEC-ERS for U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

GJO-97-25-TAR, GJO-HAN-15. 1998. *Enhancements, Validations, and Applications of Spectrum Shape-Analysis Techniques Applied to Hanford Tank Farms*

Spectral Gamma Logs. R. D. Wilson, MACTEC-ERS for U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

GJO-97-31-TAR, GJO-HAN-17. 1998. *Hanford Tank Farms Vadose Zone, S Tank Farm Report*. MACTEC-ERS for U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

GJO-98-39-TAR, GJO-HAN-18. 1998. *Hanford Tank Farms Vadose Zone, C Tank Farm Report*. MACTEC-ERS for U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

GJO-98-40-TAR, GJO-HAN-19. 1998. *Hanford Tank Farms Vadose Zone, BX Tank Farm Report*. MACTEC-ERS for U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

GJO-98-41-TAR, GJO-HAN-20. 1998. *Hanford Tank Farms Vadose Zone, Fifth Biannual Recalibration of Spectral Gamma-Ray Logging Systems Used for Baseline Characterization Measurements in the Hanford Tank Farms*. MACTEC-ERS for U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

GJO-98-48-TAR, GJO-HAN-21. 1998. *Hanford Tank Farms Vadose Zone, Reassessment of the Vadose Zone Contamination at Tank SX-104 and a Comparison to the 1995 Baseline*. MACTEC-ERS for U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

GJO-98-64-TAR, GJO-HAN-23. 1999. *Hanford Tank Farms Vadose Zone, A Tank Farm Report*. MACTEC-ERS for U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

GJO-99-80-TAR, GJO-HAN-24. 1999. *Hanford Tank Farms Vadose Zone, Effects of Differing Source Distributions on Spectral Shape Factors for Contaminant Logging at the Hanford Site*. B. J. Higgins and C. J. Koizumi, MACTEC-ERS for U.S. Department of Energy, Albuquerque Operations Office, Grand Junction Office, Grand Junction, Colorado.

GJPO-HAN-1. 1995. *Vadose Zone Characterization Project at the Hanford Tank Farms, Calibration of Two Spectral Gamma-Ray Logging Systems for Baseline Characterization Measurements in the Hanford Tank Farms*. Prepared by Rust Geotech for U.S. Department of Energy Grand Junction Projects Office, Grand Junction, Colorado.

HNF-2855. 1998. *Findings of the Extension of Borehole 41-09-39, 241-SX Tank Farm*. D. A. Myers, Lockheed Martin Hanford Corporation; D. L. Parker, MACTEC-ERS; G. W. Gee, V. G. Johnson, G. V. Last, and R. J. Serne, Pacific Northwest National Laboratory; and D. J. Moak, Waste Management Northwest for Lockheed Martin Hanford Corporation, Richland, Washington.

Johnson, V. G., and F. N. Hodges. 1997. "Mobile Transuranics: A Hanford Site Case History." Presented at *The 2nd Symposium on the Hydrogeology of Washington State. Abstracts, August 25, 26, and 27, 1997, The Evergreen State College*. State of Washington Department of Ecology, Olympia, Washington.

MAC-1000. 1996. *General Administrative Procedures Manual*. Prepared by MACTEC-ERS for U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

MAC-VZCP-1.7.2, Rev. 1. 1997. *Hanford Tank Farms Vadose Zone, Project Management Plan*. Prepared by MACTEC-ERS for U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

MAC-VZCP-1.7.3, Rev. 1. 1997. *Hanford Tank Farms Vadose Zone, Calibration Plan for Spectral Gamma-Ray Logging Systems*. Prepared by MACTEC-ERS for U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

MAC-VZCP-1.7.9, Rev. 1. 1997. *Hanford Tank Farms Vadose Zone, Data Analysis Manual*. Prepared by MACTEC-ERS for U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

MAC-VZCP-1.7.10-1, Rev. 2. 1997. *Hanford Tank Farms Vadose Zone, High-Resolution Passive Spectral Gamma-Ray Logging Procedures.* Prepared by MACTEC-ERS for U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

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

NUREG/CR-6124. 1996. *Characterization of Radionuclide-Chelating Agent Complexes Found in Low-Level Radioactive Decontamination Waste.* R. J. Serne, A. R. Felmy, K. J. Cantrell, K. M. Krupka, J. A. Campbell, H. Bolton, Jr., and J. K. Fredrickson, U.S. Nuclear Regulatory Commission, Washington, D.C.

OSWER 9950-1. 1986. *Ground-Water Monitoring Technical Enforcement Guidance Document.* U.S. Environmental Protection Agency, Washington, D.C.

Peterson, R. E., and M. P. Connelly. 1992. "Characterization of a Chromium Plume in Groundwater Along the Columbia River Shoreline, Hanford Site, Washington." Presented at 1992 Fall Meeting, American Geophysical Union, San Francisco, California, December 7-11, 1992. *EOS Transactions, American Geophysical Union* 73:43; also WHC-SA-1674-VA, Westinghouse Hanford Company, Richland, Washington.

P-GJPO-1786. 1995. *Vadose Zone Characterization Project at the Hanford Tank Farms, Spectral Gamma-Ray Borehole Geophysical Logging Characterization and Baseline Monitoring Plan for the Hanford Single-Shell Tanks.* Prepared by Rust Geotech for U.S. Department of Energy, Grand Junction Projects Office, Grand Junction, Colorado.

PNL-5041. 1984. *Ground-Water Surveillance at the Hanford Site for CY 1993.* L. S. Prater, J. T. Rieger, C. S. Cline, E. J. Jensen, T. L. Liikala, K. R. Oster, and P. A. Eddy, Pacific Northwest Laboratory, Richland, Washington.

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

PNL-6456. 1988. *Hazard Ranking System Evaluation of CERCLA Inactive Waste Sites at Hanford.* R. D. Stenner, K. H. Cramer, K. A. Higley, S. J. Jette, D. A. Lamar, T. J. McLaughlin, D. R. Sherwood, and N. C. Van Houten, Pacific Northwest Laboratory, Richland, Washington.

PNL-6825. 1989. *Hanford Site Environmental Report for Calendar Year 1988.* R. E. Jaquish and R. W. Bryce, Pacific Northwest Laboratory, Richland, Washington.

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

PNL-6894, Rev. 1. 1993. *Procedures for Ground-Water Investigations.* Pacific Northwest Laboratory, Richland, Washington.

PNL-7120. 1989. *Hanford Site Ground-Water Monitoring for July Through December 1988.* J. C. Evans, R. W. Bryce, D. R. Sherwood, M. L. Kemner, and D. R. Newcomer, Pacific Northwest Laboratory, Richland, Washington.

PNL-7144. 1990. *An Initial Inverse Calibration of the Ground-Water Flow Model for the Hanford Unconfined Aquifer.* E. A. Jacobson and M. D. Freshley, Pacific Northwest Laboratory, Richland, Washington.

PNL-8073. 1992. *Hanford Site Ground-Water Monitoring for 1990.* J. C. Evans, R. W. Bryce, and D. J. Bates, Pacific Northwest Laboratory, Richland, Washington.

PNL-8337. 1992. *Summary and Evaluation of Available Hydraulic Property Data for the Hanford Site Unconfined Aquifer System.* P. D. Thorne and D. R. Newcomer, Pacific Northwest Laboratory, Richland, Washington.

PNL-9437. 1994. *Monitoring Groundwater and River Interaction Along the Hanford Reach of the Columbia River.* M. D. Campbell, Pacific Northwest Laboratory, Richland, Washington.

PNL-10158. 1994. *Summary and Evaluation of Hydraulic Property Data Available for the Hanford Site Upper Basalt Confined Aquifer System.* F. A. Spane, Jr. and V. R. Vermeul, Pacific Northwest Laboratory, Richland, Washington.

PNL-10285. 1995. *Estimated Recharge Rates at the Hanford Site.* M. J. Fayer and T. B. Walters, Pacific Northwest Laboratory, Richland, Washington.

PNL-10379, SUP. 1. 1995. *Distribution Coefficient Values Describing Iodine, Neptunium, Selenium, Technetium, and Uranium Sorption to Hanford Sediments.* D. I. Kaplan and R. J. Serne, Pacific Northwest Laboratory, Richland, Washington.

PNL-10698. 1995. *Hanford Site Ground-Water Monitoring for 1994.* P. E. Dresel, P. D. Thorne, S. P. Luttrell, B. M. Gillespie, W. D. Webber, J. K. Merz, J. T. Rieger, M. A. Chamness, S. K. Wurstner, and B. E. Optiz, Pacific Northwest Laboratory, Richland, Washington.

PNL-10817. 1995. *Hydrochemistry and Hydrogeologic Conditions Within the Hanford Site Upper Basalt Confined Aquifer System.* F. A. Spane, Jr. and W. D. Webber, Pacific Northwest Laboratory, Richland, Washington.

PNNL-11573. 1997. *Groundwater Monitoring Plan for the 183-H Solar Evaporation Basins.* M. J. Hartman, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-11574. 1997. *Results of RCRA Groundwater Quality Assessment Program at the 216-U-12 Crib.* B. A. Williams and C. J. Chou, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-11793. 1998. *Hanford Site Groundwater Monitoring for Fiscal Year 1997.* M. J. Hartman and P. E. Dresel (eds.), Pacific Northwest National Laboratory, Richland, Washington.

PNNL-11795. 1998. *Hanford Site Environmental Report for Calendar Year 1997.* R. L. Dirkes and R. W. Hanf (eds.), Pacific Northwest National Laboratory, Richland, Washington.

PNNL-11800. *Composite Analysis for Low-Level Waste Disposal in the 200 Areas Plateau of the Hanford Site.* C. T. Kincaid, M. P. Bergeron, C. R. Role, M. D. Freshley, N. L. Hassig, V. G. Johnson, D. I. Kaplan, R. J. Serne, G. P. Streile, D. L. Strenge, P. D. Thorne, L. W. Vail, G. A. Whyatt, and S. K. Wurstner, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-11801. 1998. *Three-Dimensional Analysis of Future Groundwater Flow Conditions and Contaminant Plume Transport in the Hanford Site Unconfined Aquifer System: FY 1996 and 1997 Status Report.* C. R. Cole, S. K. Wurstner, M. P. Bergeron, M. D. Williams, and P. D. Thorne, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-11809. 1998. *Results of Phase I Groundwater Quality Assessment for Single-Shell Tank Waste Management Areas T and TX-TY at the Hanford Site.* F. N. Hodges, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-11810. 1998. *Results of Phase I Groundwater Quality Assessment for Single-Shell Tank Waste Management Areas S-SX at the Hanford Site.* V. G. Johnson and C. J. Chou, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-11826. 1998. *Results of Phase I Groundwater Quality Assessment for Single-Shell Tank Waste Management Areas B-BX-BY at the Hanford Site.* S. M. Narbutovskih, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-11957. 1998. *Immobilized Low-Activity Waste Site Borehole 299-E17-21.* S. P. Reidel, K. D. Reynolds, and D. G. Horton, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-11978. 1998. *Results of 1998 Spectral Gamma-Ray Monitoring of Boreholes at the 216-Z-1A Tile Field, 216-Z-9 Trench, and 216-Z-12 Crib.* D. G. Horton and R. R. Randall, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-11989. 1998. *Integrated Monitoring Plan for the Hanford Groundwater Monitoring Project.* M. J. Hartman, P. E. Dresel, J. P. McDonald, R. B. Mercer, D. R. Newcomer, and E. C. Thornton, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-12086. 1999. *Hanford Site Groundwater Monitoring for Fiscal Year 1998.* M. J. Hartman (ed.). Pacific Northwest National Laboratory, Richland, Washington.

Price, S. M., and L. L. Ames. 1976. "Characterization of Actinide-Bearing Sediments Underlying Liquid Waste Disposal Facilities at Hanford." In *Transuranium Nuclides in the Environment*, International Atomic Energy Agency, Vienna, Austria. Also known as ARH-SA-232, Atlantic Richfield Hanford Company, Richland, Washington.

Record of Decision. 1997. *Declaration of the Record of Decision, U.S. DOE Hanford 200 Area, Hanford Site, Benton County, Washington (200-UP-1).* State of Washington Department of Ecology, U.S. Environmental Protection Agency, and U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Reidel, S. P., and K. R. Fecht. 1994a. *Geologic Map of the Priest Rapids 1:100,000 Quadrangle, Washington.* Open File Report 94-13, Washington Division of Geology and Earth Resources. Washington State Department of Natural Resources, Olympia, Washington.

Reidel, S. P., and K. R. Fecht. 1994b. *Geologic Map of the Richland 1:100,000 Quadrangle, Washington.* Open File Report 94-8, Washington Division of Geology and Earth Resources. Washington State Department of Natural Resources, Olympia, Washington.

Resource Conservation and Recovery Act. 1976. Public Law 94-580, as amended, 90 Stat. 2795, 42 USC 6901 et seq.

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

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

RHO-ST-17. 1979. *Distribution of Plutonium and Americium Beneath the 216-Z-1A Crib: Status Report.* S. M. Price, R. B. Kasper, M. K. Additon, R. M. Smith, and G. V. Last, Rockwell Hanford Operations, Richland, Washington.

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

RHO-ST-44. 1982. *216-Z-12 Transuranic Crib Characterization: Operational History and Distribution of Plutonium and Americium.* R. B. Kasper, Rockwell Hanford Operations, Richland, Washington.

Ryker, S. J., and J. L. Jones. 1995. *Nitrate Concentrations in Ground Water of the Central Columbia Plateau.* Open-File Report 95-445, U.S. Geological Survey, Richland, Washington.

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

U.S. Department of Energy (DOE). 1987. *Plan and Schedule to Discontinue Disposal of Liquids Into the Soil Column at the Hanford Site.* Richland, Washington.

Washington Administrative Code (WAC) 173-303. "Dangerous Waste Regulations." Olympia, Washington.

Washington Administrative Code (WAC) 173-304. "Minimal Functional Standards for Solid Waste Handling." Olympia, Washington.

Washington State Department of Ecology (Ecology), U.S. Environmental Protection Agency (EPA), and U.S. Department of Energy (DOE). 1989. *Hanford Federal Facility Agreement and Consent Order Between the U.S. Environmental Protection Agency, the U.S. Department of Energy, and the State of Washington Department of Ecology, May 15, 1989,* as amended. Olympia, Seattle, and Richland, Washington.

WHC-EP-0527-2. 1993. *Environmental Releases for Calendar Year 1992.* L. P. Diediker and D. J. Rokkan, Westinghouse Hanford Company, Richland, Washington.

WHC-EP-0883. 1995. *Variability and Scaling of Hydraulic Properties for 200 Area Soils, Hanford Site.* R. K. Khaleel and E. J. Freeman, Westinghouse Hanford Company, Richland, Washington.

WHC-MR-0388. 1992. *Past Practices Technical Characterization Study - 300 Area - Hanford Site.* M. S. Gerber, Westinghouse Hanford Company, Richland, Washington.

WHC-MR-0391. 1992. *Field Trip Guide to the Hanford Site.* S. P. Reidel, K. A. Lindsey, and K. R. Fecht, Westinghouse Hanford Company, Richland, Washington.

WHC-SD-EN-AP-191. 1996. *Assessment Groundwater Monitoring Plan for Single-Shell Tank Waste Management Area S-SX.* J. A. Caggiano, Westinghouse Hanford Company, Richland, Washington.

WHC-SD-EN-RPT-004. 1993. *Summary of 100-B/C Reactor Operations and Resultant Wastes, Hanford Site.* M. S. Gerber, Westinghouse Hanford Company, Richland, Washington.

WHC-SD-EN-TI-014. 1992. *Hydrogeologic Model for the 200 West Groundwater Aggregate Area.* M. P. Connelly, B. H. Ford, and J. V. Borghese, Westinghouse Hanford Company, Richland, Washington.

WHC-SD-EN-TI-019. 1992. *Hydrogeologic Model for the 200 East Groundwater Aggregate Area.* M. P. Connelly, B. H. Ford, J. W. Lindberg, S. J. Trent, and C. D. Delaney, Westinghouse Hanford Company, Richland, Washington.

WHC-SD-EN-TI-101. 1993. *Carbon Tetrachloride Evaporative Losses and Residual Inventory Beneath 200 West Area at the Hanford Site.* Westinghouse Hanford Company, Richland, Washington.

WMNW/TRS-ES-VZMA-002. 1998. *Monitoring Results for the SX Single Shell Tank Farm Dry Well Gamma Ray Surveillance Log Surveys.* R. R. Randall and R. K. Price, Waste Management Federal Services, Inc., Northwest Operations, Richland, Washington.

7.0 Other Hanford Site Environmental Programs

At the Hanford Site, a variety of environmental activities are performed to comply with laws and regulations, to enhance environmental quality, and to monitor the impact of environmental pollutants from site operations.

This section summarizes activities conducted in 1998 to monitor the climatology and meteorology, to assess the status of the ecosystem, to monitor and manage cultural resources, to actively involve the public in environmental surveillance activities, and to control noxious weeds on the Hanford Site.

7.1 Climate and Meteorology

D. J. Hoitink

Meteorological measurements are taken to support Hanford Site emergency preparedness and response, operations, and atmospheric dispersion calculations for dose assessments (Appendix D, Tables D.5 and D.7 through D.9). Support is provided through weather forecasting and maintenance and distribution of climatological data. Forecasting is provided to help manage weather-dependent operations. Climatological data are provided to help plan weather-dependent activities and are used as a resource to assess the environmental effects of site operations.

Local data to support the Hanford Meteorology Station operations are provided via the Hanford Meteorological Monitoring Network. This network consists of 30 remote monitoring stations that transmit data to the Hanford Meteorology Station via radio telemetry every 15 min. There are 27 10-m (30.5-ft) towers and 3 60-m (182.9-ft) towers. Meteorological parameters collected at these stations include wind speed, wind direction, temperature, precipitation, atmospheric pressure, and relative humidity; however, not all parameters are collected at all stations. Figure 7.1.1 shows the wind roses (diagrams showing direction and frequencies of wind) measured at a height of 10 m (30.5 ft) for the network.

The Cascade Range to the west of Yakima, Washington greatly influences the climate of the Hanford Site. These mountains create a rain shadow effect and also serve as a source of cold air drainage, which significantly affects the wind regime.

The Hanford Meteorology Station is located on the 200 Areas plateau, where the prevailing wind direction is from the northwest during all months of the year. The secondary wind direction is from the southwest. Summaries of wind direction indicate that winds from the northwest quadrant occur most often during winter and summer. During spring and fall, the frequency of southwesterly winds increases, with a corresponding decrease in the northwesterly flow. Monthly average wind speeds are lowest during winter months, averaging 10 to 11 km/h (6 to 7 mi/h), and highest during summer, averaging 13 to 15 km/h (8 to 9 mi/h). Wind speeds that are well above average are usually associated with southwesterly winds. However, summertime drainage winds are generally northwesterly and frequently reach 50 km/h (30 mi/h). These winds are most prevalent over the northern portion of the site.

Atmospheric dispersion is a function of wind speed, wind duration and direction, atmospheric stability, and mixing depth. Dispersion conditions are generally good if winds are moderate to strong, the atmosphere is of neutral or unstable stratification, and there is a deep mixing layer. Good dispersion conditions associated with neutral and unstable stratification exist approximately 57% of the time during summer. Less-favorable conditions may occur when wind speed is light and the mixing layer is shallow. These conditions are most common during winter, when moderately to extremely stable stratification exists approximately 66% of the time. Occasionally, there are extended periods of poor dispersion conditions, primarily during winter, which are associated with stagnant air in stationary high-pressure systems.

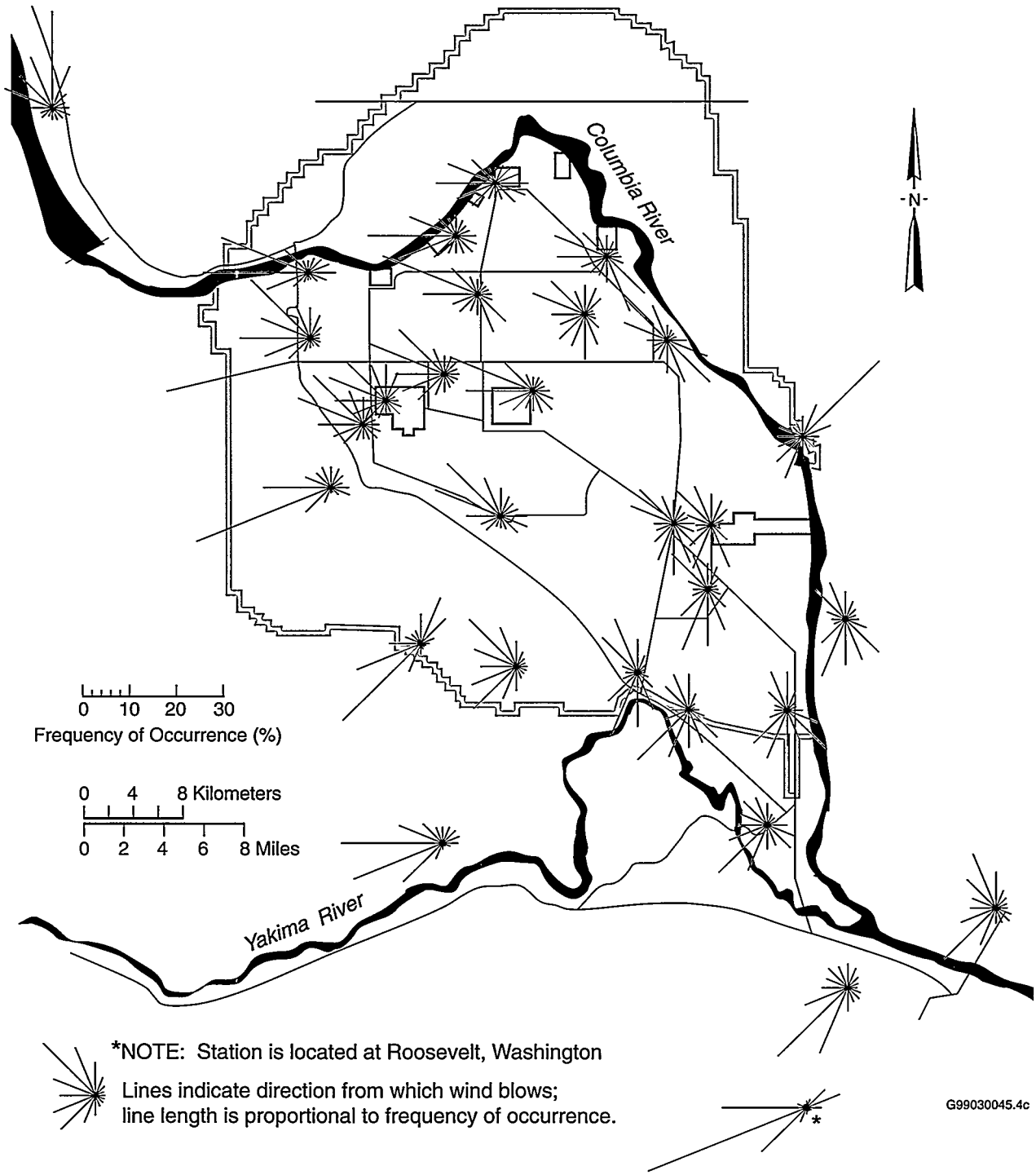


Figure 7.1.1. Hanford Meteorological Monitoring Network Wind Roses (measured at a height of 10 m [30.5 ft]), 1998. Individual lines indicate direction from which wind blows. Length of line is proportional to frequency of occurrences from a particular direction.

7.1.1 Historical Information

Daily and monthly averages and extremes of temperature, dew point temperature, and relative humidity for 1945 through 1998 are reported in PNNL-12087. From 1945 through 1998, the record maximum temperature was 45°C (113°F) recorded in August 1961, and the record minimum temperature was -30.6°C (-23°F) in February 1950. Normal monthly average temperatures ranged from a low of -0.4°C (31.3°F) in January to a high of 24.6°C (76.2°F) in July. During winter, the highest monthly average temperature at the Hanford Meteorology Station was 6.9°C (44.5°F) in February 1991, and the record lowest was -11.1°C (12.1°F) in January 1950. During summer, the record maximum monthly average temperature was 27.9°C (82.2°F) in July 1985, and the record minimum was 17.2°C (63.0°F) in June 1953. The average annual relative humidity at the Hanford Meteorology Station is 54%. Humidity is highest during winter, averaging approximately 76%, and lowest during summer, averaging approximately 36%. Average annual precipitation at the Hanford Meteorology Station is 15.9 cm (6.26 in.). The wettest year on record, 1995, received 31 cm (12.3 in.) of precipitation; the driest, 1976, received 8 cm (2.99 in.). Most precipitation occurs during late autumn and winter, with more than half of the annual amount occurring from November through February. The snowiest winter on record, 1992-1993, received 142.5 cm (56.1 in.) of snow.

7.1.2 Results of 1998 Monitoring

1998 was warmer than normal, with nearly normal precipitation. The average temperature for 1998 was 13.6°C (56.4°F), which was 1.7°C (3.1°F) above normal (11.8°C [53.3°F]), and tied 1992 as the warmest year on record. Eleven months during 1998 were warmer than normal, and one month was cooler than normal. July had the highest positive departure, 3.2°C (5.8°F); October, at 0.3°C (0.5°F) below normal, had the only negative departure. The maximum temperature of 44.4°C (112°F) on July 27, 1998 was the hottest temperature ever recorded during the month of July. For the year, there were 73 d with maximum temperature ≥32.2°C (90°F), the third highest day-total on record. The summer (June, July, and August) and autumn (September, October, and November) of 1998 were the fourth warmest on record.

Precipitation for 1998 totaled 16.4 cm (6.45 in.), 103% of normal (15.9 cm [6.26 in.]), with 18.3 cm (7.2 in.) of snow (compared to an annual normal snowfall of 35.1 cm [13.8 in.]). There were eight thunderstorms recorded at the Hanford Meteorological Station in July 1998, tying 1983 for the most thunderstorms in July.

The average wind speed for 1998 was 12.7 km/h (7.9 mi/h), which was 0.3 km/h (0.2 mi/h) above normal. The peak gust for the year was 90 km/h (56 mi/h) on November 21. November 1998 had a record number of days (10) with wind gusts ≥64 km/h (40 mi/h). Figure 7.1.1 shows the 1998 wind roses (diagrams showing direction and frequencies of wind) measured at a height of 10 m (30.5 ft) for the 30 meteorological monitoring stations on and around the Hanford Site.

Table 7.1.1 provides monthly climatological data from the Hanford Meteorology Station for 1998.

Table 7.1.1. Monthly Climatological Data from the Hanford Meteorology Station, 1998

Hanford Meteorology Station, 40 km (25 mi) northwest of Richland, Washington, latitude 46° 34'N, longitude 119° 35'W, elevation 223 m (733 ft)

Month	Temperatures, °C								Precipitation (cm)				Relative Humidity (%)		15-m Wind[a]				
	Averages				Extremes						Snowfall						Peak Gusts		
	Daily Maximum	Daily Maximum	Monthly	Departure[b]	Highest	Date	Lowest	Date	Total	Departure[b]	Total	Departure[b]	Average	Departure[b]	Average Speed, km/h	Departure[b]	Speed, km/h	Direction	Date
J	6.7	-2.1	2.3	+2.7	13.9	19[c]	-13.9	13	3.1	+1.1	16.0	+6.1	76.3	-0.1	12.6	+2.1	69	SW	24
F	10.9	0.4	5.7	+2.3	14.4	21	-5.6	27	2.9	+1.3	T[d]	-5.1	74.4	+4.1	11.7	+0.2	80	S	21
M	15.7	2.5	9.1	+1.6	22.2	13	-5.0	5	1.3	+0.1	T	-0.8	58.4	+2.5	11.7	-1.6	63	WSW	26
A	20.4	4.5	12.4	+0.9	33.3	30	-1.7	12	0.2	-0.9	0	T	49.4	+2.2	12.2	-2.3	60	W	24
M	24.6	9.2	16.9	+0.6	33.9	6[c]	3.9	15	1.3	0.0	0	0	53.2	+10.5	12.9	-1.8	88	WNW	21
J	29.8	13.6	21.7	+0.7	37.2	30	8.3	27	1.2	+0.3	0	0	41.0	+2.2	15.8	+1.0	80	WNW	15
J	36.3	19.3	27.8	+3.2	44.4	27	14.4	20[c]	0.9	+0.4	0	0	33.6	+0.1	13.0	-1.1	76	WSW	27
A	34.7	16.3	25.5	+1.6	43.3	4	10.0	24	0.1	-0.6	0	0	33.0	-2.8	13.0	+0.3	80	NW	15
S	30.6	12.8	21.7	+2.9	39.4	1	6.1	27	0.3	-0.5	0	0	42.6	-0.1	10.8	-1.1	56	WSW	17
O	18.7	3.9	11.3	-0.3	28.9	1	-3.9	30	0.7	-0.3	0	-0.2	56.7	+1.5	11.3	+0.8	74	SW	8
N	12.1	3.0	7.6	+3.0	19.4	25[c]	-2.8	19[c]	3.3	+1.0	0	-4.6	72.8	-0.6	14.2	+3.9	90	SSW	21
D	5.4	-4.3	0.6	+0.9	15.6	29	-18.3	21	1.1	-1.5	2.3	-12.2	72.3	-8.0	12.6	+3.1	88	WSW	26
Y[e]	20.5	6.6	13.6	+1.7	44.4	Jul 27	-18.3	Dec 21	16.4	+0.5	18.3	-16.8	55.3	+1.0	12.7	+0.3	90	SSW	Nov 21

NOTE: See Table H.2, Conversion Table in "Helpful Information" for unit conversion information.
(a) Measured on a tower 15 m (50 ft) above the ground.
(b) Departure columns indicate positive or negative departure of meteorological parameters from 30-yr (1961-1990) climatological normals.
(c) Latest of several occurrences.
(d) Trace.
(e) Yearly averages, extremes, and totals.

7.2 Ecosystem Monitoring (Plants and Wildlife)

L. L. Cadwell, D. D. Dauble, J. L. Downs, M. A. Simmons, and B. L. Tiller

The Hanford Site is a relatively large, undisturbed area of shrub-steppe that contains a rich, natural diversity of plant and animal species adapted to the region's semiarid environment. Terrestrial vegetation on the site consists of 10 major plant communities: 1) sagebrush/ bluebunch wheatgrass, 2) sagebrush/cheatgrass or sagebrush/Sandberg's bluegrass, 3) sagebrush-bitterbrush/cheatgrass, 4) grease wood/cheatgrass-saltgrass, 5) winterfat/Sandberg's bluegrass, 6) thyme buckwheat/Sandberg's bluegrass, 7) cheatgrass-tumble mustard, 8) willow or riparian, 9) spiny hopsage, and 10) sand dunes (PNNL-6415, Rev. 10). Nearly 600 species of plants have been identified on the site (WHC-EP-0054). Recent work by The Nature Conservancy of Washington has further delineated 36 distinct plant community types (Soll and Soper 1996) from within those 10 major communities.

There are two types of natural aquatic habitats on the Hanford Site. One is the Columbia River and associated wetlands and the second includes upland aquatic sites. The upland sites include small spring streams and seeps located mainly on the Fitzner/ Eberhardt Arid Lands Ecology Reserve on Rattlesnake Mountain (e.g., Rattlesnake Springs, Dry Creek, Snively Springs) and West Lake, which is a small, natural pond near the 200 Areas.

More than 1,000 species of insects (Soll and Soper 1996), 3 species of reptiles and amphibians (PNNL-6415, Rev. 10), 44 species of fish (Gray and Dauble 1977; PNNL-6415, Rev. 10), 214 species of birds (Soll and Soper 1996), and 39 species of mammals (PNNL-6415, Rev. 10) have been found on the Hanford Site. Deer and elk are the major large mammals, coyotes are plentiful, and the Great Basin pocket mouse is the most abundant mammal. Waterfowl are numerous on the Columbia River, and the bald eagle is a regular winter visitor along the river. Salmon and steelhead are the fish species of most interest to sport fishermen and are commonly consumed by local Native American tribes.

Although no Hanford Site plant species have been identified from the federal list of threatened and endangered species (Title 50, Code of Federal Regulations, Part 17, Section 12 [50 CFR 17.12]), recent biodiversity inventory work conducted by The Nature Conservancy of Washington identified 100 populations of 30 different rare plant taxa (Hall 1998). The U.S. Fish and Wildlife Service lists the peregrine falcon as endangered and the bald eagle and Aleutian Canada goose as threatened (50 CFR 17.11). The peregrine falcon and Aleutian Canada goose are rare migrants through the site, and the bald eagle is a common winter resident and has initiated nesting on the site but has never successfully produced offspring. Several plant species, mammals, birds, molluscs, reptiles, and invertebrates occurring on the site are candidates for formal listing under the Endangered Species Act of 1973. Appendix F lists special-status species that could occur on the site.

7.2.1 Chinook Salmon

Chinook salmon are an important resource in the Pacific Northwest; they are caught commercially and for recreation. Salmon are also of cultural importance to Native American tribes. Today, the

most important natural spawning area in the mainstem Columbia River for the fall chinook salmon is found in the free-flowing Hanford Reach. In the early years of the Hanford Site, there were few spawning nests (redds) in the Hanford Reach (Figure 7.2.1). Between 1943 and 1971, a number of dams were constructed on the Columbia River, their reservoirs eliminating most mainstem spawning areas, resulting in increased numbers of salmon spawning in the Hanford Reach. Fisheries management strategies aimed at maintaining spawning populations in the mainstem Columbia River also have contributed to the observed increases. The number of fall chinook salmon redds counted in the Hanford Reach increased through the decades of the 1960s, 1970s, and 1980s until reaching a high in 1989 of nearly 9,000 (see Figure 7.2.1). In the early 1990s, redd counts declined to approximately one-third of the 1989 peak, but they appear to have rebounded in recent years. In 1998, approximately 5,370 redds were observed, or approximately 70% of the 1996 and 1997 totals. It should be noted that aerial surveys do not yield absolute counts of redds because visibility varies, depending on water depth and other factors, and because the number of redds in high-density locations cannot be counted accurately. However, redd survey data generally agree well with adult escapement figures obtained by counting migrating adult fish at fish ladders on the Columbia River.

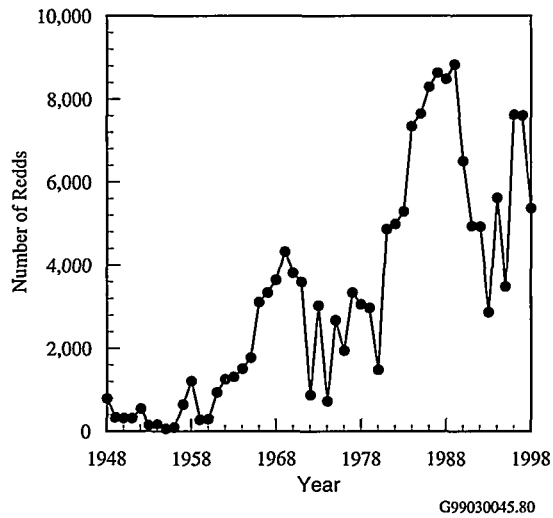


Figure 7.2.1. Chinook Salmon Spawning Redds in the Hanford Reach, 1948 Through 1998

7.2.2 Bald Eagle

The bald eagle is listed as a federally threatened species (50 CFR 17.11) and also a Washington State threatened species (Washington State Department of Wildlife 1994). Protection for bald eagles on the Hanford Site is guided by the management plan contained in DOE/RL-94-150 and coordinated with representatives of the U.S. Fish and Wildlife Service.

Historically, bald eagles have wintered along the Hanford Reach of the Columbia River. The wintering eagles originate from various places, including interior Alaska, British Columbia, Northwest Territories, Saskatchewan, and even possibly Manitoba. However, when monitoring began in the early 1960s, numbers were low (Figure 7.2.2). Following the passage of the Endangered Species Act, the number of wintering bald eagles has generally increased. Primary reasons for the observed increase are 1) reduced persecution in Alaska, 2) protection of bald eagles at nesting locations, and 3) nationwide elimination of dichlorodiphenyltrichloroethane (DDT) as an agricultural pesticide in 1972.

The number of nesting eagles was estimated approximately 25,000 in the lower 48 states when the bird was adopted as our national symbol in 1782. From fewer than 450 nesting pairs in the early 1960s, there are now >4,000 nesting pairs in the lower 48 states. When eagles were federally listed as endangered, recovery goals included at least 800 nesting pairs collectively in California, Idaho, Montana, Oregon, Utah, and Washington (i.e., the Pacific

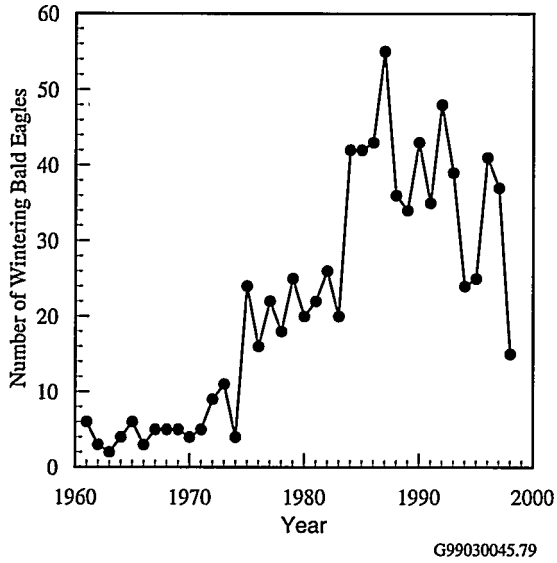


Figure 7.2.2. Bald Eagles Observed Along the Hanford Reach, 1948 Through 1998

states). In 1997, the wildlife experts estimated >1,200 nesting pairs in the Pacific states region. Only three pairs of nesting eagles are known to occur in eastern Washington. One of these pairs occurs on the Hanford Reach of the Columbia River.

Several nest-building attempts by bald eagles have been observed on the Hanford Site. In 1998, a pair of adult eagles built two separate nests in the vicinity of the White Bluffs (see Figure 1.0.1). All Hanford-related activities were prohibited from occurring within 800 m (2,600 ft) of either nest site. Nest tending activities and territorial displays were documented at these two sites in late December 1998 and continued through April 1999.

A single maximum count of only 15 bald eagles was documented on the Hanford Reach and typically only 5 were observed in the winter of 1998. Wintering eagle numbers similar to those observed in 1998 along the Hanford Reach were last seen in the 1970s (see Figure 7.2.2). The low counts observed on the Hanford Reach this winter are consistent with reports from the upper Columbia River at Rocky Reach and Rock Island Reservoirs, the Clearwater River in Idaho, and the lower Snake and Columbia Rivers of Oregon and Washington. A wildlife researcher working for the Washington State Department of Fish and Wildlife noted that many of the eagles fitted with satellite transmitters did not move their typical 1,200-km (745-mi) distance for the wintering period but, rather, stayed near their nesting territories in Alaska, British Columbia, and the Northwest Territories (Watson, personal communication 1999). The underlying cause(s) for reduced winter migration of eagles during the winter of 1998-1999 have not been fully examined. However, availability of food sources for eagles may have played a major role. Chum salmon (a major food of wintering eagles) were so abundant along the Fraser River (British Columbia) that wintering eagles may have elected to use the Fraser River area and tributaries rather than the mid-Columbia River. Also, an atypically high snow fall occurred in some portions of Alaska, resulting in an increase in winter-killed big game (another major food source for eagles that typically migrate south for the winter). Recent studies conducted along the Skagit River in northwestern Washington indicate increased recreational activities negatively affect the number of wintering eagles there (Stalmaster and Kaiser 1998).

Changes in the number of eagles on the Hanford Site have generally corresponded to changes in the number of returning fall chinook salmon, a major fall and winter food source for eagles (compare Figures 7.2.1 and 7.2.2 to see similarity in the patterns of salmon redd counts and bald eagle counts).

7.2.3 Hawks

The undeveloped land of the semiarid areas of the Hanford Site provides nest sites and food for three species of migratory buteo hawks: Swainson's, red-tailed, and ferruginous. Under natural conditions,

these hawks nest in trees, on cliffs, or on the ground. Power-line towers and poles also can serve as nest sites, and these structures are used extensively by nesting hawks on the site because of the relative scarcity of trees and cliffs. The ferruginous hawk is a Washington State threatened species (Washington State Department of Wildlife 1994) as well as a U.S. Fish and Wildlife Service candidate species for listing as threatened or endangered (50 CFR 17.11). Approximately one quarter of the state's ferrguinous hawk nesting territories are located on the site.

In recent years, the number of ferruginous hawks nesting on the Hanford Site has remained stable (10 active nests in 1998, range of 7 to 12 since 1995). The site continues to provide hawk nesting habitats that are administratively protected from public intrusion. An evaluation of selected aspects of ferruginous hawk ecology on the site and adjacent lands was completed in 1996 (Leary 1996). That work suggested that ferruginous hawks nest on the site because of suitable, disturbance-free habitat, but that much of the foraging for prey species occurred on adjacent, privately owned, agricultural fields. Male ferruginous hawks were observed to travel up to 15 km (9.3 mi) from their Hanford Site nests to hunt, making several trips each day to deliver prey to their mates and offspring. These results showed that small rodents such as northern pocket gophers, which can be serious agricultural pests, are the primary prey of ferruginous hawks.

7.2.4 Rocky Mountain Elk

Rocky Mountain elk did not inhabit the Hanford Site when it was established in 1943. Elk were first observed on the Fitzner/Eberhardt Arid Lands Ecology Reserve in the winter of 1972. A few animals stayed and reproduced. Since that time, the herd has grown and now occupies portions of the Hanford Site, the United States Army's Yakima Training Center, and private land along Rattlesnake Ridge. Herd size was estimated from census data at 742 animals prior to the 1998 hunting season (Figure 7.2.3). Although accurate counts of elk harvest on adjacent private lands are not available, the harvest appears to be small, with <5% of the herd being harvested and the majority of the harvest consisting of bulls. The 1998 harvest consisted of approximately 18 adult bulls and 15 cows. Thus, growth of the herd is largely unconstrained, and increasing damage to natural plant communities on the site and to crops on adjacent private land is likely. Several observations were made in 1996 and 1997 of elk having crossed to the northern side of State Highway 240. Four vehicle collisions with elk were documented near Hanford in 1998 alone. As the herd continues to grow, there are two safety-related concerns that will increase. The first is the potential for an increase in vehicle-elk collisions on local highways; the second is the possibility that elk will range into the recently enlarged radiologically controlled area (BC Cribs) immediately south of the 200-East Area.

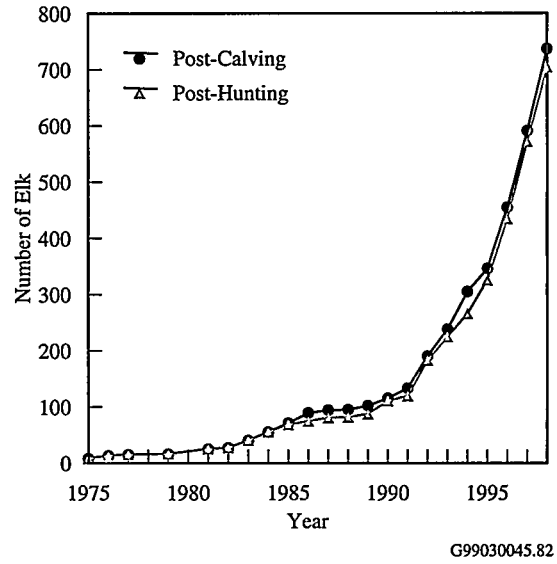


Figure 7.2.3. Elk on the Hanford Site: Post-Calving (August through September) and Post-Hunting (December through January) Periods, 1975 Through 1998

7.2.5 Mule Deer

Mule deer are a common resident of the Hanford Site and are important because of the recreational (offsite hunting) and aesthetic values they provide. Because mule deer have been protected from hunting on the site for approximately 50 yr, the herd has developed a number of unique population characteristics different from most other herds in the semiarid region of the northwest. These characteristics include a large proportion of old-age animals (older than 5 yr) and large-antlered males.

Because mule deer are often hunted and eaten, they can contribute to the radiation dose received by members of the public that consume game animals (PNL-7539, MacLellan et al. 1993). On the Hanford Site, deer are also of interest to environmental monitoring programs because they can provide useful information that can be used in contaminant cleanup efforts (Eberhardt and Cadwell 1983, PNL-10711, PNNL-11518).

The onsite deer population was estimated in 1996 by marking several Hanford Site deer and counting the ratio of marked to unmarked animals along the Columbia River. In addition, relative deer densities were determined throughout the remainder of the site by comparing the frequency of fecal pellet groups found within each region. Approximately 330 deer were estimated to reside in the region of the site bordering the Columbia River, and the total site mule deer population, exclusive of the lands lying north of the Columbia River, was estimated at 650.

Age and sex classes of deer that reside along the Columbia River of the Hanford Site have been monitored yearly since 1993. Roadside surveys have been conducted on an established route that is >64 km (40 mi) long. The route is driven several times during the post-fawning season (July-September) and the post-hunting season (December-February) to get a precise estimate of the ratio of bucks (antlered deer) to adult females (adult antlerless deer) and the ratio of fawns to adult female deer. The buck-to-doe ratios seen in this region have remained relatively stable since 1993 (20 to 40 bucks per 100 does) and are higher than ratios typically observed throughout the northwest (10 to 30 bucks per 100 does). Fawn-to-doe ratios demonstrated a significant downward trend through 1997 (Figure 7.2.4); however, in 1998, the fawn ratio appeared to be increasing again (20 fawns to 100 does). Although the causes of fluctuating fawn numbers are not known on the site, several factors that may play a role include neonatal losses, unhealthy newborns, and predation. Coyote predation on fawns is known to occur on the site and is likely a primary regulating factor for population growth.

7.2.6 Plant Biodiversity Inventories

Surveys and mapping efforts conducted by The Nature Conservancy of Washington and Pacific Northwest National Laboratory Ecosystem Monitoring Project document the occurrence and extent of rare plant populations and plant community types on the Hanford Site (Soll and Soper 1996, Hall 1998). These populations include taxa listed by Washington State as endangered, threatened, or sensitive and the locations of populations of taxa that are listed as review group 1 (i.e., taxa in need of additional field work before status can be determined) (Washington Natural Heritage Program 1997). The data provide information that is critical to site planning processes and land-use policy development.

Figure 7.2.5 delineates the known locations of more than 100 rare plant populations of 30 different taxa (Caplow and Beck 1996, Hall 1998). Five of these 30 taxa (including the two new species,

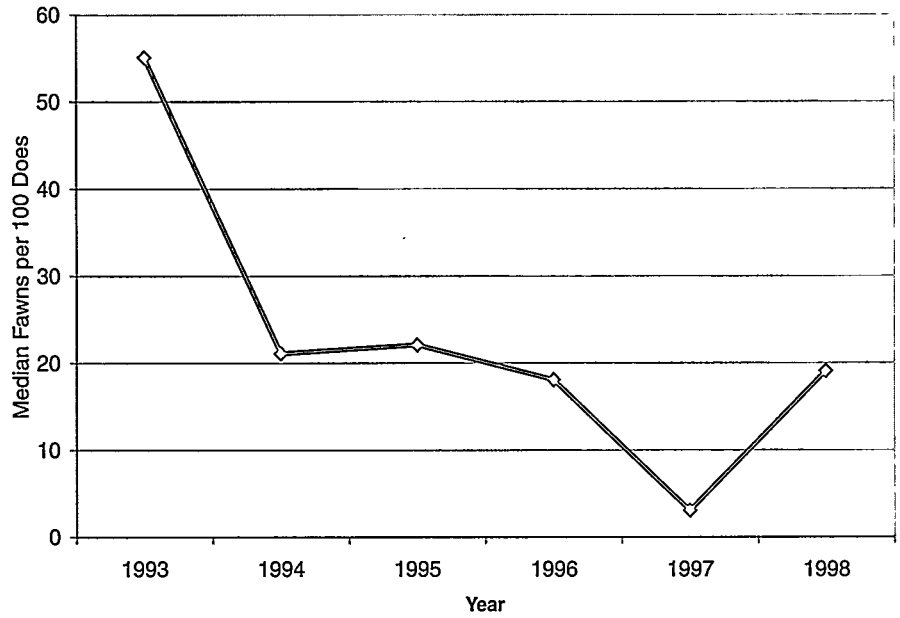


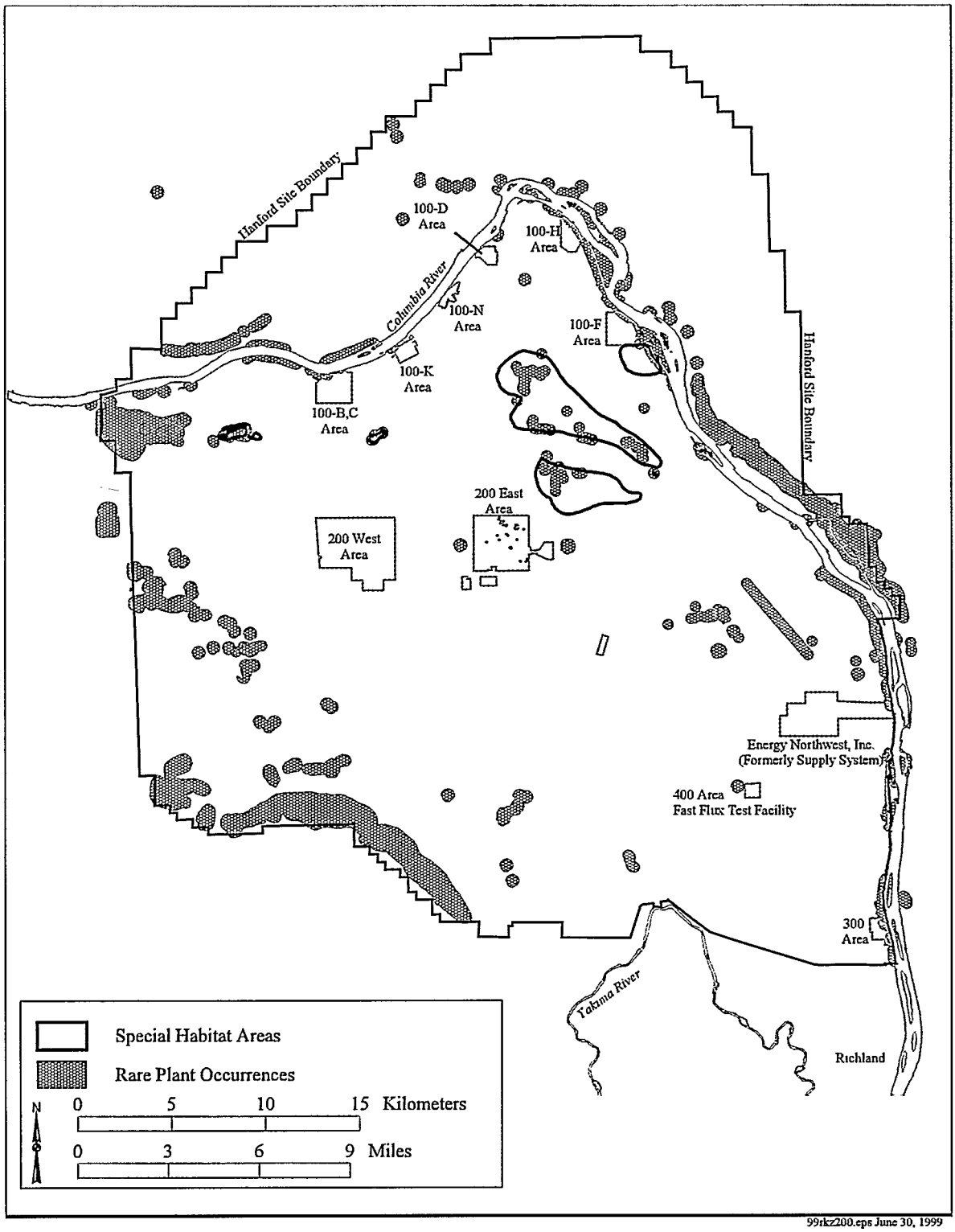
Figure 7.2.4. Median Number of Fawns Observed per 100 Adult Does During Roadside Surveys, 1993 Through 1998

Eriogonum codium and *Lesquerella tuplashensis*) have been designated as species of concern in the Columbia River Basin Ecoregion by the U.S. Fish and Wildlife Service. In addition to the rare plant populations, several areas on the Hanford Site are designated as special habitat types with regard to potential occurrence of plant species of concern. These include areas that could support populations of rare annual forbs found in adjacent habitat. The degree of protection from disturbance afforded to the site over the past 50 yr has resulted in an "island of biodiversity" for plant resources (Caplow and Beck 1998).

Populations of another species of concern in the Columbia River Basin Ecoregion, *Rorippa columbiae* (persistent sepal yellowcress), may be declining as a result of the high river flow levels over the past 3 yr. *Rorippa columbiae* is a rhizomatous perennial found in moist soils along the Columbia River within the Hanford Site. This species is often inundated by river flows, but little is known concerning long-term survival under continuous inundation. Surveys in 1998 identified far fewer stems at several locations on the Hanford Reach than previously documented (Table 7.2.1).

7.2.7 Sagebrush Die-Off

Big sagebrush (*Artemisia tridentata* subspecies *wyomingensis*) is the most common shrub component of shrub-steppe vegetation associations on the Hanford Site. These sagebrush stands represent an important resource for sagebrush-obligate wildlife species such as black-tailed jackrabbits, sage sparrows, sage thrashers, and loggerhead shrikes. Since 1993, site biologists have documented areas of sagebrush die-off in stands near the 100-D Area, the cause of which is not known. Shrub die-offs are not uncommon in the intermountain west and such episodes have been reported from British Columbia, Idaho, Nevada, Utah, and Wyoming (Dobrowolski and Ewing 1990). Die-off of shrubs has been attributed to severe rootlet



99rkz200.eps June 30, 1999

Figure 7.2.5. Rare Plant Locations on the Hanford Site Based on 1994, 1995, 1997, and 1998 Surveys Conducted by The Nature Conservancy of Washington

Table 7.2.1. Numbers of *Rorippa Columbiae* Stems Counted Along the Hanford Reach of the Columbia River, 1994 and 1998

Survey Location	1994 Counts	1998 Counts
100-F beach	>15,000	70
Locke Island	>10,000	117
Island 18[a]	>10,000	0

(a) Located in the Columbia River at the 300 Area.

mortality, root rot, soil salinity and anaerobiosis, and vascular shoot wilt induced by fungal pathogens (Nelson et al. 1989, Weber et al. 1989).

The extent of the die-off on the Hanford Site was mapped and survey data were collected in 1996 and 1997 to establish a baseline for monitoring future expansion of the die-off (PNNL-11700). That report indicated that a total area of 1,776 ha (4,388 acres) showed evidence of sagebrush decline, with a central portion of 280 ha (692 acres) where shrub death was estimated to be approximately 80% or greater. Surveys in 1997 and 1998 of shrubs within the die-off areas indicate that sagebrush plants are continuing to decline. Observations of shrub vigor (percent canopy defoliation) show continuing declines in shrub health in the die-off areas and along the boundary of the die-off area.

The cause of sagebrush die-off on the Hanford Site remains undetermined. Possible causes of shrub death that have been evaluated include insect infestation, rodent damage, and high levels of soil salinity. Repeated surveys and observations have failed to document any obvious and consistent level of insect damage across the die-off areas. Field observations do not document any rodent damage or removal of sagebrush bark from plant stems at and below ground level. Limited soil analyses show no evidence of increased soil salinity or differences in nutrient levels in die-off areas versus similar soils outside the die-off areas. Although previous observations documented the presence of fungal rust species on leaf material from sagebrush in the die-off area, rust infestation does not appear to be the cause of shrub death. Consultations with the shrub pathologist at the U.S. Department of Agriculture Shrub Sciences Laboratory (part of the U.S. Forest Service Intermountain Research Station), Provo, Utah, indicate that the most likely pathogen is a soil fungus or virus. These pathogens are difficult to isolate and sample and often contribute to an overall decline in shrub health that may lead to death.

Pathological tests of sagebrush samples from the die-off area produced 29 fungal isolates from the upper root zone and base of the shrubs. Isolates included *Fusaria* sp., *Sclerocium* sp., and *Altenaria* sp.; all fungal isolates previously observed on sagebrush. Fungal pathogens are common in the soil and the air but may not have the ability to penetrate shrub defenses and impact shrub health until the shrub is weakened by another stress or stresses brought on by drought and/or cold temperatures. Continuing pathological investigation will reveal whether the fungal isolates can successfully infect sagebrush in the absence of secondary stress. These tests may help identify the agent or agents responsible for the sagebrush decline on the Hanford Site.

To understand whether and how sagebrush may recolonize the die-off areas, seedling growth and survival were examined by transplanting 133 container-grown seedlings (averaging 3.5 cm [1.4 in.] in height) into the field. One-half of the plants were transplanted in the central die-off area (80% or greater shrub mortality) and one-half in the control plot distant from the die-off area (south of the Wye Barricade). Seedlings were planted in mid-March 1998 on north-facing slopes in sandy loam soils and watered with a dilute nutrient solution. Heights and diameters were recorded after planting.

The seedlings were measured in August 1998, January and April 1999 to determine survival and growth. Approximately 50% of the transplanted shrubs in the central die-off area and in the control area distant from the die-off area died within the first 6 mo. After 1 yr, transplanted shrub survival in the central die-off area was 39%, while survival at the control plot was 51%. Growth measurements after 1 yr reveal an overall increase in shrub height of 3 cm (1.2 in.) at the control plot (average shrub height = 7.0 cm [2.9 in.]) and a 3.7-cm (1.48-in.) increase at the die-off plot (average shrub height = 7.3 cm [2.92 in.]). There was no significant difference in seedling growth between the areas, and no differences in shrub vigor were observed for shrubs in either area.

Shrubs were classified by the amount of canopy: dead, <50% live, 50%-90% live, and >90% live. These measurements indicated that, though few shrubs actually died along each measured transect (Table 7.2.2), 10% to 35% of shrubs measured declined by at least one category.

Table 7.2.2. Decline of Shrub Conditions Measured Along Six Transects Within and Along the Boundaries of the Sagebrush Die-Off Area on the Hanford Site

Transect	% Dead at First Measurement	% Dead at Last Measurement	% Canopy >90% Live at First Measurement	% Canopy >90% Live at Last Measurement	Percentage of Shrubs Declining
1 (n=27)	95.0	95.0	5.0	0.0	5.0
2 (n=34)	18.0	18.0	41.0	35.0	35.3
3 (n=31)	81.0	84.0	10.0	0.0	12.9
4 (n=50)	48.0	48.0	14.0	4.0	10.0
5 (n=61)	15.0	16.0	43.0	15.0	28.0
6 (n=51)	18.0	19.0	54.0	9.0	27.9

Number of shrubs measured in parentheses.

7.3 Cultural Resources

M. K. Wright and D. W. Harvey

The U.S. Department of Energy (DOE), Richland Operations Office, established a cultural resources program in 1987 that has been managed by the Hanford Cultural Resources Laboratory as part of Pacific Northwest National Laboratory (PNL-6942). Pacific Northwest National Laboratory, Bechtel Hanford, Inc., and CH2M Hill Hanford, Inc. provided support to DOE for the cultural resources program on the Hanford Site throughout 1998. Thus, management of archaeological, historical, and traditional cultural resources at the Hanford Site was provided in compliance with the National Historic Preservation Act of 1966, Native American Graves Protection and Repatriation Act of 1990, Archaeological Resources Protection Act of 1979, and American Indian Religious Freedom Act of 1978.

7.3.1 Native American Involvement

Members of the Confederated Tribes of the Umatilla Indian Reservation, Yakama Indian Nation, Nez Perce Tribe, and Wanapum Band were actively involved in the cultural resources program during 1998. Monthly cultural resource issues meetings provided a venue for the exchange of information between DOE, tribal staff members, and site contractors about projects and activities on the Hanford Site. These meetings included discussions of sitewide projects dealing with a wide range of topics: the groundwater/vadose zone, 1100 Area land transfer, a new boat launch at Vernita Bridge, Office of River Protections Project W-519, and Hanford's native plants. Tribal staff and site contractors worked together during the completion of several field surveys to identify and record cultural features, sites, and landscapes in advance of new construction (an excavation at the 100-KR-4 Operable Unit pump-and-treat project) and monitoring of numerous projects requiring excavation during the year. Bechtel Hanford, Inc. contracted with the Nez Perce Tribe for the identification and propagation of traditional plants and with the Confederated Tribes of the Umatilla Indian Reservation for a native plant nursery. In addition, one Wanapum Band member was hired by Pacific Northwest National Laboratory and trained to work as an archaeological technician and assist DOE with cultural resources management activities.

Several other activities involving tribes and tribal expertise were conducted during 1998. These activities included a technical exchange held for members in each of four tribes to present summarizations of their overall involvement in cultural resources efforts at Hanford, a tour of the Hanford Site's environmental restoration projects for Nez Perce Elders and Tribal Council members, a Traditional Places Visitation led by Wanapum Elders for regional tribes, and an Archaeological Resources Protection Act training workshop conducted by the Confederated Tribes of the Umatilla Indian Reservation for law enforcement personnel.

7.3.2 Public Involvement

The cultural resources staff of the Pacific Northwest National Laboratory, Bechtel Hanford, Inc., and CH2M Hill Hanford, Inc. assisted DOE in organizing and conducting public meetings for reviewing the implementation of DOE's programmatic agreement for building mitigation activities (DOE/RL-96-77) and the sitewide treatment plan (DOE/RL-97-56, Rev. 1). There were discussions of the future uses of

historic buildings at the Hanford Site; one meeting specifically focused on the reuse of historic structures in the 300 Area to preserve a selected number to maintain the integrity of the Manhattan Project/ Cold War Era Historic District. Additional meetings focused on assessing historic buildings for the purpose of identifying those suitable for public interpretation and educational/museum purposes.

Discussions were held at public issues exchange workshops on a variety of cultural resources issues, including National Landmark approach for the Hanford Site, transition of the 1100 Area from DOE to the Port of Benton, and potential of heritage tourism at the Hanford Site (i.e., a tour program that envisioned utilization of the defunct Hanford Site railroad). These discussions broadened to include strong support for the use of B Reactor as a publicly accessible museum, including the rehabilitation of the nearby historic cobblestone structure known as Bruggeman's Warehouse into an interpretive center for the site's cultural resources.

Public involvement activities are important components of a cultural resources management program. To accomplish this goal, DOE developed mechanisms that allow the public access to cultural resources information and the ability to comment and make recommendations concerning the management of cultural resources on the Hanford Site. In 1998, these mechanisms were woven into a draft involvement plan that includes input provided by the public and Hanford Site staff over the past several years.

7.3.3 Section 106 Activities

Pursuant to Section 106 of the National Historic Preservation Act, cultural resources reviews must be conducted before each proposed ground disturbance or building alteration/demolition project can take place. Cultural resources reviews are required to identify properties that may be eligible for or listed in the National Register of Historic Places within the proposed project area and evaluate the effect the proposed project may have on any such property.

During 1998, 150 cultural resources reviews were requested (Figure 7.3.1). A majority of the reviews involved project areas that had been previously surveyed or were located in previously disturbed ground. Of the projects reviewed, 6 were also monitored during the construction phase, 7 required archaeological surveys, and 18 involved building modification or demolition. The surveys covered a total of 584 ha (1,444 acres) and resulted in the discovery of 5 isolated finds and 23 archaeological sites (Figure 7.3.2).

A survey of 256 ha (632 acres) was done in preparation for the land transfer of the 1100 Area from DOE to the Port of Benton. A total of 20 archaeological sites were recorded, including sites relating to homesteading and farming (1905 to 1943) and sites related to development of the Hanford Site (post 1943). Fields, irrigation canals, and roadways related to the early twentieth century Richland, Washington farming community are apparent in 1948 aerial photographs (Figure 7.3.3), as is the encroaching development related to the Hanford Site.

7.3.4 Section 110 Activities

Section 110 of the National Historic Preservation Act requires that federal agencies undertake a program to identify, evaluate, and nominate historic properties and consider the use and reuse of historic buildings or structures. Staff of DOE, Bechtel Hanford, Inc., and Pacific Northwest National Laboratory applied for a "Save America's Treasures" Millennium Grant to fund renovation of the historic B Reactor as

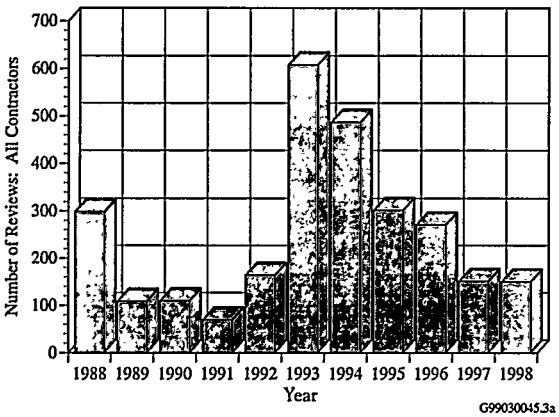


Figure 7.3.1. Cultural Resources Reviews Requested Each Calendar Year

Figure 7.3.2. Historic Sites are Commonly Found During Surveys Conducted at the Hanford Site

a publicly accessible museum and the historic Bruggeman Warehouse as an interpretive center. Agencies are required to maintain and manage historic properties in a way that considers preservation of their values and ensures that preservation-related activities are completed in consultation with other agencies, the tribes, and the general public.

In 1998, management activities conducted to fulfill Section 110 requirements included continual implementation of the programmatic agreement for the built environment (DOE/RL-96-77) and application of the Hanford Site curation strategy for the purpose of identifying, evaluating, and preserving Manhattan Project and Cold War era artifacts

Figure 7.3.3. 1948 Aerial Photograph of the Former 1100 Area Showing Irrigated Farms and Hanford Development

(DOE/RL-97-71). Since the initiation of Section 110 activities on the Hanford Site, 495 buildings/structures have been documented on historic property inventory forms and are on file at the Hanford Cultural Resources Laboratory (Figure 7.3.4).

The Vernita Section 110 Survey, conducted in 1998, resulted in an intensive survey of 744 ha (1,838 acres) of the Hanford Site and documentation of 48 archaeological sites and 19 isolated finds associated with historic farmsteads and prehistoric lithic scatters. This survey represented a cooperative approach to investigations of previously unsurveyed lands on the site. The Yakama Indian Nation, Wanapum Band, Nez Perce Tribe, DOE, Bechtel Hanford, Inc., CH2M Hill, Inc., and Pacific Northwest National Laboratory each contributed staff time to the project.

National Register sites were also monitored in a continuing effort to assess impacts caused by erosion associated with high water levels along the Columbia River.

7.3.4.1 Historic District

During 1998, implementation of the building mitigation project continued to carry out the stipulations of the programmatic agreement (DOE/RL-96-77) and as outlined in the sitewide treatment plan (DOE/RL-97-56, Rev. 1). The plan is stipulated in the programmatic agreement and directs the production of a mitigation document that chronicles the history of the Hanford Site during the Manhattan Project and Cold War periods.

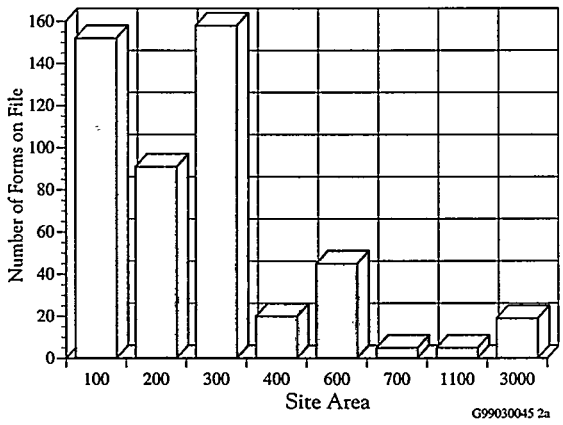


Figure 7.3.4. Hanford Buildings and Structures Documented with a Washington State Historic Property Inventory Form

In 1996, the Hanford Site Manhattan Project and Cold War Era Historic District was established, and 185 buildings, structures, and complexes were identified as contributing properties recommended for mitigation. Subsequent public meetings and staff evaluations resulted in additional properties in the 600, 700, and former 1100 Areas, including the Hanford Site railroad, being identified as contributing properties within the historic district and recommended for mitigation, bringing the total to 190 (Figure 7.3.5). Of the buildings, structures, and complexes recommended for mitigation, 139 have been documented according to mitigation standards identified in the sitewide treatment plan (DOE/RL-97-56, Rev. 1). Four historic properties, including B Reactor, have been documented at the Historic American Engineering Record level, 29 have been documented with Expanded Historic Property Inventory Forms, while standard Historic Property Inventory Forms have been prepared for the remaining 106 buildings and structures.

Approximately 900 buildings and structures have been identified as either contributing properties with no individual documentation requirement (not selected for mitigation) or as noncontributing/exempt buildings and structures and will be documented in a database maintained by DOE. According to the programmatic agreement (DOE/RL-96-77), certain property types such as mobile trailers, modular buildings, storage tanks, towers, wells, and structures with minimal or no visible surface manifestations are exempt from the identification and evaluation requirement.

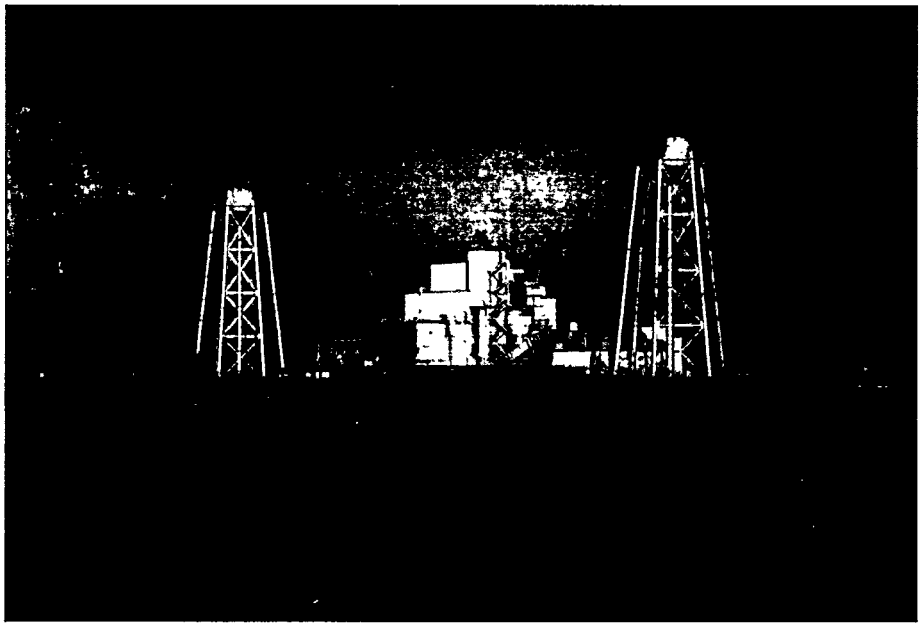


Figure 7.3.5. 105-C Reactor, One of Several Structures Included in the Hanford Site Manhattan Project and Cold War Era Historic District

7.3.4.2 Hanford Curation Strategy

The application of the curation strategy for artifacts and records associated with the Hanford Site Manhattan Project and Cold War Era Historic District continued in 1998. The strategy is stipulated in the programmatic agreement (DOE/RL-96-77), which directs DOE to assess the contents of Hanford's historic buildings and structures prior to the commencement of deactivation, decontamination, or decommissioning activities. The purposes of these assessments are to identify and preserve any artifacts (e.g., control panels, signs, scale models, machinery) that may have interpretive or educational value as exhibits within national, state, or local museums. The assessments are accomplished by conducting walkthroughs of the contributing properties within the historic district by teams made up of cultural resources specialists, historians, archivists/curators, and facility experts. Fifteen assessments/walkthroughs were conducted in 1998, including several facilities in the Plutonium Finishing Plant, DR and F Reactors, and five buildings in the former 1100 Area. Staff of Pacific Northwest National Laboratory and DOE participated in the assessment process that contributed to the transfer of the 1100 Area and the railroad.

In 1998, DOE and the Columbia River Exhibition of History, Science, and Technology assembled a team of historians, curators, cultural resources specialists, and Hanford retirees for the purposes of evaluating the makeup and condition of the Manhattan Project/Cold War era artifact collection and DOE's curation strategy and developing a new collection management policy.

DOE's archaeological collections and associated records continued to be housed in Pacific Northwest National Laboratory's repository during 1998. A draft management plan that deals specifically with archaeological collections was developed in 1998 to guide access to and uses of the collections and to provide guidelines for acquisition and deaccessioning processes.

7.3.4.3 Locke Island Monitoring

Locke Island, in the Hanford Reach of the Columbia River, contains some of the best-preserved evidence of prehistoric village sites extant in the Columbia Basin and is included within the Locke Island National Register Archaeological District. Since 1995, field monitoring of this large island continues. The erosion along the northeastern shoreline of Locke Island and also along the entire Hanford Reach was substantial as a result of sustained high waters during the spring floods of 1997. The monitoring includes the rates of erosion and associated impacts to archaeological features. During 1998, the highest loss recorded at any one monitoring transect was 3.1 m (10.4 ft). A summary of monitoring efforts at Locke Island was published in PNNL-11970 and documents the geologic history of the island, the erosional history of the past few years, and the cultural materials recorded during monitoring trips.

7.3.5 Education and Research

Educational activities associated with the cultural resources program in 1998 included presenting lectures to groups, ranging from public school classrooms to civic groups, colleges, and professional societies. Several symposia were organized throughout the Pacific Northwest region to present DOE's cultural resources management techniques to professional groups and societies. The annual cultural resources forum, sponsored by the DOE Federal Preservation Office, was held at a professional conference in Seattle, Washington, and was attended by staff of Pacific Northwest National Laboratory, Bechtel Hanford, Inc., and DOE. Washington's Archaeology Month provided educational opportunities in the form of tours, lectures, social gatherings, and workshops for residents of the Tri-Cities' area through the efforts of staff and professionals from the East Benton County Historical Society; Columbia River Exhibition of History, Science, and Technology; Confederated Tribes of the Umatilla Reservation; City of Richland; DOE; Pacific Northwest National Laboratory; CH2M Hill, Inc.; and Bechtel Hanford, Inc.

Pacific Northwest National Laboratory participated in the Associated Western Universities, Inc., Northwest program by hosting a student intern involved in field and laboratory work with Hanford Cultural Resources Laboratory staff.

Research activities continued as part of compliance work. Research in the field of archaeology and history focused on archaeological site preservation and protection and documentation of the built environment of the Manhattan Project and Cold War periods.

7.4 Community-Operated Environmental Surveillance Program

R. W. Hanf

Since 1991, citizens living near the Hanford Site have been actively participating in site environmental surveillance activities through the Community-Operated Environmental Surveillance Program. During 1998, nine radiological air sampling stations were operated by local teachers at selected locations around the site perimeter. These stations are located in Basin City, Richland, Pasco, Kennewick, north Franklin County, Othello, Mattawa, Toppenish, and Benton City, Washington (see Figure 4.1.1). Each station consists of equipment for collecting air samples and for monitoring ambient radiation levels. Four of the nine stations also include large, lighted, informational displays that provide real-time meteorological and radiological information as well as general information on station equipment, sample types, and analyses (Figure 7.4.1). The station managers' names and telephone numbers are provided on the four displays for anyone desiring additional information about the purpose of the station, station equipment, or analytical results.

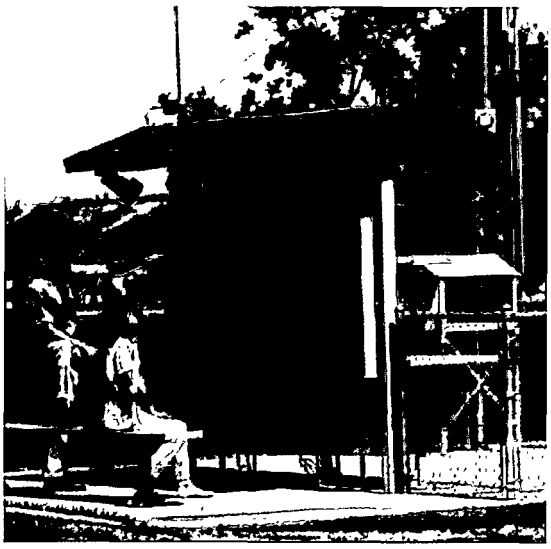


Figure 7.4.1. Community Members See Environmental Surveillance in Action at a Community-Operated Environmental Surveillance Station in Richland

Two teachers from schools located near the stations were selected to operate each station. Each pair of teachers is responsible for collecting a variety of air samples, preparing the samples and collection records for submission to the analytical laboratory, monitoring the performance of station equipment, performing minor station maintenance, and participating in scheduled training. They also serve as spokespersons for the Community-Operated Environmental Surveillance Program and are points of contact for local citizens. Pacific Northwest National Laboratory staff worked closely with the teachers to provide training, maintain station equipment and displays, and coordinate sampling and analytical efforts with other Hanford environmental surveillance activities. Analytical results for samples collected at these stations in 1998 are discussed in Section 4.1, "Air Surveillance." Results of gamma radiation measurements are discussed briefly in Section 4.7, "External Radiation Surveillance."

7.5 Noxious Weed Control Program

R. C. Roos

The noxious weed control program on the Hanford Site was developed in response to federal, state, and local laws requiring eradication or control of noxious weeds. Developed in an effort to satisfy agreements made in the federal interagency memorandum of understanding (1994), the noxious weed control program has been designated as a model for other DOE sites.

The four counties surrounding the Hanford Site (Adams, Benton, Franklin, and Grant Counties) have active noxious weed control programs to protect their important agricultural industries, native ecology, and other interests. The Hanford Site is viewed with great interest and concern as a potential source for invasion of noxious weeds into these counties.

7.5.1 Background

A noxious weed is defined as any plant that, when established, is highly destructive, competitive, or difficult to control by cultural or chemical practices. Typically, noxious weeds are non-native (alien) species that invade and displace native species, reduce habitat for fish and wildlife, and contribute to the extinction of sensitive species.

Priorities for control of noxious weeds on the Hanford Site are based primarily on 1) the potential for a weed species to spread and cause ecological damage, 2) the potential for a weed species to spread into radiological control areas and serve as a biological vector of contamination (take up stabilized radioactive elements and bring them to the surface), 3) the potential for a weed species to cause financial harm to neighboring landowners, and 4) the control effort activities of neighboring counties.

Planning and field control for the noxious weed control program at Hanford is closely coordinated with the Washington State Department of Agriculture and Adams, Benton, Franklin, and Grant Counties. Weed control plans and progress of ongoing field control activities are reviewed in quarterly meetings. Other agencies and groups attending the quarterly meetings and assisting in the technical review of the program include Washington State University Agricultural Extension Service, U.S. Fish and Wildlife Service, Washington Department of Fish and Wildlife, U.S. Bureau of Reclamation, and South Columbia Irrigation District.

7.5.2 1998 Noxious Weed Control Activities

Nine plant species are on a high-priority list for control at the Hanford Site. These species are listed below, with a summary of the 1998 control activities.

Yellow starthistle (*Centaurea solstitialis*) represents the most rapidly expanding weed infestation in the western United States. Hanford is at a critical point in the infestation cycle. Over 800 ha (2,000 acres) of the site have been heavily infested, and a large seed bank has been established in the soil. Many additional acres have scattered starthistle infestation. In the absence of control, starthistle will take over additional acres in the next few years, multiplying the size of the current infestation. Pioneer populations have begun in areas widely scattered from the

main infestation. Pioneer populations expand rapidly in size and serve as seed source for even wider distribution.

Efforts to control yellow starthistle were concentrated in three major areas in 1998: spot treatment of pioneer populations; control and maintenance on roadways; and aerial application of herbicide to a portion of the main infestation, including both the core population and the invasion zone. Approximately 320 ha (800 acres) were aerially treated. This constituted approximately one-third of the area of major infestation. An application is planned for the spring of 1999 to cover the remaining portion of the major infestation. It is expected that, with the aerial applications and a vigorous, timely control campaign in 1999, flowering and seed set for yellow starthistle will be dramatically reduced. Biological control organisms have been released in the major population of yellow starthistle over the past 3 yr. As chemical controls reduce the number and size of populations, it is hoped that biocontrols will assist in reducing seed production in scattered plants and isolated populations.

Rush skeletonweed (*Chondrilla juncea)* is widely scattered across the Hanford Site. Included are four populations of one or more acres where skeletonweed is either the dominant or codominant species. The remainder of the site has plants or small patches scattered many to hundreds of meters (feet) apart. Each of the four large populations of skeletonweed were treated with herbicide in 1998. Additionally, approximately one-fourth of the area known to harbor scattered skeletonweed was surveyed, and the plants were treated with herbicide as they were located.

Rush skeletonweed has a deep, extensive root system and minimal leaf area. These characteristics make it very difficult to control. Although initial chemical control of individual plants have appeared very effective, sprouts from deep roots that were not killed by the herbicide occasionally appear at the surface within 2 to 3 yr. Treated skeletonweed populations are monitored for several years to identify and re-treat sprouts before the plants fully recover from previous control efforts. Biological controls for rush skeletonweed have been introduced at Hanford. Effectiveness of controls vary widely from population to population and from year to year. In 1998, as in most other years, some populations were highly affected by the biocontrols and flowering was eliminated. Other populations were less affected and some were not significantly impacted by the biocontrol agents. On the site, biocontrol agents available for rush skeletonweed rarely, if ever, prove lethal to plants. Nevertheless, under good conditions, individual populations can be prevented from flowering and setting seed during a year.

A number of babysbreath (*Gypsophila paniculata)* control methods were tested, including several chemical combinations; in 1996 and 1997, none proved effective. A new treatment tried in 1998 was very successful in killing the aerial portions of the plant. After positive results in trial plots, this treatment was implemented on approximately 80% of the Hanford population before the plants matured to the point that controls were no longer effective. Flowering and seed set were prevented in virtually 100% of the plants treated. However, mortality of the perennial root was only 10% to 20%. Although the treatments killed only the aerial portions of the plant, by destroying the leaves and stems, photosynthesis was curtailed, preventing plants from storing energy reserves for winter and spring 1999 sprouting.

Plants not killed by the 1998 treatments have been weakened. With consistent, follow-up treatment, it is expected that the plants will ultimately be weakened to the point of death. The babysbreath invasion is relatively small, and control by attrition is a practical alternative.

Three small populations of dalmation toadflax (*Linaria genistifolia ssp. Dalmatica)* have been found on the Hanford Site. All sites were treated in 1998 and will be monitored and treated in the future if resprouting occurs.

Five populations of spotted knapweed (*Centaurea maculosa)* are identified on the Hanford Site. All known individuals were treated in 1998. Follow-up monitoring has identified resprouting from seeds and roots that were not completely killed by initial herbicide treatments. Populations were inconsistent in response to treatment. Treatment of some populations appeared to be 100% successful, while other populations, given the same treatment, showed considerable resprouting. Spotted knapweed is a prolific seed producer and seeds remain viable in the soil for 10 yr or more. All populations will be monitored in subsequent years to check for resprouting and follow-up control.

Diffuse knapweed (*Centaurea diffusa)* has become established in several locations on the Hanford Site and is rapidly invading and expanding in many areas. Invasion of this weed threatens much of the site. 1998 was the first year that an aggressive attempt at control of diffuse knapweed had been made; approximately 20% of the population was treated. Control efforts are expected to increase in 1999. Major populations of diffuse knapweed were sprayed with herbicide to reduce overall seed production. A special effort was made to treat roadways to prevent seed production. Vehicle traffic is a major vector for dispersal of diffuse knapweed. Isolated populations can serve as seed sources to infest large areas and were spot sprayed. By controlling these pioneer populations, relatively large areas can be kept free of knapweed. Diffuse knapweed is a prolific seed producer and seeds remain viable in the soil for 10 yr or more. All populations will be monitored in subsequent years to check for resprouting and to coordinate additional control measures.

Treatment of Russian knapweed (*Acroptilon repens)* was delayed until 1999 to focus attention on the more-invasive species.

Several individual plants of saltcedar (*Tamarix spp.)* are found on the Hanford Site, south and west of the Columbia River. Most remain from ornamental plantings around homes in the early part of this century. These plants are being controlled to prevent seed dispersal to sensitive habitats where uncontrolled populations may establish. A few populations are the result of natural seed dispersal; all plants were treated in 1998.

Saltcedar has an extensive root system that is very difficult to eliminate. Most plants on the Hanford Site have been treated for 3 yr; however, some continue to sprout new growth. Monitoring and annual treatment will continue until saltcedar is eradicated.

Actively reproducing populations of saltcedar have also established on DOE-owned land north and east of the Columbia River. These lands are leased and managed by the U.S. Fish and Wildlife Service and the Washington State Department of Fish and Wildlife. An active program is in place by these agencies, and the associated counties, to control saltcedar on these lands.

Portions of Hanford's riparian areas were monitored for purple loosestrife (*Lythrum salicaria)* in 1998. A single plant was identified and destroyed.

7.6 References

50 CFR 17. U.S. Fish and Wildlife Service, Department of the Interior. "Endangered and Threatened Wildlife and Plants." *Code of Federal Regulations.*

American Indian Religious Freedom Act. 1978. Public Law 95-341, as amended, 92 Stat. 469.

Archaeological Resources Protection Act. 1979. Public Law 96-95, as amended, 93 Stat. 721.

Caplow, F., and K. Beck. 1996. *A Rare Plant Survey of the Hanford Nuclear Reservation (1995) – The Hanford Biodiversity Project.* The Nature Conservancy of Washington, Seattle, Washington.

Caplow F., and K. Beck. 1998. *A Rare Plant Survey of the Hanford Nuclear Reservation (1997) – The Hanford Biodiversity Project.* The Nature Conservancy of Washington, Seattle, Washington.

Dobrowolski, J. P., and K. Ewing. 1990. "Vegetation Dynamics and Environmental Attributes of a Great Basin Valley Exhibiting Widespread Shrub Dieback." In *Symposium on Cheatgrass Invasion, Shrub Die-Off, and Other Aspects of Shrub Biology and Management, Las Vegas, Nevada.* U.S. Department of Agriculture, Intermountain Research Station, Provo, Utah, pp. 103-114.

DOE/RL-94-150. 1994. *Bald Eagle Site Management Plan for the Hanford Site, South-Central Washington.* R. E. Fitzner and S. G. Weiss, Pacific Northwest Laboratory and CH2M Hill for U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-96-77. 1996. *Programmatic Agreement Among the U.S. Department of Energy, Richland Operations Office, the Advisory Council on Historic Preservation, and the Washington State Historic Preservation Office for the Maintenance, Deactivation, Alteration, and Demolition of the Built Environment on the Hanford Site, Washington.* U. S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-97-56, Rev. 1. 1998. *Hanford Site Manhattan Project and Cold War Era Historic District Treatment Plan.* T. E. Marceau, Bechtel Hanford, Inc. for U.S. Department of Energy, Richland Operations Office, Richland, Washington

DOE/RL-97-71. 1997. *Hanford Curation Strategy: Manhattan Project and Cold War Era Artifacts and Records.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Eberhardt, L. E., and L. L. Cadwell. 1983. "Radiotelemetry as an Aid to Environmental Contaminant Evaluation of Mobile Wildlife Species." *Environmental Monitoring and Assessment 5:283-289.*

Endangered Species Act. 1973. Public Laws 93-205 through 100-707, as amended, 87 Stat. 884, 16 USC 1531 et seq.

Gray, R. H., and D. D. Dauble. 1977. "Checklist and Relative Abundance of Fish Species from the Hanford Reach of the Columbia River." *Northwest Science* 51:208-215.

Hall, J. A. (ed.). 1998. *Biodiversity Inventory and Analysis of the Hanford Site: 1997 Annual Report.* The Nature Conservancy of Washington, Seattle, Washington.

Leary, A. W. 1996. *Home Ranges, Core Use Areas, and Dietary Habits of Ferruginous Hawks in South-central Washington.* Master Thesis in Raptor Biology, Boise State University, Boise, Idaho.

MacLellan, J. A., T. P. Lynch, G. A. Rieksts, and R. L. Brodzinski. 1993. "Identification of Environmentally Derived Cesium-137 Burdens in a Worker Population." In *Environmental Health Physics, Proceedings of the 26th Year Topical Meeting of the Health Physics Society, January 24-28, 1993, Coeur d'Alene, Idaho.* R. L. Kathern, D. H. Denham, K. Salmon, and D. Felton (eds.), Research Enterprises, Inc., Richland, Washington, pp. 171-179.

Memorandum of Understanding. 1994. "Memorandum of Understanding for the Establishment of a Federal Interagency Committee for the Management of Noxious and Exotic Weeds." G. Buntrock, S. W. Goodman, R. E. Slater, and T. O'Toole, U.S. Department of Agriculture, U.S. Department of Defense, U.S. Department of Transportation, and U.S. Department of Energy, Washington, D.C.

National Historic Preservation Act. 1966. Public Law 89-665, as amended, 80 Stat. 915-919.

Native American Graves Protection and Repatriation Act. 1990. Public Law 101-601, as amended, 25 USC 3001 et seq.

Nelson, D. L., D. J. Weber, and S. C. Garvin. 1989. "The Possible Role of Plant Disease in the Recent Wildland Shrub Dieoff in Utah." In *Symposium on Cheatgrass Invasion, Shrub Die-Off, and Other Aspects of Shrub Biology and Management, Las Vegas, Nevada.* U.S. Department of Agriculture, Intermountain Research Station, Provo, Utah, pp. 84-90.

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

PNL-7539. 1990. *Methodology Used to Compute Maximum Potential Doses from Ingestion of Edible Plants and Wildlife Found on the Hanford Site.* J. K. Soldat, K. R. Price, and W. H. Rickard, Pacific Northwest Laboratory, Richland, Washington.

PNL-10711. 1995. *Location Analysis and Strontium-90 Concentrations in Deer Antlers on the Hanford Site.* B. L. Tiller, L. E. Eberhardt, and T. M. Poston, Pacific Northwest Laboratory, Richland, Washington.

PNNL-6415, Rev. 10. 1998. *Hanford Site National Environmental Policy Act (NEPA) Characterization.* D. A. Neitzel (ed.), and C. J. Fosmire, R. A. Fowler, S. M. Goodwin, D. W. Harvey, P. L. Hendrickson, D. J. Hoitink, T. M. Poston, A. C. Rohay, P. D. Thorne, and M. K. Wright, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-11518. 1997. *Investigation of Anatomical Anomalies in Hanford Site Mule Deer.* B. L. Tiller, G. E. Dagle, L. L. Cadwell, T. M. Poston, and A. Oganesian, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-11700. 1997. *Characterization of a Sagebrush (Artemisia tridentata subsp. Wyomingensis) Die-Off on the Hanford Site.* A. Cardenas, J. Lewinsohn, C. Auger, J. L. Downs, L. L. Cadwell, and R. Burrows, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-11970. 1998. *Monitoring Bank Erosion at the Locke Island Archaeological National Register District: Summary of 1996/1997 Field Activities.* B. N. Bjornstad, N. A. Cadoret, P. R. Nickens, and M. K. Wright, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-12087. 1999. *Climatological Data Summary 1998 With Historical Data.* D. J. Hoitink, K. W. Burk, and J. V. Ramsdell, Pacific Northwest National Laboratory, Richland, Washington.

Soll, J. A., and C. Soper (eds.). 1996. *Biodiversity Inventory and Analysis of the Hanford Site: 1995 Annual Report.* The Nature Conservancy of Washington, Seattle, Washington.

Stalmaster, M. V., and J. L. Kaiser. 1998. "Effects of Recreational Activity on Wintering Bald Eagles." Wildlife Monographs No. 137. *Journal of Wildlife Management*, Vol. 62, No 2.

Washington Natural Heritage Program. 1997. *Rare Plant Species County List.* Washington State Department of Natural Resources, Olympia, Washington (Available URL: http://www.wa.govdnr/htdocs/fr/nhp/plantco.html)

Washington State Department of Wildlife. 1994. *Species of Special Concern in Washington.* Olympia, Washington.

Weber, D. J., D. L. Nelson, W. M. Hess, and R. B. Bhat. 1989. "Salinity and Moisture Stress in Relation to Dieoff of Wildland Shrubs." In *Symposium on Cheatgrass Invasion, Shrub Die-Off, and Other Aspects of Shrub Biology and Management, Las Vegas, Nevada.* U.S. Department of Agriculture, Intermountain Research Station, Provo, Utah.

WHC-EP-0054. 1992. *Vascular Plants of the Hanford Site.* M. R. Sackschewsky, D. S. Landeen, G. I. Baird, W. H. Rickard, and J. L. Downs, Westinghouse Hanford Company, Richland, Washington.

8.0 Quality Assurance

B. M. Gillespie

Quality assurance and quality control practices encompass all aspects of Hanford Site environmental monitoring and surveillance programs. Samples are collected and analyzed according to documented standard analytical procedures. Analytical data quality is verified by a continuing program of internal laboratory quality control, participation in interlaboratory crosschecks, replicate sampling and analysis, submittal of blind standard samples and blanks, and splitting samples with other laboratories.

Quality assurance/quality control for the Hanford Site environmental monitoring program also includes procedures and protocols for 1) documenting instrument calibrations, 2) conducting program-specific activities in the field, 3) maintaining wells to ensure representative samples are collected, and 4) using dedicated well sampling pumps to avoid crosscontamination.

This section discusses specific measures taken to ensure quality in project management, sample collection, and analytical results.

8.0.1 Environmental Surveillance and Groundwater Monitoring

Comprehensive quality assurance programs, including various quality control practices, are maintained to ensure the quality of data collected through the Surface Environmental Surveillance Project and the Hanford Groundwater Monitoring Project. Quality assurance plans are maintained for all program activities and define the appropriate controls and documentation required by the U.S. Environmental Protection Agency (EPA) and/or the U.S. Department of Energy (DOE) for the project-specific requirements.

8.0.1.1 Project Management Quality Assurance

Site environmental surveillance, groundwater monitoring, and related programs such as processing of thermoluminescent dosimeters and performing dose calculations are subject to an overall quality assurance program. This program implements the requirements of DOE Order 5700.6C.

The site surveillance and groundwater monitoring projects have quality assurance plans that describe the specific quality assurance elements that apply to each project. These plans are approved by a quality assurance organization that conducts surveillances and audits to verify compliance with the plans. Work performed through contracts such as sample analysis must meet the same quality assurance requirements. Potential equipment and services suppliers are audited before service contracts or material purchases that could have a significant impact on quality within the project are approved and awarded.

8.0.1.2 Sample Collection Quality Assurance/Quality Control

Surface Environmental Surveillance Project samples are collected by staff trained to conduct sampling according to approved and documented procedures (PNL-MA-580, Rev. 2). Continuity of all sampling location identities is maintained through careful

documentation. Field duplicates are collected for specific media and a summary of the results is provided in Table 8.0.1. The percentage of acceptable field duplicate results for 1998 was very high at 91%.

Samples for the Hanford Groundwater Monitoring Project are collected by trained staff according to approved and documented procedures (ES-SSPM-001). Chain-of-custody procedures are followed (SW-846) that provide for the use of evidence tape in sealing sample bottles to maintain the integrity of the samples during shipping. Full trip blanks and field duplicates are obtained during field operations. Summaries of the 1998 groundwater field quality control sample results are provided in Appendix D of PNNL-12086. The percentages of acceptable field blank and duplicate results in fiscal year 1998 were very high, 93% for blanks and 95% for field duplicates.

8.0.1.3 Analytical Results Quality Assurance/Quality Control

Routine hazardous and nonhazardous chemical analyses for environmental and groundwater surveillance and monitoring water samples are performed primarily by the Quanterra Laboratory, St. Louis, Missouri. Some routine analyses of hazardous and nonhazardous chemicals for the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) groundwater program were also performed by Recra Environmental, Inc., Lionsville, Pennsylvania. Each laboratory participates in the EPA Water Pollution and Water Supply Performance Evaluation Studies. Each laboratory maintains an internal quality control program that meets the requirements in SW-846, which is audited and reviewed internally and by Pacific Northwest

Table 8.0.1. Summary of Surface Environmental Surveillance Project Field Duplicate Results, 1998

Medium	Radionuclides	Number of Results Reported	Number Within Control Limits[a]
Air filters	Gross alpha	28	24
	Gross beta	28	27
	^{3}H	13	8
	^{7}Be, ^{40}K, ^{60}Co, ^{106}Ru, ^{125}Sb, ^{134}Cs, ^{137}Cs, ^{154}Eu, ^{155}Eu	36	36
Water	Gross alpha	1	0
	Gross beta	1	1
	^{3}H	2	2
	^{7}Be, ^{40}K, ^{60}Co, ^{106}Ru, ^{125}Sb, ^{134}Cs, ^{137}Cs, ^{154}Eu, ^{155}Eu	9	9
	^{90}Sr	3	3
	^{99}Tc	1	1
	^{234}U, ^{235}U, ^{238}U	3	3
Milk	^{40}K	2	0
	^{7}Be, ^{60}Co, ^{106}Ru, ^{125}Sb, ^{134}Cs, ^{137}Cs, ^{154}Eu, ^{155}Eu	16	16

(a) Control limit of ±30% for sample and duplicate results above the detection limit or minimum detectable concentration.

National Laboratory. Pacific Northwest National Laboratory submits additional quality control double-blind spiked samples for analysis.

Routine radiochemical analyses on samples for the Surface Environmental Surveillance Project and the Hanford Groundwater Monitoring Project are performed primarily by Quanterra's Richland, Washington laboratory. Data from Thermo NUtech, Richmond, California were also used in the fiscal year 1998 groundwater evaluations. Each laboratory participates in DOE's Quality Assessment Program, Environmental Measurements Laboratory, New York, and EPA's Laboratory Intercomparison Studies at the National Exposure Research Laboratory, Characterization Research Division, Las Vegas, Nevada. An additional quality control blind spiked sample program is conducted for each project. Each laboratory also maintains an internal quality control program, which is audited and reviewed internally and by Pacific Northwest National Laboratory. Additional information on these quality control efforts is provided in the following sections.

8.0.1.4 DOE and EPA Comparison Studies

Standard water samples are distributed blind to participating laboratories. These samples contain specific organic and inorganic analytes that have concentrations unknown to the analyzing laboratories. After analysis, the results are submitted to the EPA for comparison with known values and results from other participating laboratories. Summaries of the results for 1998 are provided in Table 8.0.2 for the primary laboratory, Quanterra, St. Louis, Missouri. The percentage of EPA-acceptable results is high for the laboratory, indicating acceptable performance.

The DOE Quality Assessment Program and EPA's Laboratory Intercomparison Studies provide standard samples of environmental media (e.g., water, air filters, soil, vegetation) that contain specific amounts of one or more radionuclides that were unknown by the participating laboratory. After analysis, the results are forwarded to DOE or EPA for

Table 8.0.2. Summary of Performance on EPA Water Pollution and Water Supply Studies, 1998

Laboratory	Water Supply Study March 1998 % Acceptable	Water Pollution Study May 1998 % Acceptable	Water Supply Study September 1998 % Acceptable	Water Pollution Study November 1998 % Acceptable
Quanterra Laboratory, St. Louis, Missouri	94[a]	95[b]	91[c]	83[d]

(a) Unacceptable results were for vinyl chloride, 1,1-dichloroethylene, dichloromethane, and pH.
(b) Unacceptable results were for total hardness, nitrate-nitrogen, orthophosphate, and oil and grease.
(c) Unacceptable results were for orthophosphate, bromoform, chlorodibromomethane, total trihalomethane, dichloromethane, and total cyanide.
(d) Unacceptable results were for alkalinity, nitrogen (Kjeldahl), polychlorinated biphenyl in oil 1016/1232, polychlorinated biphenyl in oil 1254, benzene, ethylbenzene, toluene, 1,2-dichlorobenzen, 1,4-dichlorobenzen, and total phenolics.

comparison with known values and results from other laboratories. Both DOE and EPA have established criteria for evaluating the accuracy of results (EPA-600/4-81-004, EML-596, EML-600). Summaries of the 1998 results are provided in Tables 8.0.3 and 8.0.4.

Table 8.0.3. Summary of Performance on DOE Quality Assessment Program Samples, 1998

Medium	Radionuclides	Number of Results Reported for Each Analyte	Number Within Acceptable Control Limits[a]
Quanterra Environmental Services, Richland, Washington			
Air filter particulate	^{54}Mn, ^{60}Co, ^{137}Cs, ^{234}U, ^{238}Pu, ^{238}U, ^{239}Pu, ^{241}Am, gross alpha, gross beta, total uranium	2	2
	^{57}Co, ^{134}Cs, ^{144}Ce, total uranium	1	1
Soil	^{40}K, ^{90}Sr, ^{137}Cs, ^{234}U, ^{238}U, ^{239}Pu, ^{241}Am, total uranium	2	2
	^{208}Tl, ^{210}Pb, ^{212}Bi, ^{212}Pb, ^{214}Bi, ^{214}Pb, ^{226}Ra, ^{228}Ac, ^{228}Th, ^{234}Th, ^{238}Pu, total uranium	1	1
Vegetation	^{241}Am, ^{244}Cm	2	2
	^{90}Sr	1	1
Water	^{3}H, ^{54}Mn, ^{60}Co, ^{90}Sr, ^{137}Cs, ^{234}U, ^{238}Pu, ^{238}U, ^{239}Pu, ^{241}Am, gross alpha, gross beta, total uranium	2	2
	Total uranium	1	1
Thermo NUtech, Richmond, California			
Water	^{55}Fe, ^{234}U, ^{238}U, ^{241}Am, gross alpha, gross beta, total uranium	2	2
	^{54}Mn, ^{60}Co, ^{137}Cs, ^{238}Pu, ^{239}Pu	2	1
	^{3}H, ^{63}Ni	1	1

(a) Control limits are from EML-596 and EML-600.

Table 8.0.4. Summary of Performance on EPA Laboratory Intercomparison Studies Samples, 1998

Medium	Radionuclides	Number of Results Reported for Each Analyte	Number Within Control Limits for Each Analyte[a]
Quanterra Environmental Services, Richland, Washington			
Water	^{3}H, ^{65}Zn, ^{131}I, ^{133}Ba	2	2
	^{89}Sr, ^{90}Sr	3	3
	^{137}Cs	4	4
	^{134}Cs	4	3
	Gross alpha, gross beta, ^{226}Ra, ^{228}Ra, total uranium	5	5
Thermo NUtech, Richmond, California			
Water	^{3}H	1	1
	^{65}Zn, ^{131}I, ^{133}Ba	2	2
	^{60}Co, ^{89}Sr, ^{90}Sr, ^{134}Cs, ^{137}Cs, ^{226}Ra, ^{228}Ra, total uranium	4	4
	Gross alpha, gross beta	5	5

(a) Control limits are from EPA-600/4-81-004.

8.0.1.5 Pacific Northwest National Laboratory Evaluations

In addition to DOE and EPA interlaboratory quality control programs, Pacific Northwest National Laboratory maintains a quality control program to evaluate analytical contractor precision and accuracy and to conduct special intercomparisons. This program includes the use of blind spiked samples. Blind spiked quality control samples and blanks were prepared and submitted to check the accuracy and precision of analyses at Quanterra. In 1998, blind spiked samples were submitted for groundwater (Table 8.0.5) and for air filters, vegetation, soil, and surface water (Table 8.0.6). For all water samples, 72% of nonradiochemistry blind spiked determinations were within control limits (see discussion of results in Appendix D of PNNL-12086). For all media, 92% of Quanterra's radiochemistry blind spiked determinations were within control limits, which indicates acceptable results.

Pacific Northwest National Laboratory also participates in a Quality Assurance Task Force, a program conducted by the Washington State Department of Health. Public and private organizations from Idaho, Oregon, and Washington participate in analyzing the intercomparison samples. Samples from a Hanford Site well were collected for the 1998 intercomparison sample exchange. Ten of the Quality Assurance Task Force participants analyzed the sample.

The intercomparison sample was chosen to be representative of the type of sample that may be

Table 8.0.5. Summary of Hanford Groundwater Monitoring Project Double-Blind Spike Determinations, 1998[a]

Constituent	Number of Results Reported[b]	Number Within Control Limits[c]	Control Limits, %
General Chemical Parameters			
Total organic carbon spiked with potassium phthalate	15	8	±25
Total organic halides spiked with 2,4,6-trichlorophenol	14	11	±25
Total organic halides spiked with carbon tetrachloride, chloroform, and trichloroethene	14	7	Determined each quarter
Ammonia and Anions			
Cyanide	12	3	±25
Fluoride	12	9	±25
Nitrate	12	12	±25
Volatile Organic Compounds			
Carbon tetrachloride	12	10	Determined each quarter
Chloroform	12	8	Determined each quarter
Trichloroethene	12	11	Determined each quarter
Metals			
Chromium	12	12	±20
Radiological Parameters			
Gross alpha (spiked with ^{239}Pu)	12	10	±25
Gross beta (spiked with ^{90}Sr)	13	9	±25
Cobalt-60	12	12	±30
Strontium-90	12	12	±30
Technetium-99	12	12	±30
Iodine-129	12	12	±30
Cesium-137	12	12	±30
Plutonium-239,240	12	10	±30
Tritium	12	12	±30
Uranium	12	12	±30

(a) The Hanford Groundwater Monitoring Project reporting requirements are by fiscal year (October 1 through September 30).
(b) Blind standards were submitted in triplicate or quadruplicate each quarter and compared to actual spike values.
(c) Quality control limits are given in the Hanford Groundwater Monitoring Project's quality assurance plan.

Table 8.0.6. Summary of Surface Environmental Surveillance Project Blind Spiked Determinations, 1998

Medium	Radionuclides	Number of Results Reported	Number Within Control Limits[a]
Air filters	^{54}Mn, ^{60}Co, ^{90}Sr, ^{125}Sb, ^{134}Cs, ^{137}Cs, ^{144}Ce, ^{238}Pu, ^{239}Pu, ^{241}Am	16	11
Soil	^{40}K, ^{90}Sr, ^{137}Cs, ^{234}U, ^{238}U, ^{238}Pu, ^{239}Pu	13	11[b]
Surface water	^{3}H, ^{54}Mn, ^{60}Co, ^{90}Sr, ^{134}Cs, ^{137}Cs, ^{234}U, ^{238}Pu, ^{238}U, ^{239}Pu	18	18
Vegetation	^{40}K, ^{60}Co, ^{90}Sr, ^{137}Cs, ^{238}Pu, ^{239}Pu	9	9

(a) Control limit of ±30%.
(b) Uranium isotopic results were determined using a different preparation method than was used to determine the standard value.

encountered in this region. The sample was analyzed for gross alpha, gross beta, technetium-99, tritium, iodine-129, uranium alpha-emitting isotopes, and total uranium. Table 8.0.7 provides the Pacific Northwest National Laboratory results with respect to the grand mean of the study. The results fell within the ±2 standard error of the mean of the concentration of the other participating laboratories and were acceptable, except for the gross beta results. The sample for gross beta was reanalyzed by the laboratory, but the difference in the results between the grand mean and the laboratory remains unresolved.

8.0.1.6 Laboratory Internal Quality Assurance Programs

The analyzing laboratories are required to maintain an internal quality assurance and control program. Periodically, the laboratories are audited internally for compliance to the quality assurance and control programs. At Quanterra St. Louis, the quality control programs meet the quality assurance and control criteria in SW-846. The laboratories are also required to maintain a system for reviewing and analyzing the results of the quality control samples to detect problems that may arise from contamination, inadequate calibrations, calculation errors, or improper procedure performance. Method detection levels are determined at least annually for each analytical method.

The internal quality control program at Quanterra Richland involves routine calibrations of counting instruments, yield determinations of radiochemical procedures, frequent radiation check sources and background counts, replicate and spiked sample analyses, matrix and reagent blanks, and maintenance of control charts to indicate analytical deficiencies. Available calibration standards traceable to the National Institute of Standards and Technology are used for radiochemical calibrations. Calculation of minimum detectable activities involves the use of factors such as the average counting efficiencies and background for detection instruments, length of time for background and sample counts, sample volumes, radiochemical yields, and a predesignated uncertainty multiplier (EPA 520/1-80-012).

Periodically, inspections of services are performed, which document conformance with contractual requirements of the analytical facility and provide the framework for identifying and resolving

Table 8.0.7. Comparison[a] of the Quality Assurance Task Force Intercomparison Well Water Sample, 1998

Radionuclide	Number of Sample Results	Intercomparison Sample Concentration, pCi/L
Gross Alpha		
Grand mean	21	129 ± 41
PNNL (Quanterra)	2	122 ± 17
Gross Beta		
Grand mean	21	993 ± 311
PNNL (Quanterra)	2	390 ± 3
Tritium		
Grand mean	22	587 ± 86
PNNL (Quanterra)	1	433 ± 223[b]
Technetium-99		
Grand mean	18	1,831 ± 252
PNNL (Quanterra)	2	1,470 ± 113
Iodine-129		
Grand mean	7	1.8 ± 2.1
PNNL (Quanterra)	1	-0.06 ± 0.3[b]
Total Uranium		
Grand mean	13	183 ± 36
PNNL (Quanterra)	1	158 ± 51[b]
Uranium-234		
Grand mean	12	85 ± 10
PNNL (Quanterra)	1	78 ± 12[b]
Uranium-235		
Grand mean	14	5 ± 1
PNNL (Quanterra)	1	3 ± 1[b]
Uranium-238		
Grand mean	14	84 ± 11
PNNL (Quanterra)	1	79 ± 12[b]

(a) Pacific Northwest National Laboratory (PNNL) analyses by Quanterra, Richland, Washington, are compared against grand mean (±2 standard error of the mean) of all participating laboratories.
(b) ±2 sigma total analytical uncertainty.

potential performance problems. Responses to assessment and inspection findings are documented by written communication, and corrective actions are verified by follow-up audits and inspections. Assessments of Quanterra St. Louis and Quanterra Richland were conducted in 1998 by the Hanford Site's Integrated Contractor Assessment Team, consisting of representatives from Bechtel Hanford, Inc., Pacific Northwest National Laboratory, and Waste Management Federal Services of Hanford, Inc. The purpose of the assessment of services was to evaluate the continued capability of the laboratories to analyze and process samples for the Hanford Site as specified in the statement of work between the DOE contractors and the laboratories.

Internal laboratory quality control program data are summarized by the laboratories in monthly or quarterly reports. The results of the quality control sample summary reports and the observations noted by each laboratory indicated an acceptably functioning internal quality control program.

8.0.1.7 Media Audits and Comparisons

Additional audits and comparisons are conducted on several specific types of samples. The Washington State Department of Health routinely cosampled various environmental media and measured external radiation levels at multiple locations during 1998. Media that were cosampled and analyzed for radionuclides included groundwater from 32 wells, water from 11 Columbia River locations along and across the river, water from 5 riverbank springs, water from 2 onsite drinking water locations, sediment from 9 Columbia River sites, surface soil samples from 4 locations, samples from 3 air monitoring stations, thermoluminescent dosimeters from 14 sites, pheasant, deer, and carp. Also cosampled and analyzed for radionuclides were upwind and downwind samples of leafy vegetables, fruit, perennial vegetation, potatoes, and wine. Results will be published in the Washington State Department of Health 1998 annual report.

The U.S. Food and Drug Administration also cosampled and analyzed sugar beets, cabbage, and potatoes for radionuclides from upwind and downwind sampling locations. The data are presented in Table 8.0.8.

Quality control for environmental thermoluminescent dosimeters includes the audit exposure of three environmental thermoluminescent dosimeters per quarter to known values of radiation (between 17 and 28 mR). A summary of 1998 results is shown in Table 8.0.9. On average, the thermoluminescent dosimeter measurements were biased 1.6% higher than the known values.

8.0.2 Effluent Monitoring and Near-Facility Environmental Monitoring

The Effluent Monitoring and Near-Facility Environmental Monitoring Programs are subject to the quality assurance requirements specified in the Hanford Analytical Services Quality Assurance Requirements Document (DOE/RL-96-68). These quality assurance programs comply with DOE Order 5700.6C, using standards from the American Society of Mechanical Engineers (ASME NQA-1-1997 Edition) as their basis. The programs also adhere to the guidelines and objectives in EPA/005/80 and EPA QA/R-5.

The monitoring programs each have a quality assurance project plan describing applicable quality assurance elements. These plans are approved by contractor quality assurance groups, who conduct surveillances and audits to verify compliance with

Table 8.0.8. Comparison of U.S. Food and Drug Administration Cosampling, 1998

Medium	Area[a]	Organization	Potassium-40, pCi/g[b]	Strontium-90, pCi/g[b,c]	Cesium-137, pCi/g[b,c]	Ruthenium-106, pCi/g[c]
Leafy vegetables	Riverview	FDA[d]	3.6 ± 1.1	0.0038 ± 0.0012	<0.01	<0.01
		PNNL[e]	œ4.4 ± 0.49	0.021 ± 0.0042	0.0055 ± 0.0043	<0.038
	Sunnyside	FDA	2.7 ± 0.8	0.0043 ± 0.0011	<0.01	<0.01
		PNNL	1.2 ± 0.31	<0.0045	<0.0081	<0.071
Potatoes	Sunnyside	FDA	6.0 ± 0.8	<0.002	<0.01	<0.01
		PNNL	3.8 ± 0.51	<0.0034	0.011 ± 0.0086	<0.079

(a) Locations are identified in Figure 4.4.1.
(b) ±2 sigma total propagated analytical uncertainty.
(c) < values are ±2 sigma total propagated analytical uncertainties.
(d) FDA = U.S. Food and Drug Administration.
(e) PNNL = Pacific Northwest National Laboratory.

Table 8.0.9. Comparison of Thermoluminescent Dosimeter Results with Known Exposure, 1998

	Quarter/ Exposure	Known Exposure, mR[a]	Determined Exposure, mR[b]	Determined/ Known Exposure, %
1st	February 17, 1998	19 ± 0.70	19.88 ± 1.12	105
	February 17, 1998	24 ± 0.89	23.69 ± 0.25	99
	February 17, 1998	26 ± 0.96	26.66 ± 0.02	103
2nd	May 15, 1998	17 ± 0.63	16.60 ± 0.39	98
	May 15, 1998	20 ± 0.74	19.70 ± 0.15	99
	May 15, 1998	27 ± 1.00	26.89 ± 0.29	100
3rd	August 17, 1998	21 ± 0.78	20.69 ± 0.24	99
	August 17, 1998	25 ± 0.93	25.39 ± 0.80	102
	August 17, 1998	28 ± 1.04	28.99 ± 1.50	104
4th	November 13, 1998	17 ± 0.63	17.51 ± 0.71	103
	November 13, 1998	22 ± 0.81	22.63 ± 0.68	103
	November 13, 1998	26 ± 0.96	27.05 ± 0.73	104

(a) ±2 sigma total propagated analytical uncertainty.
(b) ±2 times the standard deviation.

the plans. Work such as sample analysis performed through contracts must meet the requirements of these plans. Suppliers are audited before the contract selection is made for equipment and services that may significantly impact the quality of a project.

8.0.2.1 Sample Collection Quality Assurance

Samples for the Effluent Monitoring and Near-Facility Environmental Monitoring Programs are collected by staff trained for the task in accordance with approved procedures. Established sampling locations are accurately identified and documented to ensure continuity of data for those sites and are described in DOE/RL-91-50, Rev. 2.

8.0.2.2 Analytical Results Quality Assurance

Samples for the Effluent Monitoring and Near-Facility Environmental Monitoring Programs are analyzed by two different analytical laboratories. The use of these laboratories depends on the Hanford contractor collecting the samples and contract(s) established between the contractor and the analytical laboratory(s). Table 8.0.10 provides a summary of the Hanford Site's analytical laboratories used for effluent monitoring and near-facility monitoring samples.

The quality of the analytical data is ensured by several means. Counting room instruments, for

Table 8.0.10. Hanford Site Laboratories Used by Contractor and Sample Type, 1998

	Effluent Monitoring Samples					Near-Facility Environmental Monitoring Samples		
	Fluor Daniel Hanford, Inc.		Pacific Northwest National Laboratory	Bechtel Hanford, Inc.		Fluor Daniel Hanford, Inc.		
Analytical Laboratory	Air	Water	Air	Air	Water	Air	Water	Other
Waste Sampling and Characterization Facility[a]	X	X		X	X	X	X	X
222-S Analytical Laboratory[a]								X
Quanterra Environmental Services, Richland	X	X	X	X	X			
Analytical Chemistry Laboratory[b]	X	X	X					

(a) Operated by Waste Management Federal Services of Hanford, Inc.
(b) Operated by Pacific Northwest National Laboratory.

instance, are kept within calibration limits through daily checks, the results of which are stored in computer databases. Radiochemical standards used in analyses are regularly measured and the results are reported and tracked. Formal, written, laboratory procedures are used in analyzing samples. Analytical procedural control is ensured through administrative procedures. Chemical technologists at the laboratory qualify to perform analyses through formal classroom and on-the-job training.

The participation of the Hanford Site analytical laboratories in DOE and EPA laboratory intercomparison programs also serves to ensure the quality of the data produced. Laboratory intercomparison program results for 1998 can be found in Tables 8.0.11 through 8.0.14 for the Waste Sampling and Characterization Facility and the 222-S Analytical Laboratory. Laboratory intercomparison results for Quanterra were previously provided in Tables 8.0.3 and 8.0.4.

Table 8.0.11. Waste Sampling and Characterization Facility[a] Performance on DOE Quality Assessment Program Samples, 1998

Medium	Radionuclide	Number of Results Reported	Number Within Control Limits
Air filters	^{54}Mn, ^{57}Co, ^{60}Co, ^{90}Sr, ^{125}Sb, ^{134}Cs, ^{137}Cs, ^{144}Ce, ^{238}Pu, ^{239}Pu, ^{241}Am, total uranium	27	26
Soil	^{40}K, ^{90}Sr, ^{137}Cs, ^{234}U, ^{239}Pu, ^{241}Am	12	11
Vegetation	^{40}K, ^{60}Co, ^{90}Sr, ^{137}Cs, ^{239}Pu, ^{241}Am, ^{244}Cm	14	14
Water	^{3}H, ^{54}Mn, ^{60}Co, ^{90}Sr, ^{134}Cs, ^{137}Cs, ^{238}Pu, ^{239}Pu, ^{241}Am, total uranium	24	23

(a) Onsite laboratory operated by Waste Management Federal Services of Hanford, Inc.

Table 8.0.12. 222-S Analytical Laboratory[a] Performance on DOE Quality Assessment Program Samples, 1998

Medium	Radionuclide	Number of Results Reported	Number Within Control Limits
Air filters	^{54}Mn, ^{57}Co, ^{60}Co, ^{90}Sr, ^{125}Sb, ^{134}Cs, ^{137}Cs, ^{144}Ce, ^{238}Pu, ^{239}Pu, ^{241}Am, total uranium	23	21
Soil	^{40}K, ^{90}Sr, ^{137}Cs	6	4
Vegetation	^{40}K, ^{60}Co, ^{90}Sr, ^{137}Cs, ^{239}Pu, ^{241}Am, ^{244}Cm	14	12
Water	^{3}H, ^{54}Mn, ^{60}Co, ^{90}Sr, ^{134}Cs, ^{137}Cs, ^{238}Pu, ^{239}Pu, ^{241}Am, total uranium	18	15

(a) Onsite "high-level" radiological laboratory operated by Waste Management Federal Services of Hanford, Inc. (Note: these samples are "low-level" environmental activity samples.)

Table 8.0.13. Waste Sampling and Characterization Facility[a] Performance on EPA Laboratory Intercomparison Studies Samples, 1998

Category	Radionuclide	Number of Results Reported	Number Within Control Limits
Gross alpha-beta in water	Gross alpha	4	4
Gamma in water	^{60}Co, ^{65}Zn, ^{133}Ba, ^{134}Cs, ^{137}Cs	10	9
Uranium-radium in water	Uranium (natural)	9	8
Tritium in water	^{3}H	2	1
Blind A[b]	Gross alpha, uranium (natural)	8	7
Blind B[c]	Gross beta, ^{60}Co, ^{134}Cs, ^{137}Cs	8	7

(a) Onsite laboratory operated by Waste Management Federal Services of Hanford, Inc.
(b) Blind A samples are liquid samples with unknown quantities of alpha emitters analyzed for gross alpha and each radionuclide component.
(c) Blind B samples are liquid samples with unknown quantities of beta emitters analyzed for gross beta and each radionuclide component.

Table 8.0.14. 222-S Analytical Laboratory[a] Performance on EPA Laboratory Intercomparison Studies Samples, 1998

Category	Radionuclide	Number of Results Reported	Number Within Control Limits
Gamma in water	^{60}Co, ^{65}Zn, ^{133}Ba, ^{134}Cs, ^{137}Cs	10	8
Gross alpha-beta in water	Gross alpha	1	1
Uranium-radium in water	Uranium (natural)	3	3
Tritium in water	^{3}H	2	2
Blind A[b]	Gross alpha, uranium (natural)	3	3
Blind B[c]	^{60}Co, ^{134}Cs, ^{137}Cs	3	3

(a) Onsite "high-level" radiological laboratory operated by Waste Management Federal Services of Hanford, Inc. (Note: these samples are "low-level" environmental activity samples.)
(b) Blind A samples are liquid samples with unknown quantities of alpha emitters analyzed for gross alpha and each radionuclide component.
(c) Blind B samples are liquid samples with unknown quantities of beta emitters analyzed for gross beta and each radionuclide component.

8.0.3 References

ASME-NQA-1-1997 Edition. 1997. *Quality Assurance Requirements for Nuclear Facility Applications.* American Society of Mechanical Engineers, New York.

Comprehensive Environmental Response, Compensation, and Liability Act. 1980. Public Law 96-150, as amended, 94 Stat. 2767, 42 USC 9601 et seq.

DOE Order 5700.6C. "Quality Assurance."

DOE/RL-91-50, Rev. 2. 1997. *Environmental Monitoring Plan, United States Department of Energy Richland Operations Office.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-96-68. 1996. *Hanford Analytical Services Quality Assurance Requirements Document.* U.S. Department of Energy, Richland Operations Office, Richland, Washington.

EML-596. 1998. *Semi-Annual Report of the Department of Energy, Office of Environmental Management, Quality Assessment Program.* P. D. Greenlaw and S. K. Minick, Environmental Measurements Laboratory, U.S. Department of Energy, New York.

EML-600. 1998. *Semi-Annual Report of the Department of Energy, Office of Environmental Management, Quality Assessment Program.* P. D. Greenlaw, Environmental Measurements Laboratory, U.S. Department of Energy, New York.

EPA/005/80. 1980. *Interim Guidelines and Specifications for Preparing Quality Assurance Project Plans.* U.S. Environmental Protection Agency, Washington, D.C.

EPA QA/R-5. 1994. *Requirements for Quality Assurance Project Plans for Environmental Data Operations.* U.S. Environmental Protection Agency, Washington, D.C.

EPA 520/1-80-012. 1980. *Upgrading Environmental Radiation Data: Health Physics Society Committee Report HPSR-1 (1980).* U.S. Environmental Protection Agency, Washington, D.C.

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

ES-SSPM-001. 1998. *Sampling Services Procedures Manual.* Waste Management Federal Services, Inc., Northwest Operations, Richland, Washington.

PNL-MA-580, Rev. 2. 1996. *Surface Environmental Surveillance Procedures Manual.* R. W. Hanf and R. L. Dirkes (eds.), Pacific Northwest National Laboratory, Richland, Washington.

PNNL-12086. 1999. *Hanford Site Groundwater Monitoring for Fiscal Year 1998.* M. J. Hartman (ed.). Pacific Northwest National Laboratory, Richland, Washington.

SW-846. 1986. *Test Methods for Evaluating Solid Waste: Physical/Chemical Methods, Third Edition.* U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington, D.C.

Appendix A

Additional Monitoring Results for 1998

G. W. Patton and T. M. Poston

This appendix contains additional information on 1998 monitoring results, supplementing the data summarized in the main body of the report. More detailed information is available in PNNL-12088, APP. 1.

Table A.1. Radionuclide Activities in Columbia River Water at Priest Rapids Dam, 1998 Compared to Previous 5 Years

Radionuclide[a]		1998 No. of Samples	1998 Activity,[b] pCi/L Maximum	1998 Activity,[b] pCi/L Average	1993-1997 No. of Samples	1993-1997 Activity,[b] pCi/L Maximum	1993-1997 Activity,[b] pCi/L Average	Ambient Surface Water Quality Standard, pCi/L
Composite System								
Tritium		10	62[c] ± 12	36 ± 7.2	60	51 ± 9.4	34 ± 1.7	20,000[d]
Alpha (gross)		12	1.6 ± 0.83	0.49 ± 0.26	60	1.2 ± 0.86	0.41 ± 0.088	15[e,f]
Beryllium-7		12	17 ± 15	0.74 ± 5.0	60	18 ± 15	1.6 ± 2.0	6,000[d]
Beta (gross)		12	2.3 ± 1.5	1.1 ± 0.36	60	3.5 ± 2.4	0.93 ± 0.30	50[e,f]
Potassium-40		12	120 ± 58	38 ± 28	60	280 ± 54	48 ± 12	--[g]
Cobalt-60		12	3.0 ± 1.9	0.21 ± 0.76	60	1.6 ± 0.99	0.016 ± 0.22	100[d]
Strontium-90		12	0.11 ± 0.038	0.080 ± 0.0076	60	0.14 ± 0.0049	0.086 ± 0.0060	8[e,f]
Technetium-99		12	0.21 ± 0.49	0.026 ± 0.076	60	1.6 ± 0.69	0.026 ± 0.072	900[d]
Iodine-129[h]		3	0.000020 ± 0.0000027	0.000015 ± 0.0000094	21	0.00013 ± 0.000013	0.000014 ± 0.000012	1[d]
Ruthenium-106		12	20 ± 22	6.5 ± 4.4	43	12 ± 22	-0.70 ± 2.2	30[d]
Antimony-125		12	4.3 ± 6.2	-0.74 ± 1.5	43	6.4 ± 5.6	-0.50 ± 0.64	300[d]
Cesium-134		12	2.6 ± 2.1	0.075 ± 0.68	60	2.8 ± 2.4	0.030 ± 0.22	20,000[d]
Cesium-137		12	3.5 ± 2.4	0.64 ± 0.76	60	2.0 ± 2.3	0.15 ± 0.18	200[d]
Europium-154		12	5.5 ± 6.6	-1.2 ± 2.2	60	5.2 ± 2.9	0.035 ± 0.64	200[d]
Europium-155		12	4.8 ± 3.9	-0.52 ± 1.5	60	5.8 ± 4.7	0.097 ± 0.46	600[d]
Uranium-234		12	0.38 ± 0.068	0.26 ± 0.030	60	0.44 ± 0.13	0.24 ± 0.014	--
Uranium-235		12	0.024 ± 0.014	0.0082 ± 0.0048	60	0.032 ± 0.039	0.0091 ± 0.0020	--
Uranium-238		12	0.32 ± 0.062	0.22 ± 0.028	60	0.35 ± 0.11	0.19 ± 0.012	--
Uranium (total)		12	0.71 ± 0.14	0.48 ± 0.056	60	0.83 ± 0.28	0.43 ± 0.026	--
Continuous System								
Plutonium-230,240	P	4	0.00028 ± 0.00011	0.000099 ± 0.00012	21	0.00015 ± 0.000098	0.000036 ± 0.000016	--
	D	4	0.000040 ± 0.000060	0.000015 ± 0.000018	21	0.00063 ± 0.00021	0.000055 ± 0.000064	--

(a) Radionuclides measured using the continuous system show the particulate (P) and dissolved (D) fractions separately. Other radionuclides are based on unfiltered samples collected by the composite system (see Section 4.2, "Surface Water and Sediment Surveillance").
(b) Maximum values are ± total propagated analytical uncertainty (2 sigma). Averages are ±2 standard error of the calculated mean.
(c) Excludes one result of 200 ± 22 pCi/L.
(d) WAC 173-201A-050 and EPA-570/9-76-003.
(e) WAC 246-290.
(f) 40 CFR 141.
(g) Dashes indicate no concentration guides available.
(h) From 1993 through 1995, iodine-129 activities were obtained from the dissolved fraction of the continuous system.

Table A.2. Radionuclide Activities in Columbia River Water at the Richland Pumphouse, 1998 Compared to Previous 5 Years

Radionuclide[a]	1998 No. of Samples	1998 Activity,[b] pCi/L Maximum	1998 Activity,[b] pCi/L Average	1993-1997 No. of Samples	1993-1997 Activity,[b] pCi/L Maximum	1993-1997 Activity,[b] pCi/L Average	Ambient Surface Water Quality Standard, pCi/L
Composite System							
Tritium	10	150 ± 18	76 ± 21	60	160 ± 19	79 ± 7.4	20,000[c]
Alpha (gross)	12	0.86 ± 0.61	0.47 ± 0.12	60	2.2 ± 1.1	0.60 ± 0.12	15[c,d]
Beryllium-7	12	26 ± 26	1.4 ± 7.0	60	20 ± 12	1.5 ± 2.0	6,000[c]
Beta (gross)	12	2.2 ± 2.0	0.68 ± 0.50	60	3.4 ± 1.7	1.0 ± 0.24	50[c,d]
Potassium-40	12	200 ± 52	67 ± 42	60	240 ± 61	48 ± 9.4	--[f]
Cobalt-60	12	4.1 ± 2.2	-0.44 ± 1.1	60	1.7 ± 2.1	0.059 ± 0.22	100[e]
Strontium-90	12	0.098 ± 0.036	0.077 ± 0.0092	60	0.30 ± 0.081	0.088 ± 0.0092	8[c,d]
Technetium-99	12	0.53 ± 0.52	0.12 ± 0.12	60	0.31 ± 0.56	0.019 ± 0.040	900[e]
Iodine-129[g]	4	0.00016 ± 0.000020	0.00012 ± 0.000042	18	0.00016 ± 0.000013	0.00010 ± 0.000020	1[e]
Ruthenium-106	12	19 ± 20	1.0 ± 6.2	43	13 ± 18	0.46 ± 2.2	30[e]
Antimony-125	12	5.0 ± 5.5	1.7 ± 1.4	43	6.0 ± 4.7	0.17 ± 0.56	300[e]
Cesium-134	12	1.4 ± 2.2	-0.88 ± 1.1	60	1.1 ± 0.89	-0.10 ± 0.18	20,000[e]
Cesium-137	12	3.1 ± 2.2	0.23 ± 0.82	60	3.7 ± 2.1	0.34 ± 0.20	200[e]
Europium-154	12	8.8 ± 5.4	1.4 ± 2.4	60	4.1 ± 3.4	-0.20 ± 0.50	200[e]
Europium-155	12	3.4 ± 4.2	1.2 ± 0.84	60	3.4 ± 4.6	-0.020 ± 0.40	600[e]
Uranium-234	12	0.37 ± 0.070	0.29 ± 0.024	60	0.50 ± 0.13	0.27 ± 0.020	--
Uranium-235	12	0.024 ± 0.015	0.010 ± 0.0048	60	0.048 ± 0.022	0.0098 ± 0.0022	--
Uranium-238	12	0.30 ± 0.060	0.23 ± 0.026	60	0.53 ± 0.14	0.22 ± 0.0022	--
Uranium (total)	12	0.68 ± 0.14	0.53 ± 0.040	60	1.0 ± 0.30	0.50 ± 0.036	--
Continuous System							
Plutonium-239,240 P	4	0.00017 ± 0.000087	0.000066 ± 0.000068	18	0.00015 ± 0.000051	0.000034 ± 0.000017	--
D	4	0.000052 ± 0.000058	0.000038 ± 0.000011	18	0.00020 ± 0.00012	0.000050 ± 0.000024	--

(a) Radionuclides measured using the continuous system show the particulate (P) and dissolved (D) fractions separately. Other radionuclides are based on unfiltered samples collected by the composite system (see Section 4.2, "Surface Water and Sediment Surveillance").
(b) Maximum values are ± total propagated analytical uncertainty (2 sigma). Averages are ±2 standard error of the calculated mean.
(c) 40 CFR 141.
(d) WAC 246-290.
(e) WAC 173-201A-050 and EPA-570/9-76-003.
(f) Dashes indicate no concentration guides available.
(g) From 1993 through 1995, iodine-129 activities were obtained from the dissolved fraction of the continuous system.

Table A.3. Radionuclide Activities Measured in Columbia River Water Along Transects of the Hanford Reach, 1998

Transect/Radionuclide	No. of Samples	Activity,[a] pCi/L Maximum	Minimum	Mean
Vernita Bridge				
Tritium	12	85 ± 13	26 ± 7.9	49 ± 11
Strontium-90	16	0.15 ± 0.052	0.045 ± 0.029	0.080 ± 0.011
Uranium (total)	16	0.60 ± 0.15	0.33 ± 0.083	0.44 ± 0.034
100-N Area				
Tritium	7	61 ± 12	33 ± 10	45 ± 5.4
Strontium-90	10	0.088 ± 0.034	0.053 ± 0.042	0.072 ± 0.0068
Uranium (total)	10	0.45 ± 0.11	0.34 ± 0.083	0.40 ± 0.024
100-F Area				
Tritium	10	96 ± 14	39 ± 9.7	52 ± 11
Strontium-90	10	0.11 ± 0.037	0.020 ± 0.021	0.076 ± 0.015
Uranium (total)	10	0.46 ± 0.099	0.33 ± 0.084	0.40 ± 0.026
Old Hanford Townsite				
Tritium	10	4,100 ± 350	53 ± 10	730 ± 910
Strontium-90	10	0.086 ± 0.034	0.055 ± 0.027	0.072 ± 0.0070
Uranium (total)	10	0.58 ± 0.12	0.30 ± 0.086	0.42 ± 0.050
300 Area				
Tritium	10	63 ± 11	34 ± 8.4	42 ± 5.6
Strontium-90	10	0.11 ± 0.053	-0.22 ± 0.33	0.046 ± 0.060
Uranium (total)	8	0.77 ± 0.25	0.26 ± 0.15	0.43 ± 0.11
Richland Pumphouse				
Tritium	30	99 ± 13	23 ± 7.6	52 ± 3.7
Strontium-90	42	0.11 ± 0.056	0.042 ± 0.030	0.074 ± 0.0050
Uranium (total)	42	0.88 ± 0.16	0.34 ± 0.094	0.50 ± 0.034

(a) Maximum and minimum values are ± total propagated analytical uncertainty (2 sigma). Mean values are ±2 standard error of the mean.

Table A.4. Selected U.S. Geological Survey Columbia River Water Quality Data,[a] 1998

Analysis	Units	Vernita Bridge (upstream) No. of Samples	Median	Maximum	Minimum	Richland Pumphouse (downstream) No. of Samples	Median	Maximum	Minimum	Washington Ambient Surface Water Quality Standard[b]
Temperature	°C	10	12	20	4.0	4	11	20	5.5	20 (maximum)
Dissolved oxygen	mg/L	10	12	13	9.3	4	11	13	9.1	8 (minimum)
Turbidity	NTU[c]	10	0.50	1.6	0.30	4	0.8	1.8	0.6	5 + background
pH	pH units	10	8.0	8.1	7.8	4	7.9	8.1	7.8	6.5 - 8.5
Suspended solids, 105°C (221°F)	mg/L	10	2.0	4	<0.5	4	4.0	10	2.0	--[d]
Dissolved solids, 180°C (356°F)	mg/L	10	81	97	72	4	84	92	80	--
Specific conductance	µS/cm	10	140	150	110	4	150	150	130	--
Total hardness, as $CaCO_3$	mg/L	10	63	69	50	4	64	71	59	--
Phosphorus, total	mg/L	10	<0.05	0.02	<0.01	4	<0.03	0.01	<0.01	--
Chromium, dissolved	µg/L	8	<1	2	<1	4	<1	<1	<1	--
Dissolved organic carbon	mg/L	10	1.3	2.1	1.1	4	1.2	1.8	1.1	--
Iron, dissolved	µg/L	10	<10	24	<10	4	<10	<10	<10	--
Ammonia, dissolved, as N	mg/L	10	<0.002	0.002	<0.002	4	<0.02	0.06	<0.02	--
Nitrogen, total Kjeldahl, as N	mg/L	10	<0.1	0.2	<0.1	4	<0.1	0.1	<0.1	--
Nitrite + nitrate, dissolved, as N	mg/L	10	0.092	0.17	0.033	4	0.14	0.17	0.090	--

(a) Provisional data from U.S. Geological Survey National Stream Quality Accounting Network (NASQAN), subject to revision.
(b) From WAC 173-201A.
(c) NTU = nephelometric turbidity units.
(d) Dashes indicate no standard available.

Table A.5. Radionuclide Activities in Sediments from the Columbia and Snake Rivers and from Columbia River Shoreline Springs, 1998 Compared to Previous 5 Years

Location	Radionuclide	1998 No. of Samples	1998 Activity, pCi/g Median[a]	1998 Activity, pCi/g Maximum[b]	1993-1997 No. of Samples	1993-1997 Activity, pCi/g Median[a]	1993-1997 Activity, pCi/g Maximum[b]
River Sediment							
100-F Slough	Cobalt-60	1		0.023 ± 0.010	6	0.026	0.033 ± 0.011
	Cesium-137	1		0.36 ± 0.042	6	0.43	0.49 ± 0.054
	Europium-155	1		0.028 ± 0.030	6	0.028	0.061 ± 0.033
	Plutonium-239,240	1		0.0017 ± 0.00038	6	0.0018	0.0024 ± 0.00082
	Strontium-90	1		0.0052 ± 0.0037	6	0.0034	0.013 ± 0.0052
	Uranium-235	1		0.0022 ± 0.0052	6	0.022	0.064 ± 0.068
	Uranium-238	1		0.10 ± 0.022	6	0.94	1.4 ± 0.41
Hanford Slough	Cobalt-60	1		0.011 ± 0.011	6	0.14	0.32 ± 0.046
	Cesium-137	1		0.13 ± 0.021	6	0.41	0.59 ± 0.068
	Europium-155	1		0.067 ± 0.036	6	0.080	0.16 ± 0.075
	Plutonium-239,240	1		0.0014 ± 0.00039	6	0.0047	0.0076 ± 0.0014
	Strontium-90	1		0.0036 ± 0.0036	6	0.0084	0.017 ± 0.0052
	Uranium-235	1		0.0090 ± 0.0068	6	0.064	0.24 ± 0.16
	Uranium-238	1		0.27 ± 0.044	6	1.2	2.4 ± 0.88
McNary Dam	Cobalt-60	6	0.048	0.063 ± 0.035	24	0.058	0.26 ± 0.033
	Cesium-137	6	0.36	0.81 ± 0.090	24	0.46	1.0 ± 0.11
	Europium-155	6	0.056	0.085 ± 0.058	24	0.055	0.13 ± 0.069
	Plutonium-239,240	6	0.0084	0.013 ± 0.0019	24	0.0081	0.014 ± 0.0026
	Strontium-90	6	0.020	0.039 ± 0.010	24	0.024	0.049 ± 0.011
	Uranium-235	6	0.028	0.030 ± 0.011	24	0.066	0.21 ± 0.10
	Uranium-238	6	0.62	0.67 ± 0.086	24	1.5	2.3 ± 0.71
Priest Rapids Dam	Cobalt-60	6	-0.0011	0.026 ± 0.015	23	0.0020	0.038 ± 0.049
	Cesium-137	6	0.32	0.52 ± 0.065	23	0.41	1.0 ± 0.14
	Europium-155	6	0.061	0.076 ± 0.043	23	0.049	0.10 ± 0.050
	Plutonium-239,240	6	0.0081	0.013 ± 0.0032	23	0.0082	0.018 ± 0.0032
	Strontium-90	6	0.015	0.019 ± 0.0074	23	0.014	0.025 ± 0.0068
	Uranium-235	6	0.016	0.028 ± 0.012	23	0.079	0.32 ± 0.17
	Uranium-238	6	0.44	0.70 ± 0.087	23	0.99	2.2 ± 0.71

Table A.5. (contd)

Location	Radionuclide	1998 No. of Samples	1998 Activity, pCi/g Median[a]	1998 Activity, pCi/g Maximum[b]	1993-1997 No. of Samples	1993-1997 Activity, pCi/g Median[a]	1993-1997 Activity, pCi/g Maximum[b]
Ice Harbor Dam (Snake River)	Cobalt-60	3	-0.016	-0.0022 ± 0.014	0		
	Cesium-137	3	0.23	0.29 ± 0.044	0		
	Europium-155	3	0.079	0.081 ± 0.044	0		
	Plutonium-239,240	3	0.0085	0.0087 ± 0.0019	0		
	Strontium-90	3	0.018	0.019 ± 0.0095	0		
	Uranium-235	3	0.018	0.027 ± 0.011	0		
	Uranium-238	3	0.66	0.73 ± 0.090	0		
Richland	Cobalt-60	1		0.012 ± 0.013	5	0.051	0.074 ± 0.019
	Cesium-137	1		0.086 ± 0.018	5	0.30	0.34 ± 0.042
	Europium-155	1		0.028 ± 0.037	5	0.059	0.066 ± 0.034
	Plutonium-239,240	1		0.0014 ± 0.00061	5	0.0020	0.0034 ± 0.00073
	Strontium-90	1		0.0041 ± 0.0042	5	0.0027	0.0050 ± 0.0035
	Uranium-235	1		0.014 ± 0.0080	5	0.053	0.14 ± 0.080
	Uranium-238	1		0.24 ± 0.039	5	1.1	2.1 ± 0.54
White Bluffs Slough	Cobalt-60	1		0.11 ± 0.024	6	0.081	0.20 ± 0.031
	Cesium-137	1		0.60 ± 0.067	6	0.80	0.97 ± 0.11
	Europium-155	1		0.10 ± 0.034	6	0.051	0.065 ± 0.034
	Plutonium-239,240	1		0.0050 ± 0.0012	6	0.0040	0.0073 ± 0.0017
	Strontium-90	1		0.0082 ± 0.0049	6	0.0055	0.017 ± 0.0055
	Uranium-235	1		0.0087 ± 0.0063	6	0.019	0.16 ± 0.12
	Uranium-238	1		0.26 ± 0.041	6	1.2	1.9 ± 0.52
Riverbank Springs Sediment							
100-B Spring	Cobalt-60	1		0.021 ± 0.015	3	0.029	0.051 ± 0.024
	Cesium-137	1		0.10 ± 0.023	3	0.079	0.095 ± 0.015
	Europium-155	1		0.11 ± 0.072	3	0.065	0.074 ± 0.036
	Strontium-90	1		0.0041 ± 0.0083	3	0.0027	0.0041 ± 0.0050
	Uranium-235	1		0.029 ± 0.016	3	0.10	0.20 ± 0.10
	Uranium-238	1		0.26 ± 0.055	3	1.2	1.2 ± 0.38

Table A.5. (contd)

Location	Radionuclide	1998 No. of Samples	1998 Activity, pCi/g Median[a]	1998 Activity, pCi/g Maximum[b]	1993-1997 No. of Samples	1993-1997 Activity, pCi/g Median[a]	1993-1997 Activity, pCi/g Maximum[b]
100-F Spring	Cobalt-60	1		0.016 ± 0.0071	3	0.040	0.044 ± 0.024
	Cesium-137	1		0.14 ± 0.019	3	0.19	0.32 ± 0.040
	Europium-155	1		0.024 ± 0.025	3	0.037	0.055 ± 0.031
	Strontium-90	1		0.0041 ± 0.0071	3	0.0087	0.0096 ± 0.010
	Uranium-235	1		0.022 ± 0.0095	3	0.16	0.17 ± 0.13
	Uranium-238	1		0.43 ± 0.059	3	1.2	1.4 ± 0.54
100-K Spring	Cobalt-60	(c)			2	0.011	0.015 ± 0.021
	Cesium-137	(c)			2	0.17	0.19 ± 0.046
	Europium-155	(c)			2	0.084	0.13 ± 0.066
	Strontium-90	(c)			2	0.0049	0.0085 ± 0.0048
	Uranium-235	(c)			2	0.17	0.20 ± 0.14
	Uranium-238	(c)			2	1.2	1.5 ± 0.54
300 Area Spring	Cobalt-60	(d)			5	0.013	0.016 ± 0.0076
	Cesium-137	(d)			5	0.074	0.15 ± 0.026
	Europium-155	(d)			5	0.045	0.13 ± 0.14
	Strontium-90	(d)			5	0.0073	0.012 ± 0.0060
	Uranium-235	(d)			5	0.12	0.41 ± 0.16
	Uranium-238	(d)			5	3.2	5.2 ± 1.1
Hanford Spring	Cobalt-60	(c)			5	0.059	0.090 ± 0.021
	Cesium-137	(c)			5	0.25	0.29 ± 0.032
	Europium-155	(c)			5	0.062	0.068 ± 0.034
	Strontium-90	(c)			5	0.0068	0.0086 ± 0.011
	Uranium-235	(c)			5	0.023	0.23 ± 0.14
	Uranium-238	(c)			5	1.3	1.9 ± 0.54

(a) Median values are not provided when only one sample analyzed.
(b) Values are ± total propagated analytical uncertainty (2 sigma).
(c) Sediment was not available at the 1998 spring location.
(d) Sample was collected but not analyzed.

Table A.6. Median Metal Concentrations (mg/kg dry wt.) in Columbia and Snake River Sediments, 1998

Metal	Priest Rapids Dam	Hanford Reach[a]	McNary Dam	Ice Harbor Dam (Snake River)	Riverbank Springs[b]
Antimony	0.63	0.50	0.70	0.67	0.77
Arsenic	3.8	3.6	6.9	7.4	6.8
Beryllium	0.84	1.2	1.2	1.4	2.9
Cadmium	5.8	0.86	1.8	0.19	1.6
Chromium	55	46	53	46	82
Copper	38	25	33	30	22
Lead	31	32	22	15	31
Mercury	0.12	0.057	0.10	0.043	0.014
Nickel	33	20	28	22	23
Selenium	0.52	0.47	0.42	0.45	<1.6
Silver	0.10	0.074	0.13	0.072	0.077
Thalium	1.4	0.79	0.80	0.41	0.88
Zinc	460	260	210	120	260

(a) 100-F Slough, Hanford Slough, Richland, and White Bluffs Slough.
(b) 100-B and 100-F Area.

Table A.7. Radionuclide Activities Measured in Riverbank Springs Water, 1998 Compared to Previous 5 Years

Location/Radionuclide	1998 No. of Samples	1998 Activity,[a] pCi/L Maximum	1993-1997 No. of Samples	1993-1997 Activity,[a] pCi/L Maximum	1993-1997 Activity,[a] pCi/L Median	Washington State Ambient Surface Water Quality Standard,[b] pCi/L
100-B Spring						
Alpha (gross)	1	1.6 ± 1.7	7	3.5 ± 1.8	1.4	15
Beta (gross)	1	7.6 ± 2.7	7	38 ± 4.6	10	50
Strontium-90	1	-0.022 ± 0.067	7	0.072 ± 0.11	0.023	8
Technetium-99	1	10 ± 1.4	7	25 ± 3.2	10	900[c]
Tritium	1	14,000 ± 1,100	7	24,000 ± 1,800	14,000	20,000
100-D Spring						
Alpha (gross)	1	0.98 ± 1.4	8	2.9 ± 1.9	1.1	15
Beta (gross)	1	14 ± 3.6	8	21 ± 3.3	9.1	50
Strontium-90	1	5.3 ± 1.2	8	9.4 ± 1.8	4.1	8
Tritium	1	4,800 ± 450	8	12,000 ± 1,000	6,200	20,000
100-F Spring						
Alpha (gross)	1	4.0 ± 2.0	4	41 ± 18	3.4	15
Beta (gross)	1	5.7 ± 2.5	4	65 ± 11	2.9	50
Strontium-90	1	0.012 ± 0.024	4	0.099 ± 0.091	0.064	8
Tritium	1	740 ± 170	4	1,800 ± 240	1,400	20,000
Uranium (total)	1	3.1 ± 0.40	4	9.2 ± 1.2	4.6	--[d]
100-H Spring						
Alpha (gross)	1	10 ± 3.7	6	4.6 ± 1.9	4.1	15
Beta (gross)	1	72 ± 8.6	6	69 ± 7.0	55	50
Strontium-90	1	[c]	6	25 ± 4.5	17	8
Technetium-99	1	77 ± 8.7	6	140 ± 15	87	900
Tritium	1	2,300 ± 270	6	1,200 ± 240	1,100	20,000
Uranium (total)	1	9.3 ± 1.0	6	8.4 ± 1.2	6.1	--
100-K Spring						
Alpha (gross)	1	3.2 ± 1.8	4	1.6 ± 1.2	0.98	15
Beta (gross)	1	5.0 ± 2.4	4	3.6 ± 2.5	2.3	50
Strontium-90	1	0.035 ± 0.016	4	0.59 ± 0.13	0.041	8
Tritium	1	12,000 ± 970	4	20,000 ± 1,500	18,000	20,000

Table A.7. (contd)

Location/Radionuclide	1998 No. of Samples	1998 Activity,[a] pCi/L Maximum	1993-1997 No. of Samples	1993-1997 Activity,[a] pCi/L Maximum	1993-1997 Activity,[a] pCi/L Median	Washington State Ambient Surface Water Quality Standard,[b] pCi/L
100-N Spring (8-13)[f]						
Alpha (gross)	1	1.3 ± 1.3	6	8.1 ± 3.3	1.1	15
Beta (gross)	1	2.3 ± 2.1	6	8.8 ± 2.3	4.0	50
Strontium-90	1	[e]	6	0.59 ± 0.3	0.066	8
Tritium	1	24,000 ± 1,900	6	31,000 ± 2,400	24,000	20,000
300 Area Spring						
Alpha (gross)	1	56 ± 10	7	110 ± 21	45	15
Beta (gross)	1	21 ± 4.1	7	21 ± 3.3	9.6	50
Iodine-129	1	0.0055 ± 0.00058	4	0.0049 ± 0.00063	0.0033	1
Technetium-99	1	13 ± 1.7	7	14 ± 1.9	8.8	900[c]
Tritium	1	9,600 ± 800	7	12,000 ± 940	9,800	20,000
Uranium (total)	1	58 ± 6.1	7	110 ± 13	61	--
Old Hanford Townsite Spring						
Alpha (gross)	1	3.2 ± 2.2	7	4.9 ± 2.2	1.2	15
Beta (gross)	1	23 ± 4.3	7	95 ± 140	18	50
Iodine-129	1	0.14 ± 0.0081	5	0.22 ± 0.014	0.086	1
Technetium-99	1	100 ± 12	7	130 ± 16	43	900[c]
Tritium	1	120,000 ± 8,800	7	170,000 ± 13,000	56,000	20,000
Uranium (total)	1	3.4 ± 0.43	7	4.3 ± 0.52	2.5	--

(a) Maximum values are ± total propagated analytical uncertainty (2 sigma).
(b) WAC 246-290, 40 CFR 141, and Appendix C, Table C.2.
(c) WAC 173-201A-050 and EPA-570/9-76-003.
(d) Dashes indicate no concentration guides available.
(e) Sample was destroyed during processing at the analytical laboratory.
(f) Refer to Table 4.2.4 for additional details on 100-N Spring samples.

Table A.8. Activities of Selected Radionuclides (pCi/g dry wt.) in Soil, 1998 Compared to Previous 6 Years

		1998				1992-1997			
Location	Radionuclide	No. of Samples	Mean[a]	Minimum[b]	Maximum[c]	No. of Samples	Mean[a]	Minimum[b]	Maximum[c]
Onsite	^{241}Am	4	0.079 ± 0.057	0.002 ± 0.001	0.24 ± 0.14	6	0.01 ± 0.006	0.0008 ± 0.002	0.037 ± 0.006
	$^{239,240}Pu$	13	0.074 ± 0.047	0.0004 ± 0.0002	0.53 ± 0.057	38	0.027 ± 0.012	0.00038 ± 0.0076	0.39 ± 0.38
	^{238}Pu	13	0.0008 ± 0.0006	0.0000 ± 0.0001	0.0081 ± 0.0013	38	0.0005 ± 0.0001	-0.00046 ± 0.0008	0.0039 ± 0.0007
	^{137}Cs	13	0.33 ± 0.14	0.01 ± 0.01	1.8 ± 0.18	38	1.1 ± 0.41	0.0031 ± 0.029	12.3 ± 1.25
	^{90}Sr	13	0.1 ± 0.031	0.014 ± 0.005	0.38 ± 0.069	41	0.16 ± 0.023	0.028 ± 0.0079	0.7 ± 0.13
	$^{238}U_{lerg}$[d]					38	0.71 ± 0.043	0.32 ± 0.2	1.5 ± 0.29
	$^{239}U_{iso}$[e]	13	0.15 ± 0.01	0.11 ± 0.02	0.25 ± 0.04	3	0.26 ± 0.053	0.17 ± 0.02	0.36 ± 0.04
Perimeter	^{241}Am	1			0.003 ± 0.0015	5	0.011 ± 0.0097	0.00029 ± 0.0015	0.05 ± 0.018
	$^{239,240}Pu$	6	0.0086 ± 0.0011	0.0057 ± 0.001	0.012 ± 0.002	23	0.0079 ± 0.001	0.0006 ± 0.0004	0.021 ± 0.0029
	^{238}Pu	6	0.0003 ± 0.0001	0.00015 ± 0.0001	0.0004 ± 0.0002	23	0.0003 ± 0.0001	-0.0007 ± 0.001	0.0011 ± 0.0013
	^{137}Cs	6	0.24 ± 0.032	0.16 ± 0.024	0.34 ± 0.04	28	0.35 ± 0.047	0.014 ± 0.026	0.95 ± 0.12
	^{90}Sr	6	0.052 ± 0.005	0.033 ± 0.008	0.067 ± 0.015	28	0.078 ± 0.008	0.013 ± 0.006	0.15 ± 0.032
	$^{238}U_{lerg}$[d]					23	0.71 ± 0.05	0.15 ± 0.46	1.1 ± 0.51
	$^{239}U_{iso}$[e]	6	0.17 ± 0.03	0.12 ± 0.02	0.3 ± 0.05	13	0.54 ± 0.07	0.18 ± 0.021	0.84 ± 0.10
Distant	^{241}Am	1			0.004 ± 0.002	3	0.024 ± 0.019	0.0041 ± 0.0056	0.063 ± 0.019
	$^{239,240}Pu$	1			0.006 ± 0.001	5	0.009 ± 0.0024	0.002 ± 0.0005	0.017 ± 0.0021
	^{238}Pu	1			0.0001 ± 0.0002	5	0.0004 ± 0.0001	0.0002 ± 0.0002	0.0007 ± 0.0003
	^{137}Cs	1			0.18 ± 0.03	5	0.51 ± 0.059	0.42 ± 0.053	0.74 ± 0.083
	^{90}Sr	1			0.081 ± 0.017	5	0.1 ± 0.036	0.038 ± 0.0087	0.24 ± 0.055
	$^{238}U_{lerg}$[d]					5	0.74 ± 0.035	0.66 ± 0.32	0.84 ± 0.3
	$^{239}U_{iso}$[e]	1			0.1 ± 0.02				
ALE[f]	^{241}Am					2	0.001 ± 0.0003	0.0007 ± 0.0011	0.0013 ± 0.0013
	$^{239,240}Pu$	2	0.0042 ± 0.034	0.0009 ± 0.0005	0.0076 ± 0.0012	2	0.0049 ± 0.0006	0.0043 ± 0.001	0.0055 ± 0.0011
	^{238}Pu	2	0.0002 ± 0.0002	-0.0000 ± 0.0001	0.0004 ± 0.0002	2	0.00014 ± 0.0001	0.000053 ± 0.00013	0.00022 ± 0.00018
	^{137}Cs	2	0.11 ± 0.09	0.02 ± 0.01	0.21 ± 0.03	2	0.21 ± 0.12	0.20 ± 0.05	0.22 ± 0.05
	^{90}Sr	2	0.046 ± 0.034	0.012 ± 0.004	0.08 ± 0.018	2	0.089 ± 0.007	0.082 ± 0.017	0.097 ± 0.021
	$^{238}U_{lerg}$[d]					2	0.56 ± 0.14	0.419 ± 0.33	0.71 ± 0.30
	$^{239}U_{iso}$[e]	2	0.16 ± 0.048	0.11 ± 0.024	0.21 ± 0.036				

(a) Reported mean error values ± standard error of the mean.
(b) Reported minimum error values ± total propagated analytical error.
(c) Reported maximum error values ± total propagated analytical error.
(d) Samples analyzed by low-energy photon system.
(e) Isotopic uranium.
(f) Fitzner/Eberhardt Arid Lands Ecology Reserve.

Table A.9. Radionuclide Activities (pCi/g dry wt.) in Soil Collected from the Fitzner-Eberhardt Arid Lands Ecology Reserve

Location[a]	Radionuclide	1993[b]	1998[b]
Rattlesnake Springs	Strontium-90	0.07 ± 0.02	0.08 ± 0.02
	Cesium-137	0.29 ± 0.04	0.21 ± 0.03
	Uranium-238[c]	0.51 ± 0.39	0.11 ± 0.02
	Plutonium-238	0.0002 ± 0.0001	0.0004 ± 0.0002
	Plutonium-239,240	0.007 ± 0.001	0.008 ± 0.001
Arid Lands Ecology Field Laboratory	Strontium-90	0.11 ± 0.02	0.012 ± 0.004
	Cesium-137	0.22 ± 0.04	0.02 ± 0.01
	Uranium-238[c]	1.01 ± 0.50	0.21 ± 0.04
	Plutonium-238	0.0002 ± 0.0002	ND[d]
	Plutonium-239,240	0.006 ± 0.001	0.0009 ± 0.0005

(a) See Figure 4.6.1.
(b) ± total propagated uncertainty (2 sigma).
(c) 1993 uranium-238 was determined by low-energy photon analysis; 1998 sample was determined by alpha spectrometry.
(d) ND = Not detected.

Table A.10. Activities of Selected Radionuclides (pCi/g dry wt.) in Vegetation, 1998 Compared to Previous 6 Years

	1998				1992-1997			
Radionuclide	No. Less Than Dectection	Mean[a]	Minimum[b]	Maximum[c]	No. Less Than Detection	Mean[a]	Minimum[b]	Maximum[c]
Onsite								
$^{239,240}Pu$	5 of 6	0.00007 ± 0.0006	0.00003 ± 0.0001	0.0039 ± 0.0008	7 of 14	0.0027 ± 0.0013	-0.00002 ± 0.0002	0.015 ± 0.0024
^{238}Pu	6 of 6	0.00003 ± 0.00002	-0.00003 ± 0.0001	0.0001 ± 0.0002	11 of 14	0.0072 ± 0.0045	-0.0006 ± 0.0007	0.051 ± 0.0062
^{137}Cs	6 of 6	0.001 ± 0.01	-0.02 ± 0.01	0.02 ± 0.01	6 of 14	0.29 ± 0.15	-0.003 ± 0.01	1.54 ± 0.17
^{90}Sr	2 of 7	0.02 ± 0.01	0.001 ± 0.005	0.037 ± 0.01	0 of 14	3.07 ± 2.65	0.01 ± 0.004	37.4 ± 9.19
$^{238}U_{NAT}$[d]					2 of 4	0.003 ± 0.01	-0.02 ± 0.02	0.02 ± 0.01
$^{239}U_{iso}$[e]	7 of 7	-0.002 ± 0.002	-0.007 ± 0.004	0.003 ± 0.001	7 of 10	0.002 ± 0.001	-0.0005 ± 0.005	0.01 ± 0.003
Perimeter								
$^{239,240}Pu$	2 of 4	0.0001 ± 0.0001	0.00004 ± 0.00008	0.0003 ± 0.0003	7 of 13	0.0002 ± 0.00003	-0.00001 ± 0.0003	0.0004 ± 0.0003
^{238}Pu	4 of 4	0.0001 ± 0.0001	0.00002 ± 0.0001	0.0001 ± 0.0001	13 of 13	0.00003 ± 0.0001	-0.0003 ± 0.0009	0.0006 ± 0.001
^{137}Cs	4 of 4	0.01 ± 0.006	0.004 ± 0.01	0.03 ± 0.02	12 of 13	0.003 ± 0.003	-0.03 ± 0.03	0.02 ± 0.02
^{90}Sr	0 of 4	0.02 ± 0.005	0.01 ± 0.01	0.04 ± 0.01	1 of 13	0.02 ± 0.006	0.002 ± 0.003	0.07 ± 0.02
$^{238}U_{NAT}$[d]					4 of 4	-0.003 ± 0.003	-0.01 ± 0.01	0.005 ± 0.01
$^{239}U_{iso}$[e]	4 of 4	0.006 ± 0.002	0.001 ± 0.006	0.016 ± 0.019	2 of 9	0.01 ± 0.003	0.0002 ± 0.002	0.03 ± 0.008
Distant								
$^{239,240}Pu$	2 of 2	0.00001 ± 0.00001	-0.00001 ± 0.00006	0.00002 ± 0.0001	4 of 5	0.0001 ± 0.00002	0.00004 ± 0.0001	0.0002 ± 0.0001
^{238}Pu	2 of 2	0.00002 ± 0.00003	-0.00001 ± 0.0001	0.00004 ± 0.0001	5 of 5	0.00001 ± 0.00001	-0.00001 ± 0.0001	0.0001 ± 0.0001
^{137}Cs	2 of 2	0.02 ± 0.01	0.01 ± 0.01	0.03 ± 0.01	4 of 5	0.01 ± 0.01	-0.02 ± 0.02	0.03 ± 0.03
^{90}Sr	0 of 2	0.03 ± 0.02	0.01 ± 0.01	0.04 ± 0.01	1 of 5	0.01 ± 0.003	0.003 ± 0.003	0.02 ± 0.005
$^{238}U_{NAT}$[d]					1 of 1			-0.002 ± 0.01
$^{239}U_{iso}$[e]	2 of 2	-0.004 ± 0.004	-0.01 ± 0.007	-0.0002 ± 0.006	1 of 4	0.004 ± 0.001	0.001 ± 0.002	0.005 ± 0.003

(a) Reported mean error values ± standard error of the mean.
(b) Reported minimum error values ± total propagated analytical error.
(c) Reported maximum error values ± total propagated analytical error.
(d) U_{NAT} is a chemical analysis not used in 1998.
(e) Isotopic uranium.

Table A.11. Metal Concentrations in Hanford Site Fruit Tree Samples, 1997 and 1998

Location	Medium	Antimony ICP-MS[a]	Arsenic ICP-MS	Beryllium ICP-MS	Cadmium ICP-MS	Chromium ICP-MS	Copper ICP-MS	Lead ICP-MS
		Concentration, µg/kg dry wt.						
1997								
100-D Area	Apricot leaves	0.015 U[b]	0.250	0.150 U	0.151	0.285	8.73	0.114
100-D Area	Apricot leaves	0.015 U	0.170	0.150 U	0.206	0.314	8.75	0.194
100-F Area	Apricot leaves	0.015 U	0.394	0.150 U	0.0971	0.200 U	4.25	0.145
Old Hanford Townsite	Quince fruit	0.015 U	0.154	0.150 U	0.0528	0.200 U	4.78	0.111
Old Hanford Townsite	Quince leaves	0.015 U	0.0327	0.150 U	0.0794	0.200 U	3.38	0.036 U
1997 Detection Limits		0.015	0.030	0.150	0.020	0.200	0.020	0.036
1998								
Old Hanford Townsite	Apple fruit	0.020 U	0.15 U	0.010 U	0.055	1.0 U	2.59	0.0298
Old Hanford Townsite	Apple leaves	0.020 U	0.248	0.010 U	0.04 U	1.0 U	6.70	0.251
100-F Area	Apricot fruit	0.020 U	0.214	0.010 U	0.04 U	1.0 U	14.1	0.0343
100-F Area	Apricot leaves	0.020 U	0.333	0.010 U	0.04 U	1.0 U	5.50	0.119
1998 Detection Limits		0.020	0.15	0.010	0.04	1.0	0.8	0.01

Location	Medium	Mercury CVAA[c]	Nickel ICP-MS	Selenium ICP-MS	Silver ICP-MS	Thallium ICP-MS	Zinc ICP-MS
		Concentration, µg/kg dry wt.					
1997							
100-D Area	Apricot leaves	0.0203	0.842	1.00 U	0.045 U	0.005 U	12.9
100-D Area	Apricot leaves	0.0210	1.08	1.00 U	0.045 U	0.0188	16.7
100-F Area	Apricot leaves	0.0174	0.790	1.00 U	0.045 U	0.005 U	9.81
Old Hanford Townsite	Quince fruit	0.0221	0.946	1.00 U	0.045 U	0.005 U	5.86
Old Hanford Townsite	Quince leaves	0.00180	0.125	1.00 U	0.045 U	0.00640	3.08
1997 Detection Limits		0.001	0.020	1.00	0.045	0.005	0.150
1998							
Old Hanford Townsite	Apple fruit	0.0016 U	0.15 U	2.0 U	0.01 U	0.01 U	2.00
Old Hanford Townsite	Apple leaves	0.0210	0.931	2.0 U	0.0243	0.01 U	12.2
100-F Area	Apricot fruit	0.0016 U	0.634	2.0 U	0.0164	0.01 U	16.7
100-F Area	Apricot leaves	0.0016 U	0.469	2.0 U	0.01 U	0.01 U	16.7
1998 Detection Limits		0.0016	0.15	2.00	0.010	0.01	1.00

(a) ICP-MS = Inductively coupled plasma-mass spectrometry.
(b) U = Undetected.
(c) CVAA = Cold vapor atomic absorption.

References

40 CFR 141. U.S. Environmental Protection Agency. "National Primary Drinking Water Regulations; Radionuclides; Proposed Rule." *Code of Federal Regulations*.

EPA-570/9-76-003. 1976. *National Interim Primary Drinking Water Regulations*. Office of Water Supply, U.S. Environmental Protection Agency, Washington, D.C.

PNNL-12088, APP. 1. 1999. *Hanford Site Environmental Surveillance Data Report for Calendar Year 1998*. L. E. Bisping, Pacific Northwest National Laboratory, Richland, Washington.

Washington Administrative Code (WAC) 246-290. *Group A Public Water Systems*. Olympia, Washington.

Washington Administrative Code (WAC) 173-201A. *Water Quality Standards for Surface Waters of the State of Washington*. Olympia, Washington.

Appendix B
Glossary

absorbed dose - Energy absorbed per unit mass from any kind of ionizing radiation in any kind of matter.

activation product - Material made radioactive by exposure to radiation from a source such as a nuclear reactor's neutrons.

anion - A negatively charged ion.

aquifer - Permeable geologic unit that can hold and/or transmit significant quantities of water.

background radiation - Radiation in the natural environment, including cosmic rays from space and radiation from naturally occurring radioactive elements in the air, in the earth, and in our bodies. In the United States, the average person receives approximately 300 millirems (mrem) of background radiation per year.

bank storage - Hydrologic term that describes river water that flows into and is retained in permeable stream banks during periods of high river stage. Flow is reversed during periods of low river stage.

becquerel (Bq) - Unit of radioactivity equal to one nuclear transformation per second (1 Bq = 1/s). Another unit of radioactivity, the curie, is related to the becquerel in which 1 Ci = 3.7×10^{10} Bq.

boundary dose rate - Dose rate measured or calculated at publicly accessible locations on or near the Hanford Site boundary.

collective effective dose equivalent - Sum of the effective dose equivalents for individuals composing a defined population. The units for this are "person-rem" or "person-sievert."

composite sample - Sample formed by mixing discrete samples taken at different times or from different locations.

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

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

controlled area - An area to which access is controlled to protect individuals from exposure to radiation or radioactive and/or hazardous materials.

cosmic radiation - High-energy subatomic particles and electromagnetic radiation from outer space that bombard the earth. Cosmic radiation is part of natural background radiation.

curie (Ci) - A unit of radioactivity equal to 37 billion (3.7×10^{10}) nuclear transformations per second.

decay - The decrease in the amount of any radioactive material with the passage of time, as a result of the spontaneous emission from the atomic nuclei of nucleons or either alpha or beta particles, often accompanied by gamma radiation. When a radioactive material decays, the material may be converted to another radioactive species (decay product) or to a nonradioactive material.

derived concentration guide (DCG) - Concentrations of radionuclides in air and water that an individual could continuously consume, inhale, or be immersed in at average annual rates, and not receive an effective dose equivalent of greater than 100 mrem/yr.

detection level - Minimum amount of a substance that can be measured with a 99% confidence that the analytical result is greater than zero.

dispersion - Process whereby effluents are spread or mixed as they are transported by groundwater or air.

dose equivalent - Product of the absorbed dose, the quality factor, and any other modifying factors. The dose equivalent is a quantity for comparing the biological effectiveness of different kinds of radiation on a common scale. The unit of dose equivalent is the rem. A millirem is one one-thousandth of a rem.

dosimeter - Portable device for measuring the total accumulated exposure or absorbed dose from ionizing radiation fields.

effective dose - See "effective dose equivalent."

effective dose equivalent - A value used for estimating the total risk of potential health effects from radiation exposure. This estimate is the sum of the committed effective dose equivalent (see above) from internal deposition of radionuclides in the body and the effective dose equivalent from external radiation received during a year.

effluent - Liquid or gaseous waste streams released from a facility.

effluent monitoring - Sampling or measuring specific liquid or gaseous effluent streams for the presence of pollutants.

exposure - The interaction of an organism with a physical agent (e.g., radiation) or a chemical agent (e.g., arsenic) of interest. Also used as a term for quantifying x and gamma radiation fields (see "roentgen").

external radiation - Radiation originating from a source outside the body.

fallout - Radioactive materials that are released into the earth's atmosphere following a nuclear explosion or atmospheric release and that eventually fall to earth.

fission - The splitting or breaking apart of a nucleus into at least two other nuclei, accompanied with a release of a relatively large amount of energy. For example, when a heavy atom such as uranium is split, large amounts of energy, including radiation and neutrons, are released along with the new nuclei (which are fission products; see below).

fission products - Elements formed from fissioning. Many fission products are radioactive.

gamma radiation - Form of electromagnetic, high-energy radiation emitted from a nucleus. They require heavy shielding (e.g., concrete, steel) to be stopped and may cause biological damage when originating internally or externally to the body in sufficient amounts.

grab sample - A sample that is randomly collected or "grabbed" from the collection site.

grand mean - A "means of means" or an "overall mean" where there is some subdivision of the data where means were already provided for each subdivision.

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

gray (Gy) - Unit of absorbed dose in the International System of Units (SI) equal to 1 joule per kilogram. 1 Gy = 100 rad.

half-life - Length of time in which a radioactive substance will lose one half of its radioactivity by decay. Half-lives range from a fraction of a second to billions of years, and each radionuclide has a unique half-life.

ion exchange - The reversible exchange of one species of ion for a different species of ion within a medium.

irradiation - Exposure to radiation.

isotopes - Radionuclides (or nuclides) with the same number of protons (same atomic number) but a different number of neutrons (different mass). Isotopes of the same element (e.g., ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu) have almost identical chemical properties.

maximally exposed individual - A hypothetical member of the public residing near the Hanford Site who, by virtue of location and living habits, could receive the highest possible radiation dose from nuclides/radiation originating from Hanford.

mean - Average value of a series of measurements. The mean, X, was computed as:

$$X = \frac{1}{n}\sum_{i=1}^{n} X_i$$

where n is the number of measurements and X_i is the ith measurement.

median - Middle value in a set of results when the data are ranked in increasing or decreasing order.

millirem (mrem) - A unit of radiation dose equivalent that is equal to one one-thousandth (1/1000) of a rem. According to U.S. Department of Energy standards, an individual member of the public may receive no more than 100 mrem per year from a site's operation. This limit does not include radiation received for medical treatment or the approximately 300 mrem that people receive annually from natural background radiation.

minimum detectable concentration - Smallest amount or concentration of a radioactive or nonradioactive element that can be reliably detected in a sample.

noble gas - Any of a group of chemically and biologically inert gases that includes argon, krypton, and xenon. These gases are not retained in the body following inhalation. The principal exposure pathways for radioactive noble gases are direct external dose from the surrounding air.

nuclide -A general term referring to all known isotopes, both stable and unstable, of the chemical elements (Shleien 1992).

offsite locations - Sampling and measurement locations outside the Hanford Site boundary.

onsite locations - Sampling and measurement locations within the Hanford Site boundary.

operable unit - A discrete area for which an incremental step can be taken toward comprehensively addressing site problems. The cleanup of a site can be divided into a number of operable units, depending on the complexity of the problems associated with the site.

outfall - End of a drain or pipe that carries wastewater or other effluents into a ditch, pond, or river.

plume - The cloud of a pollutant in air, surface water, or groundwater formed after the pollutant is released from a source.

plutonium - A heavy, radioactive, man-made metallic element consisting of several isotopes. One important isotope is ^{239}Pu, which is produced by the irradiation of ^{238}U. Routine analysis cannot distinguish between the ^{239}Pu and ^{240}Pu isotopes; hence, the term $^{239,240}Pu$ as used in this report is symbolic of the presence of one or both of these isotopes in the analytical results.

quality assurance - Actions that provide confidence that an item or process meets or exceeds that user's requirements and expectations.

quality control - Comprises all those actions necessary to control and verify the features and characteristics of a material, process, product, or service to specified requirements. Quality control is an element of quality assurance.

rad - A special unit of absorbed dose equal to 100 ergs/g or 0.01 J/kg.

radiation - The energy emitted in the form of photons or particles such as those thrown off by transforming (decaying) atoms. For this report, radiation refers to ionizing types of radiation; not radiowaves, microwaves, radiant light, or other types of non-ionizing radiation.

radioactivity - Property possessed by some isotopes of elements of emitting radiation (such as alpha, beta, or gamma photons) spontaneously in their decay process to stable element isotopes.

radioisotope - An unstable isotope of an element that decays or disintegrates spontaneously, emitting radiation (Shleien 1992).

radionuclide - A species of atoms having a particular number of protons (Z), a particular number of neutrons (A), and a particular atomic weight (N = Z + A) that happens to emit radiation. Carbon-14 is a radionuclide. Carbon-12 is not and is called just a "nuclide."

recruitment - Survival from one life form or stage to the next or from one age class to the next.

rem - A unit of dose equivalent and effective dose equivalent.

risk - The probability that a detrimental health effect will occur.

roentgen (R) - Unit of x ray or gamma photon exposure measured in air, historically used to describe external radiation levels. An exposure of 1 roentgen typically causes an effective dose of 1 rem.

sievert (Sv) - Unit of dose equivalent and effective dose equivalent in the International System of Units (SI) equal to 100 rem.

spectrometer - A spectroscope with a calibrated scale for measuring the positions of spectral lines.

spectroscopy - The branch of physics concerned with the production, measurement, and interpretation of electromagnetic spectra arising from either emission or absorption of radiant energy by various substances.

spent fuel - Uranium metal or oxide and its metal container that have been used to power a nuclear reactor. It is highly radioactive and typically contains fission products, plutonium, and residual uranium.

standard error of the mean - A measure of the precision of a mean of observed values; that is, an estimate of how close a mean of observed values is expected to be to the true mean. The standard error (SE) of the mean is computed as

$$SE = \sqrt{\frac{S^2}{n}}$$

where S^2 is the variance of the measurements, n, computed as

$$S_M^2 = \frac{1}{n-1}\sum_{i=1}^{n} (X_i - X)^2$$

This estimator, S^2, includes the variance among the samples and the counting variance. The estimated S^2 may occasionally be less than the average counting variance.

thiourea - An organic chemical soluble in cold water used in photography, photocopying, and thyroid medication.

transuranic - An element with an atomic number greater than 92 (92 is the atomic number of uranium).

thermoluminescent dosimeter - A device containing a material that, after being exposed to beta and/or gamma radiation, emits light when processed and heated. The amount of light emitted is proportional to the absorbed dose to the thermoluminescent dosimeter.

unconfined aquifer - An aquifer containing groundwater that is not confined above by relatively impermeable rocks. The pressure at the top of the unconfined aquifer is equal to that of the atmosphere. At Hanford, the unconfined aquifer is the uppermost aquifer and is most susceptible to contamination from site operations.

vadose zone - Underground area from the surface to the top of the water table or aquifer.

volatile organic compounds - Lightweight organic compounds that vaporize easily. Used in solvents and degreasing compounds as raw materials, volatile compounds are generally considered to be below the molecular weight of C_{10} hydrocarbons.

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

wind rose - Star-shaped diagram that shows how often winds of various speeds blow from different directions, usually based on yearly averages.

Reference

Shleien, B. (ed.). 1992. *The Health Physics and Radiological Health Handbook, Revised Edition*. Scinta, Inc., Silver Spring, Maryland.

Appendix C
Standards and Permits

Operations at the Hanford Site must conform to a variety of governmental standards and permits designed to ensure the biological and physical quality of the environment for public health, ecological, or aesthetic considerations. The primary environmental quality standards and permits applicable to Hanford Site operations in 1998 are listed in the following tables. The State of Washington has promulgated water quality standards for the Columbia River, Washington Administrative Code (WAC) 173-201A. The Hanford Reach of the Columbia River has been designated as Class A (Excellent). This designation requires that the water be usable for substantially all needs, including drinking water, recreation, and wildlife. Class A water standards are summarized in Table C.1. Drinking water standards promulgated by the U.S. Environmental Protection Agency (EPA) in Title 40, Code of Federal Regulations, Part 141 (40 CFR 141) and WAC 246-290 are summarized in Table C.2. Select surface freshwater quality criteria for toxic pollutants are included in Table C.3.

Environmental radiation protection standards are published in U.S. Department of Energy (DOE) Order 5400.5. That Order establishes limits for public radiation dose and gives guidance for keeping radiation exposures to members of the public as low as reasonably achievable. These standards are based on guidelines recommended by authoritative organizations such as the International Commission on Radiological Protection and the National Council on Radiation Protection and Measurements. DOE has initiated a policy for creating and implementing public radiation protection standards that are generally consistent with the standards used by the U.S. Nuclear Regulatory Commission in regulating and licensing non-DOE nuclear facilities (i.e., nuclear power plants). Table C.4 shows the radiation standards from DOE Order 5400.5 and 40 CFR 61. These standards govern allowable public exposures to ionizing radiation from DOE operations.

In DOE Order 5400.5, the derived concentration guides are established that reflect the activities of radionuclides in water and air that an individual could continuously consume, inhale, or be immersed in at average annual activities without exceeding an effective dose equivalent of 100 mrem/yr. Derived concentration guides are not exposure limits but are simply reference values that are provided to allow for comparisons of radionuclide activities in environmental media. Table C.5 lists selected DOE derived concentration guides for radionuclides of particular interest at the Hanford Site. The guides are useful reference values but do not generally represent concentrations in the environment that ensure compliance with either the DOE, the Clean Air Act of 1986, or drinking water dose standards.

Permits required for regulated releases to water and air have been issued by the EPA under the National Pollutant Discharge Elimination System of the Clean Water Act of 1977 and the Prevention of Significant Deterioration requirements of the Clean Air Act. Also, under authority granted by the Clean Air Act, the Washington State Department of Health has issued a permit for Hanford Site radioactive air emissions. Permits for collecting wildlife for environmental sampling are issued by the Washington State Department of Fish and Wildlife and the U.S. Fish and Wildlife Service. Current permits are discussed in Table C.6.

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

Parameter	Permissible Levels
Fecal coliform	1) Geometric mean value ≤100 colonies/100 mL 2) ≤10% of samples may exceed 200 colonies/100 mL
Dissolved oxygen	>8 mg/L
Temperature	1) ≤20°C (68°F) as a result of human activities 2) When natural conditions exceed 20°C (68°F), no temperature increases will be allowed that will raise the temperature of the receiving water by more than 0.3°C (32.5°F) 3) Incremental temperature increases resulting from point sources shall not at any time exceed 34/(T + 9), where T = background temperature. Incremental temperature increases resulting from nonpoint sources shall not exceed 2.8°C (37°F)
pH	1) 6.5 to 8.5 range 2) <0.5 unit induced variation
Turbidity	≤5 nephelometric turbidity units 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 most sensitive aquatic biota, or which may adversely affect characteristic water uses
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
Radioactive substances	Deleterious activities of radioactive materials for all classes shall be as determined by the lowest practicable activity attainable and in no case shall exceed EPA drinking water regulations for radionuclides, as published in EPA-570/9-76-003 or subsequent revisions thereto (see Table C.2)
Toxic substances	Shall not be introduced above natural background levels into waters of the state that have the potential either singularly or cumulatively to adversely affect characteristic water uses, cause acute or chronic toxicity to the most sensitive biota dependent on those waters, or adversely affect public health, as determined by the department (see Table C.3)

Table C.2. Selected Drinking Water Standards

Radiological Constituent	Primary Maximum Contaminant Level	Interim Drinking Water Standard	Agency[a]	Status
Gross alpha[b]	15 pCi/L		DOH,[c] EPA[d]	Final
Radium-226		3 pCi/L	DOH[c]	Final
Beta particle and photon activity	4 mrem/yr[e]		DOH,[c] EPA[d]	Final
Tritium		20,000[f] pCi/L	DOH,[c] EPA[d]	Interim
Beryllium-7		6,000[f] pCi/L	EPA[g]	Interim
Cobalt-60		100[f] pCi/L	EPA[g]	Interim
Strontium-90		8[f] pCi/L	DOH,[c] EPA[d]	Interim
Technetium-99		900[f] pCi/L	EPA[g]	Interim
Ruthenium-106		30[f] pCi/L	EPA[g]	Interim
Antimony-125		300[f] pCi/L	EPA[g]	Interim
Iodine-129		1[f] pCi/L	EPA[g]	Interim
Iodine-131		3[f] pCi/L	EPA[g]	Interim
Cesium-134		20,000[f] pCi/L	EPA[g]	Interim
Cesium-137		200[f] pCi/L	EPA[g]	Interim
Europium-154		200[f] pCi/L	EPA[g]	Interim
Europium-155		600[f] pCi/L	EPA[g]	Interim
Uranium	20 µg/L[h]		EPA[i]	Proposed
Fluoride	4 mg/L		DOH,[c] EPA[d,i]	Final/under review
Nitrate, as NO_3^-	45 mg/L		DOH,[c] EPA[d,i]	Final
Chromium	100 µg/L		DOH,[c] EPA[d,i]	Final
Cyanide	200 µg/L		EPA[c,d,i]	Final
Trichlorethylene	5 µg/L		DOH,[c] EPA[d,i]	Final
Tetrachloroethylene	5 µg/L		DOH,[c] EPA[d,i]	Final
Carbon tetrachloride	5 µg/L		DOH,[c] EPA[d,i]	Final
Chloroform (THM)[j]	100 µg/L		DOH,[c] EPA[i]	Final
cis-1,2-Dichloroethylene	0.07 mg/L		EPA[i]	Final

(a) DOH = Washington State Department of Health, EPA = U.S. Environmental Protection Agency.
(b) Including radium-226 but excluding radon and uranium.
(c) WAC 246-290.
(d) 40 CFR 141.
(e) Beta and gamma radioactivity from man-made radionuclides. Annual average activity shall not produce an annual dose equivalent from man-made radionuclides to the total body or any internal organ >4 mrem/yr. Compliance may be assumed if annual average activities of gross beta, tritium, and strontium-90 are <50, 20,000, and 8 pCi/L, respectively.
(f) Activity assumed to yield an annual dose of 4 mrem/yr.
(g) EPA-570/9-76-003.
(h) Equivalent to 13.4 pCi/L (assuming typical uranium natural abundance in rock).
(i) EPA 822-R-96-001.
(j) Standard is for total trihalomethanes (THM).

Table C.3. Selected Surface Freshwater Quality Criteria for Toxic Pollutants

Compound	Level that Yields Acute Toxicity, µg/L[a]	Level that Yields Chronic Toxicity, µg/L[a]	Level to Protect Human Health for the Consumption of Water and Organisms, µg/L[b]
Total Recoverable Metals			
Antimony	--	--	14
Arsenic	360.0	190.0	0.018
Cadmium	1.7[c]	0.64[d]	--
Chromium(III)[e]	950[f]	110[g]	--
Chromium(VI)	16.0	11.0	--
Copper	8.9[h]	6.3[i]	--
Lead	32[j]	1.2[k]	--
Mercury	2.4	0.012	0.14
Nickel	760[l]	85[m]	610
Selenium	20.0	5.0	--
Silver	1.2[n]	--	--
Thallium	--	--	1.7
Zinc	63[o]	57[p]	--
Anions			
Cyanide[q]	22.0	5.2	700
Chloride[r]	860,000	230,000	--
Organic Compounds			
Benzene	--	--	1.2
Carbon tetrachloride	--	--	0.25
Chloroform	--	--	5.7
1,2-Dichloroethane	--	--	0.38
Methylene chloride	--	--	4.7
Toluene	--	--	6,800
Tetrachloroethylene	--	--	0.8
1,1,2-Trichloroethane	--	--	0.60
Trichloroethylene	--	--	2.7
Vinyl chloride	--	--	2
1,4-Dichlorobenzene	--	--	400

(a) WAC 173-201A-040.
(b) 40 CFR 131.36.
(c) exp(1.128[ln(hardness)]-3.828). Limiting value for 1992-1997 U.S. Geological Survey results is 48 mg $CaCO_3$/L. Hardness expressed as mg $CaCO_3$/L.
(d) exp(0.7852[ln(hardness)]-3.490).
(e) Where methods to measure trivalent chromium are unavailable, these criteria are to be represented by total recoverable chromium.
(f) exp(0.8190[ln(hardness)]+3.688).
(g) exp(0.8190[ln(hardness)]+1.561).
(h) exp(0.9422[ln(hardness)]-1.464).
(i) exp(0.8545[ln(hardness)]-1.465).
(j) exp(1.273[ln(hardness)]-1.460).
(k) exp(1.273[ln(hardness)]-4.705).
(l) exp(0.8460[ln(hardness)]+3.3612).
(m) exp(0.8460[ln(hardness)]+1.1645).
(n) exp(1.72[ln(hardness)]-6.52).
(o) exp(0.8473[ln(hardness)]+0.8604).
(p) exp(0.8473[ln(hardness)]+0.7614).
(q) Criteria based on weak and dissociable method.
(r) Dissolved in association with sodium.

Table C.4. Radiation Standards (dose limits[a]) for Protection of the Public from All Routine DOE Activities

All Pathways (limits from DOE Order 5400.5)

The effective dose equivalent for any member of the public from all routine DOE activities[b] shall not exceed the values given below.

	Effective Dose Equivalent[c]	
	mrem/yr	mSv/yr
Routine public dose	100	1
Potential authorized temporary public dose[d]	500	5

Dose to Native Aquatic Animal Organisms from Liquid Discharges (interim limits from DOE Order 5400.5)

Radioactive material in liquid wastes discharged to natural waterways shall not cause an absorbed dose[e] to native aquatic animal organisms that exceeds 1 rad/d (10 mGy/d).

Drinking Water Pathway Only (limits from 40 CFR 141 and DOE Order 5400.5)

Radionuclide concentrations in DOE-operated public drinking water supplies shall not cause persons consuming the water to receive an effective dose equivalent >4 mrem/yr (0.04 mSv/yr). DOE activities shall not cause private or public drinking water systems downstream of the facility discharge to exceed the radiological drinking water limits in 40 CFR 141 (see Table C.2).

Air Pathways Only (limits from 40 CFR 61)

	Effective Dose Equivalent[c]	
	mrem/yr	mSv/yr
Public dose limit at location of maximum annual air concentration as a consequence of routine DOE activities[b]	10	0.1

(a) Radiation doses received from natural background, residual weapons testing and nuclear accident fallout, medical exposures, and consumer products are excluded from the implementation of these dose limits.
(b) "Routine DOE activities" implies normal, planned activities and does not include actual or potential accidental or unplanned releases.
(c) Effective dose equivalent is expressed in rem (or millirem) and sievert (or millisievert).
(d) Authorized temporary annual dose limits may be >100 mrem/yr (but cannot exceed 500 mrem/yr) if unusual circumstances exist that make avoidance of doses >100 mrem/yr to the public impracticable. DOE Richland Operations Office is required to request and receive specific authorization from DOE Headquarters for an increase from the routine public dose limit to a temporary annual dose limit.
(e) Absorbed dose is expressed in rad (or millirad) with the corresponding value in gray (or milligray) in parentheses.

Table C.5. Selected Derived Concentration Guides[a,b,c]

Radionuclide	Ingested Water, pCi/L	Inhaled Air, pCi/m^3
Tritium	2,000,000	100,000
Carbon-14	70,000	500,000
Chromium-51	1,000,000	60,000
Manganese-54	50,000	2,000
Cobalt-60	5,000	80
Zinc-65	9,000	600
Krypton-85	NS[d]	3,000,000[e]
Strontium-90	1,000	9
Technetium-99	100,000	2,000
Ruthenium-103	50,000	2,000
Ruthenium-106	6,000	30
Antimony-125	60,000	1,000
Iodine-129	500	70
Iodine-131	3,000	400
Cesium-137	3,000	400
Cerium-144	7,000	30
Europium-154	20,000	50
Europium-155	100,000	300
Uranium-234	500	0.09
Uranium-235	600	0.1
Uranium-238	600	0.1
Plutonium-238	40	0.03
Plutonium-239	30	0.02
Plutonium-240	30	0.02
Americium-241	30	0.02

(a) Activity of a specific radionuclide in water or air that could be continuously consumed or inhaled at average annual rates and not exceed an effective dose equivalent of 100 mrem/yr.
(b) Values in this table represent the lowest, most-conservative, derived concentration guides considered potentially applicable to Hanford Site operations and may be adjusted upward (larger) if accurate solubility information is available.
(c) From DOE Order 5400.5.
(d) NS = No numerical standard, but the effective dose equivalent cannot exceed 100 mrem/yr.
(e) Air immersion derived concentration guides.

Table C.6. Environmental Permits

Clean Water Act Permit

Additional details are given in Section 2.2, "Compliance Status."

Clean Air Act Permits

Prevention of Significant Deterioration Permit No. PSD-X80-14, issued to DOE Richland Operations Office by EPA Region 10; covers emission of NO_x to the atmosphere from the Plutonium-Uranium Extraction Plant and the Uranium-TriOxide Plant. No expiration date.

Radioactive Air Emission Permit No. FF-01, issued to DOE Richland Operations Office by the Washington State Department of Health under authority granted by the Clean Air Act; covers operations on the Hanford Site having a potential to emit radioactive airborne effluents. Initially issued August 15, 1991, the permit was updated August 1993.

Wildlife Sampling Permits

Scientific Collection Permit 98-218, issued by Washington State Department of Fish and Wildlife to Pacific Northwest National Laboratory for 1998; covered the collection of food fish, shellfish, and wildlife, including game fish, for environmental monitoring purposes. Renewed annually.

Federal Fish and Wildlife Permit No. 671877, issued by the U.S. Fish and Wildlife Service to Pacific Northwest National Laboratory; covers the collection of migratory wildlife. Expires December 31, 1999.

National Pollutant Discharge Elimination System Permits (governing effluent discharges to the Columbia River)

Permit #WA-000374-3 includes two outfalls in the 100-K Area, one in the 300 Area, and two inactive outfalls in the 100-N Area.

Permit #WA-002591-7 includes the outfall for the 300 Area Treated Effluent Disposal Facility.

Permit #'s WAR-00-000F and WAR-10-000F covering two stormwater permits.

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

State of Washington Department of Ecology P.O. Box 47600 Olympia, WA 92504-7600	U.S. Environmental Protection Agency Region 10 1200 Sixth Avenue Seattle, WA 98101	U.S. Department of Energy Richland Operations Office 825 Jadwin Ave. Richland, WA 99352

References

40 CFR 61. U.S. Environmental Protection Agency. "National Emission Standards for Hazardous Air Pollutants." *Code of Federal Regulations.*

40 CFR 131.36. U.S. Environmental Protection Agency. "Toxics Criteria for Those States not Complying with the Clean Water Act Section 303(c)(2)(B)." *Code of Federal Regulations.*

40 CFR 141. U.S. Environmental Protection Agency. "National Primary Drinking Water Regulations; Radionuclides; Proposed Rule." *Code of Federal Regulations.*

Clean Air Act. 1986. Public Law 88-206, as amended, 42 USC 7401 et seq.

Clean Water Act. 1977. Public Law 95-217, as amended, 91 Stat. 1566 and Public Law 96-148, as amended.

DOE Order 5400.5. "Radiation Protection of the Public and the Environment."

EPA-570/9-76-003. 1976. *National Interim Primary Drinking Water Regulations.* Office of Water Supply, U.S. Environmental Protection Agency, Washington, D.C.

EPA 822-R-96-001. 1996. *Drinking Water Regulations and Health Advisories.* Office of Water, U.S. Environmental Protection Agency, Washington, D.C.

Washington Administrative Code (WAC) 173-201A. "Water Quality Standards for Surface Waters of the State of Washington." Olympia, Washington.

Washington Administrative Code (WAC) 246-290. "Group A Public Water Systems." Olympia, Washington.

Appendix D
Dose Calculations

E. J. Antonio

The radiological dose that the public could have received in 1998 from Hanford Site operations was calculated in terms of the "total effective dose equivalent." The total effective dose equivalent is the sum of the effective dose equivalent from external sources and the committed effective dose equivalent for internal exposure. Effective dose equivalent is a weighted sum of doses to organs and tissues that accounts for the sensitivity of the tissue and the nature of the radiation causing the dose. It is calculated in units of millirem (millisievert)[a] for individuals and in units of person-rem for the collective dose received by the total population within an 80-km (50-mi) radius of the site. This appendix describes how the doses in this report were calculated.

Releases of radionuclides from Hanford Site activities are usually too low to be measured in offsite air, drinking water, and food crops. Therefore, the air dose calculations were based on measurements made at the point of release (stacks and vents). The water pathway dose calculations were based on measurements of releases to the Columbia River (from the 100 Areas) or the difference in detectable radionuclide concentrations measured upstream and downstream of the site. Environmental radionuclide activities were estimated from the effluent measurements by environmental transport models.

The transport of radionuclides in the environment to the point of exposure is predicted by empirically derived models of exposure pathways. These models calculate radionuclide activities in air, water, and foods. Radionuclides taken into the body by inhalation or ingestion may be distributed among different organs and retained for various times. In addition, long-lived radionuclides deposited on the ground become possible sources for long-term external exposure and uptake by agricultural products. Dietary and exposure parameters were applied to calculate radionuclide intakes and radiological doses to the public. Standardized computer programs were used to perform the calculations. These programs contain internally consistent mathematical models that use site-specific dispersion and uptake parameters. These programs are incorporated in a master code, GENII (PNL-6584), which employs the dosimetry methodology described in International Commission on Radiological Protection reports (1979a, 1979b, 1980, 1981a, 1981b, 1982a, 1982b, 1988). The assumptions and data used in these calculations are described below.

CRITRII is used for assessment of radiological doses to aquatic organisms and their predators. Both internal and external doses to fish, crustacea, molluscs, and algae, as well as organisms that subsist on them such as muskrats, raccoons, and ducks, may be estimated using CRITRII (PNL-8150).

The computer program, CAP88-PC, was used to calculate dose to a maximally exposed individual as required by Title 40, Code of Federal Regulations, Part 61, Subpart H from airborne radionuclide effluents (other than radon) released at U.S. Department of Energy (DOE) facilities. Technical details of the CAP88-PC calculations are provided in detail in the 1998 air emissions report (DOE/RL-99-41).

(a) 1 rem (0.01 Sv) = 1,000 mrem (10 mSv).

Types of Dose Calculations Performed

Calculations of radiological doses to the public from radionuclides released into the environment are performed to demonstrate compliance with applicable standards and regulations.

DOE requires:

- effective dose equivalent to be used in estimating public doses
- biokinetic models and metabolic parameters given by the International Commission on Radiological Protection to be used when estimating doses
- doses to the public to be calculated using facility effluent data when environmental concentrations are too low to measure accurately.

The calculation of the effective dose equivalent takes into account, the long-term (50-yr) internal exposure from radionuclides taken into the body during the current year. The effective dose equivalent is the sum of individual committed (50-yr) organ doses multiplied by weighting factors that represent the proportion of the total health effect risk that each organ would receive from uniform irradiation of the whole body. Internal organs may also be irradiated from external sources of radiation. The external exposure received during the current year is added to the committed internal dose to obtain the total effective dose equivalent. In this report, the effective dose equivalent is expressed in rem (or millirem) with the corresponding value in sievert (or millisievert) in parentheses. The numerous transfer factors used for pathway and dose calculations have been documented in GENII (PNL-6584) and in PNL-3777, Rev. 2.

The following types of radiological doses were estimated.

Boundary Dose Rate (mrem/h and mrem/yr). The external radiological dose rates during the year in areas accessible by the general public were determined from measurements obtained near operating facilities.

Maximally Exposed Individual Dose (mrem). The maximally exposed individual is a hypothetical member of the public who lives at a location and has a lifestyle such that it is unlikely that other members of the public would receive higher doses. All potentially significant exposure pathways to this hypothetical individual were considered, including the following:

- inhalation of airborne radionuclides
- submersion in airborne radionuclides
- ingestion of foodstuffs contaminated by radionuclides deposited on vegetation and the ground by both airborne deposition and irrigation water drawn from the Columbia River downstream of N Reactor
- exposure to ground contaminated by both airborne deposition and irrigation water
- ingestion of fish taken from the Columbia River
- recreation along the Columbia River, including boating, swimming, and shoreline activities.

80-km (50-mi) Population Doses (person-rem). Regulatory limits have not been established for population doses. However, evaluation of the collective population doses to all residents within an 80-km (50-mi) radius of Hanford Site operations is required by DOE Order 5400.5. The radiological dose to the collective population within 80 km (50 mi) of the site was calculated to demonstrate compliance with environmental regulations, confirm adherence to DOE environmental protection policies, and provide information to the public. The 80-km (50-mi) population dose is the sum of the product of the individual doses and the number of individuals exposed for all pathways.

Pathways similar to those used for the maximally exposed individual were used to calculate doses to the offsite population. In calculating the effective dose, an estimate was made of the fraction of the

offsite population expected to be affected by each pathway. The exposure pathways for the population are as follows.

Drinking Water. The cities of Richland and Pasco obtain their municipal water directly and Kennewick indirectly from the Columbia River downstream from the Hanford Site. A total population of approximately 70,000 in the three cities drinks water derived from the Columbia River.

Irrigated Food. Columbia River water is withdrawn for irrigation of small vegetable gardens and farms in the Riverview district of Pasco in Franklin County. Enough food is grown in this district to feed an estimated 2,000 people. Commercial crops are also irrigated by Columbia River water in the Horn Rapids area of Benton County. These crops are widely distributed.

River Recreation. These activities include swimming, boating, and shoreline recreation. Specific pathways include external exposure from radionuclides in the water or on the shoreline and ingestion of river water while swimming. An estimated 125,000 people who reside within 80 km (50 mi) of the Hanford Site are assumed to be affected by these pathways.

Fish Consumption. Population doses from the consumption of fish obtained locally from the Columbia River were calculated from an estimated total annual catch of 15,000 kg/yr (33,075 lb/yr) (without reference to a specified human group of consumers).

Data

The data that are needed to perform dose calculations are based on either measured upstream/downstream differences or measured effluent releases and include information on initial transport through the atmosphere or river, transfer or accumulation in terrestrial and aquatic pathways, and public exposure. By comparison, radiological dose calculations based on measured activities of radionuclides in food require data describing only dietary and recreational activities and exposure times. These data are discussed below.

Population Distribution and Atmospheric Dispersion

Geographic distributions of the population residing within an 80-km (50-mi) radius of the Hanford Site operating areas are shown in PNNL-12088, APP. 1. These distributions are based on 1990 Bureau of the Census data (PNL-7803). These data influence the population dose by providing estimates of the number of people exposed to radioactive effluents and their proximity to the points of release.

Atmospheric dispersion data are also shown in PNNL-12088, APP. 1. These data describe the transport and dilution of airborne radioactive material, which influences the amounts of radionuclides being transported through the air to specific locations.

Terrestrial and Aquatic Pathways

Important parameters affecting the movement of radionuclides within exposure pathways such as irrigation rates, growing periods, and holdup periods are listed in Table D.1. Certain parameters are specific to the lifestyles of either "maximally exposed" or "average" individuals.

Public Exposure

The offsite radiological dose is related to the extent of external exposure to or intake of

Table D.1. Food Pathway Parameters Used in Dose Calculations, 1998

Medium	Holdup, d[a] Maximally Exposed Individual	Holdup, d[a] Average Individual	Growing Period, d	Yield, kg/m²	Irrigation Rate, L/m²/mo
Leafy vegetables	1	14	90	1.5	150
Other vegetables	5	14	90	4	170
Fruit	5	14	90	2	150
Cereal	180	180	90	0.8	0
Eggs	1	18	90	0.8	0
Milk	1	4	--	--	--
Hay	(100)[b]	(100)	45	2	200
Pasture	(0)	(0)	30	1.5	200
Red meat	15	34	--	--	--
Hay	(100)	(100)	45	2	200
Grain	(180)	(180)	90	0.8	0
Poultry	1	34	90	0.8	0
Fish	1	1	--	--	--
Drinking water	1	1	--	--	--

(a) Holdup is the time between harvest and consumption.
(b) Values in ( ) are the holdup in days between harvest and consumption by farm animals.

radionuclides released from Hanford Site operations. Tables D.2 through D.4 give the parameters describing the diet, residency, and river recreation assumed for "maximally exposed" and "average" individuals.

Dose Calculation Documentation

DOE established the Hanford Dose Overview Panel to promote consistency and defensibility of environmental dose calculations at Hanford. The panel has the responsibility for defining standard, documented computer codes and input parameters to be used for radiological dose calculations for the public in the vicinity of the Hanford Site. Only those procedures, models, and parameters previously defined by the panel were used to calculate the radiological doses (PNL-3777, Rev. 2). The calculations were then reviewed by the panel. Summaries of dose calculation technical details for this report are shown in Tables D.5 through D.9 and in PNNL-12088, APP. 1.

400 Area Drinking Water

Drinking water at the Fast Flux Test Facility contained slightly elevated levels of tritium. The potential doses to 400 Area workers consuming this water in 1998 are given in Table D.10.

300 Area Drinking Water

In 1998, water to the 300 Area was primarily obtained from the Columbia River and supplied by the 312 Pumphouse. The potential doses to people consuming this water in 1998 are given in Table D.11.

Table D.2. Dietary Parameters Used in Dose Calculations, 1998

Medium	Consumption: Maximally Exposed Individual	Consumption: Average Individual
Leafy vegetables	30 kg/yr	15 kg/yr
Other vegetables	220 kg/yr	140 kg/yr
Fruit	330 kg/yr	64 kg/yr
Grain	80 kg/yr	72 kg/yr
Eggs	30 kg/yr	20 kg/yr
Milk	270 L/yr	230 L/yr
Red meat	80 kg/yr	70 kg/yr
Poultry	18 kg/yr	8.5 kg/yr
Fish	40 kg/yr	--[a]
Drinking water	730 L/yr	440 L/yr

(a) Average individual consumption not identified; radiation doses were calculated based on estimated total annual catch of 15,000 kg (33,075 lb).

Table D.3. Residency Parameters Used in Dose Calculations, 1998

Parameter	Exposure, h/yr: Maximally Exposed Individual	Exposure, h/yr: Average Individual
Ground contamination	4,383	2,920
Air submersion	8,766	8,766
Inhalation[a]	8,766	8,766

(a) Inhalation rates: adult 270 cm^3/s.

Table D.4. Recreational Parameters Used in Dose Calculations, 1998

Parameter	Exposure, h/yr[a] Maximally Exposed Individual	Average Individual
Shoreline	500	17
Boating	100	5
Swimming	100	10

(a) Assumed river-water travel times from 100-N Area to the point of aquatic recreation were 8 h for the maximally exposed individual and 13 h for the average individual. Correspondingly lesser times were used for other locations.

Table D.5. Technical Details of 100 Areas Airborne Release Dose Calculations, 1998

Facility name	100-N Area
Releases (Ci)	^{90}Sr (1.7×10^{-5}), ^{137}Cs (3.0×10^{-5}), ^{238}Pu (5.2×10^{-7}), $^{239,240}Pu$ (3.4×10^{-6})[a], ^{241}Pu (3.8×10^{-5}), ^{241}Am (2.0×10^{-6})
Meteorological conditions	1998 annual average, calculated from data collected at the 100-N Area and the Hanford Meteorology Station from January through December 1998, using the computer code HANCHI
$\overline{X}/Q'$	Maximally exposed individual, 1.1×10^{-8} s/m^3 at 41 km (26 mi) SE; 80-km (50-mi) population, 1.0×10^{-2} s/m^3 person-s/m^3
Release height	10-m (33-ft) effective stack height
Population distribution	375,000 (PNNL-11796, Table D-1)
Computer code	GENII, Version 1.485, December 3, 1990 (e.g., PNL-6584)
Doses calculated	Chronic, 1-yr exposure, 50-yr committed internal dose equivalent, and annual effective dose equivalent to individual and population
Pathways considered	External exposure to plume and ground deposits Inhalation Ingestion of locally produced foods
Files addressed	Radionuclide Library, Rev. 7-1-92 Food Transfer Library, Rev. 8-29-88 External Dose Factor Library, Rev. 5-9-88 Internal Dose Factor Library, Rev. 12-3-90

(a) This value includes gross alpha release data. Gross alpha and unspecified alpha results assumed to be $^{239,240}Pu$ for dose calculations.

Table D.6. Technical Details of 100-N Area Liquid Release Dose Calculations, 1998

Facility name	100-N Area
Releases (Ci)	^{3}H (2.9×10^{-1}), ^{90}Sr (2.9×10^{-1}), ^{239}Pu (1.3×10^{-6}), ^{241}Am (1.7×10^{-5})
Mean river flow	3,255 m^3/s (115,000 ft^3/s)
Shore-width factor	0.2
Population distribution	70,000 for drinking water pathway 125,000 for aquatic recreation 2,000 for consumption of irrigated foodstuffs 15,000 kg/yr (33,075 lb/yr) total harvest of Columbia River fish
Computer code	GENII, Version 1.485, December 3, 1990 (e.g., PNL-6584)
Doses calculated	Chronic, 1-yr exposure, 50-yr committed internal dose equivalent, and annual effective dose equivalent to individual and population
Pathways considered	External exposure to irrigated soil, to river water, and to shoreline sediments Ingestion of aquatic foods and irrigated farm products
Files addressed	Radionuclide Library, Rev. 7-1-92 Food Transfer Library, Rev. 8-29-88 External Dose Factor Library, Rev. 5-9-88 Internal Dose Factor Library, Rev. 12-3-90 Bioaccumulation Factor Library, Rev. 10-26-92

Table D.7. Technical Details of 200 Areas Airborne Release Dose Calculations, 1998

Facility name	200 Areas
Releases (Ci)	200-East Area ^{90}Sr (1.2×10^{-4})[a], ^{125}Sb (4.8×10^{-7}), ^{129}I (3.1×10^{-4}), ^{137}Cs (1.9×10^{-4}), ^{238}Pu (7.9×10^{-10}), $^{239,240}Pu$ (1.1×10^{-6})[b], ^{241}Pu (2.9×10^{-8}), ^{241}Am (5.0×10^{-7}) 200-West Area ^{90}Sr (2.3×10^{-4})[a], ^{137}Cs (3.2×10^{-9}), ^{238}Pu (3.4×10^{-6}), $^{239,240}Pu$ (2.0×10^{-4})[b], ^{241}Pu (4.4×10^{-5}), ^{241}Am (3.0×10^{-5})
Meteorological conditions	1998 annual average, calculated from data collected at the Hanford Meteorology Station from January through December 1998, using the computer code HANCHI
$\overline{X}/Q'$	Maximally exposed individual, 7.6×10^{-9} s/m^3 at 28 km (17 mi) SE; 80-km (50-mi) population, 7.3×10^{-3} person-s/m^3
Release height	89-m (292-ft) effective stack height
Population distribution	376,000 (PNNL-11796, Table D-2)
Computer code	GENII, Version 1.485, December 3, 1990 (e.g., PNL-6584)
Doses calculated	Chronic, 1-yr exposure, 50-yr committed internal dose equivalent, and annual effective dose equivalent to individual and population
Pathways considered	External exposure to plume and ground deposits Inhalation Ingestion of locally produced foods
Files addressed	Radionuclide Library, Rev. 7-1-92 Food Transfer Library, Rev. 8-29-88 External Dose Factor Library, Rev. 5-9-88 Internal Dose Factor Library, Rev. 12-3-90

(a) This value includes gross beta release data. Gross beta and unspecified beta results assumed to be ^{90}Sr for dose calculations.
(b) This value includes gross alpha release data. Gross alpha and unspecified alpha results assumed to be $^{239,240}Pu$ for dose calculations.

Table D.8. Technical Details of 300 Area Airborne Release Dose Calculations, 1998

Facility name	300 Area
Releases (Ci)[a]	^{3}H (as HTO)[b] (6.5×10^{1}), ^{3}H (as HT)[b] (9.3×10^{1}), ^{90}Sr (9.6×10^{-6})[c], ^{129}I (4.6×10^{-8}), ^{137}Cs (5.8×10^{-7}), ^{238}Pu (1.7×10^{-9}), $^{239,240}Pu$ (1.1×10^{-6})[d], ^{241}Am (2.3×10^{-8})
Meteorological conditions	1998 annual average, calculated from data collected at the 300 Area and the Hanford Meteorology Station from January through December 1998, using the computer code HANCHI
$\overline{X}/Q'$	Maximally exposed individual at residence, 8.2×10^{-7} s/m^3 at 1.5 km (1 mi) E; 80-km (50-mi) population, 1.4×10^{-1} person-s/m^3
Release height	10 m (33 ft)
Population distribution	282,000 (PNNL-11796, Table D-3)
Computer code	GENII, Version 1.485, December 3, 1990 (e.g., PNL-6584)
Doses calculated	Chronic, 1-yr exposure, 50-yr committed internal dose equivalent, and annual effective dose equivalent to individual and population
Pathways considered	External exposure to plume and ground deposits Inhalation Ingestion of locally produced foods
Files addressed	Radionuclide Library, Rev 7-1-92 Food Transfer Library, Rev. 8-29-88 External Dose Factor Library, Rev. 5-9-88 Internal Dose Factor Library, Rev. 12-3-90

(a) These release quantities do not include 17 Ci (HT) and 106 Ci (HTO), which were released acutely on August 26, 1998 and which are addressed separately in Section 2.4.2.
(b) HT = elemental tritium; HTO = tritiated water vapor.
(c) This value includes gross beta release data. Gross beta and unspecified beta results assumed to be ^{90}Sr for dose calculations.
(d) This value includes gross alpha release data. Gross alpha and unspecified alpha results assumed to be $^{239,240}Pu$ for dose calculations.

Table D.9. Technical Details of 400 Area Airborne Release Dose Calculations, 1998

Facility name	400 Area
Releases (Ci)	^{3}H (as HTO)[a] (4.2×10^{0}), ^{137}Cs (5.5×10^{-6})[b], $^{239,240}Pu$ (5.0×10^{-7})[c]
Meteorological conditions	1998 annual average, calculated from data collected at the 400 Area and the Hanford Meteorology Station from January through December 1998, using the computer code HANCHI
$\overline{X}/Q'$	Maximally exposed individual at residence, 9.6×10^{-8} s/m^3 at 11 km (7 mi) SE; 80-km (50-mi) population, 1.3×10^{-1} person-s/m^3
Release height	10 m (33 ft)
Population distribution	283,000 (PNNL-11796, Table D-4)
Computer code	GENII, Version 1.485, December 3, 1990 (e.g., PNL-6584)
Doses calculated	Chronic, 1-yr exposure, 50-yr committed internal dose equivalent, and annual effective dose equivalent to individual and population
Pathways considered	External exposure to plume and ground deposits Inhalation Ingestion of locally produced foods
Files addressed	Radionuclide Library, Rev 7-1-92 Food Transfer Library, Rev. 8-29-88 External Dose Factor Library, Rev. 5-9-88 Internal Dose Factor Library, Rev. 12-3-90

(a) HTO = tritiated water vapor.
(b) ^{137}Cs value for the 400 Area is derived fully from gross beta measurements.
(c) This value includes gross alpha release data. Gross alpha and unspecified alpha results assumed to be $^{239,240}Pu$ for dose calculations.

Table D.10. Annual Dose to Workers in the 400 Area from Ingestion of Drinking Water Obtained from Groundwater Wells

Radionuclide	Drinking Water Activity, pCi/L[a]	Intake, pCi/yr[b]	Ingestion Dose Factor, rem/pCi[c]	Ingestion Dose, rem/yr (Sv/yr)
Gross alpha[d]	0.97 ± 2.4	233	2.83×10^{-7}	6.6×10^{-5} (6.6×10^{-7})
Gross beta[e]	6.36 ± 1.6	1,526	5.00×10^{-8}	7.6×10^{-5} (7.6×10^{-7})
Tritium	4,913 ± 658	1.18×10^{6}	6.40×10^{-11}	7.5×10^{-5} (7.5×10^{-7})
^{90}Sr	0.014 ± 0.048	3.36	1.42×10^{-7}	4.8×10^{-7} (4.8×10^{-9})
Total				2.2×10^{-4} (2.2×10^{-6})

(a) Drinking water activities are annual averages obtained from monthly samples taken during 1998.
(b) Intake is based on the assumption that a worker ingests 1 L/d of groundwater during the entire working year (taken to be 240 d for the analysis).
(c) Ingestion intake-to-dose conversion factors are taken from EPA/520/1-88-020 and converted from International System of Units (SI). Where the document lists dose factors for more than one chemical form of a radionuclide, the most soluble chemical form was assumed.
(d) Gross alpha activities were assumed to be ^{234}U for the purposes of this analysis.
(e) Gross beta activities were assumed to be ^{137}Cs for the purposes of this analysis.

Table D.11. Annual Dose to Workers in the 300 Area from Ingestion of Drinking Water Obtained from the Columbia River

Radionuclide	Drinking Water Activity, pCi/L[a]	Intake, pCi/yr[b]	Ingestion Dose Factor, rem/pCi[c]	Ingestion Dose, rem/yr (Sv/yr)
Gross alpha[d]	1.65 ± 1.52	396	2.83×10^{-7}	1.1×10^{-4} (1.1×10^{-6})
Gross beta[e]	1.68 ± 1.80	403	5.0×10^{-8}	2.0×10^{-5} (2.0×10^{-7})
Tritium	277 ± 347	66,480	6.4×10^{-11}	4.3×10^{-6} (4.3×10^{-8})
^{90}Sr	0.07 ± 0.08	16.8	1.42×10^{-7}	2.4×10^{-6} (2.4×10^{-8})
^{234}U	0.91 ± 0.88	218	2.83×10^{-7}	6.2×10^{-5} (6.2×10^{-7})
^{235}U	0.033 ± 0.038	7.9	2.66×10^{-7}	2.1×10^{-6} (2.1×10^{-8})
^{238}U	0.80 ± 0.86	192	2.55×10^{-7}	4.9×10^{-5} (4.9×10^{-7})
Total				2.5×10^{-4} (2.5×10^{-6})

(a) Drinking water activities are annual averages obtained from monthly samples taken during 1998.
(b) Intake is based on the assumption that a worker ingests 1 L/d of groundwater during the entire working year (taken to be 240 d for the analysis).
(c) Ingestion intake-to-dose conversion factors are taken from EPA/520/1-88-020 and converted from International System of Units (SI). Where the document lists dose factors for more than one chemical form of a radionuclide, the most soluble chemical form was assumed.
(d) Gross alpha activities were assumed to be ^{234}U for the purposes of this analysis.
(e) Gross beta activities were assumed to be ^{137}Cs for the purposes of this analysis.

References

40 CFR 61, Subpart H. U.S. Environmental Protection Agency. "National Emission Standards for Hazardous Air Pollutants." *Code of Federal Regulations*.

DOE Order 5400.5. "Radiation Protection of the Public and the Environment."

DOE/RL-99-41. 1999. *Radionuclide Air Emissions Report for the Hanford Site, Calendar Year 1998.* B. P. Gleckler and K. Rhóads, Waste Management Federal Services of Hanford, Inc. for U.S. Department of Energy, Richland Operations Office, Richland, Washington.

EPA/520/1-88-020. 1988. *Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion. Federal Guidance Report No. 11.* K. F. Eckerman, A. B. Wolbarst, and A.C.B. Richardson, Office of Radiation Programs, U.S. Environmental Protection Agency, Washington, D.C.

International Commission on Radiological Protection. 1979a. "ICRP Publication 30, Part 1, Limits for Intakes of Radionuclides by Workers." *Annals of the ICRP* 2:3/4, Pergamon Press, Elmsford, New York.

International Commission on Radiological Protection. 1979b. "ICRP Publication 30, Supplement to Part 1, Limits for Intakes of Radionuclides by Workers." *Annals of the ICRP* 3:1-4, Pergamon Press, Elmsford, New York.

International Commission on Radiological Protection. 1980. "ICRP Publication 30, Part 2, Limits for Intakes of Radionuclides by Workers." *Annals of the ICRP* 4:3/4, Pergamon Press, Elmsford, New York.

International Commission on Radiological Protection. 1981a. "ICRP Publication 30, Supplement to Part 2, Limits for Intakes of Radionuclides by Workers." *Annals of the ICRP* 5:1-6, Pergamon Press, Elmsford, New York.

International Commission on Radiological Protection. 1981b. "ICRP Publication 30, Part 3 Including Addendum to Parts 1 and 2, Limits for Intakes of Radionuclides by Workers." *Annals of the ICRP* 6:2/3, Pergamon Press, Elmsford, New York.

International Commission on Radiological Protection. 1982a. "ICRP Publication 30, Supplement A to Part 3, Limits for Intakes of Radionuclides by Workers." *Annals of the ICRP* 7:1-3, Pergamon Press, Elmsford, New York.

International Commission on Radiological Protection. 1982b. "ICRP Publication 30, Supplement B to Part 3 Including Addendum to Supplements to Parts 1 and 2, Limits for Intakes of Radionuclides by Workers." *Annals of the ICRP* 8:1-3, Pergamon Press, Elmsford, New York.

International Commission on Radiological Protection. 1988. "ICRP Publication 30, Part 4, Limits for Intakes of Radionuclides by Workers: an Addendum." *Annals of the ICRP* 19:4, Pergamon Press, Elmsford, New York.

PNL-3777, Rev. 2. 1993. *Recommended Environmental Dose Calculation Methods and Hanford-Specific Parameters.* R. G. Schreckhise, K. Rhoads, J. S. Davis, B. A. Napier, and J. V. Ramsdell, Pacific Northwest Laboratory, Richland, Washington.

PNL-6584. 1988. *GENII - The Hanford Environmental Radiation Dosimetry Software System.* B. A. Napier, R. A. Peloquin, D. L. Strenge, and J. V. Ramsdell, Pacific Northwest Laboratory, Richland, Washington, 3 vols.

PNL-7803. 1991. *Hanford Area 1990 Population and 50-Year Projections.* D. M. Beck, B. A. Napier, M. J. Scott, A. G. Thurman, M. D. Davis, D. B. Pittenger, S. F. Shindle, and N. C. Batishko, Pacific Northwest Laboratory, Richland, Washington.

PNL-8150. 1992. *Methods for Estimating Doses to Organisms from Radioactive Materials Released into the Aquatic Environment.* D. A. Baker and J. K. Soldat, Pacific Northwest Laboratory, Richland, Washington.

PNNL-11796. 1998. *Hanford Site Environmental Data for Calendar Year 1997.* L. E. Bisping, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-12088, APP. 1. 1999. *Hanford Site Environmental Surveillance Data for Calendar Year 1998.* L. E. Bisping, Pacific Northwest National Laboratory, Richland, Washington.

Appendix E

Radionuclides Detected by Gamma Spectroscopy (Gamma Scan)

One of the several forms of radiation is gamma radiation. Gamma radiation is emitted by many radionuclides. Gamma spectroscopy, sometimes called a gamma scan, is used to detect the presence of the radionuclides shown in Table E.1. These radionuclides may be natural or result from Hanford Site activities. They include activation products formed by the absorption of a neutron by a stable element and fission products that occur following fission (splitting) of nuclear fuel radionuclides such as uranium-235 or plutonium-239. Some of these radionuclides may not be discussed in the main body of this report if they are below detection levels.

Table E.1. Radionuclides Analyzed by Gamma Spectroscopy

Radionuclide	Symbol	Source
Beryllium-7	^{7}Be	Natural
Sodium-22	^{22}Na	Activation product
Sodium-24	^{24}Na	Activation product
Potassium-40	^{40}K	Natural
Manganese-54	^{54}Mn	Activation product
Cobalt-58	^{58}Co	Activation product
Cobalt-60	^{60}Co	Activation product
Iron-59	^{59}Fe	Activation product
Zinc-65	^{65}Zn	Activation product
Zirconium/niobium-95	$^{95}Zr/Nb$	Activation product and fission product
Molybdenum-99	^{99}Mo	Activation product and fission product
Ruthenium-103	^{103}Ru	Activation product and fission product
Ruthenium-106	^{106}Ru	Fission product
Antimony-125	^{125}Sb	Activation product
Iodine-131	^{131}I	Fission product
Cesium-134	^{134}Cs	Activation product
Cesium-137	^{137}Cs	Fission product
Barium/lanthanum-140	$^{140}Ba/La$	Fission product
Cerium-141	^{141}Ce	Activation product and fission product
Cerium/praseodymium-144	$^{144}Ce/Pr$	Fission product
Europium-152	^{152}Eu	Activation product
Europium-154	^{154}Eu	Activation product
Europium-155	^{155}Eu	Activation product

Appendix F
Threatened and Endangered Species

B. L. Tiller

This appendix discusses the federal and state threatened and endangered species, candidate species, and plant species of concern potentially found on the Hanford Site. Threatened and endangered species are listed by the federal government in Title 50, Code of Federal Regulations, Part 17 (50 CFR 17); Washington Natural Heritage Program (1997); and Washington State Department of Fish and Wildlife (1996).

The purposes of the Endangered Species Act of 1973, as amended, are to 1) provide a means to conserve critical ecosystems, 2) provide a program for the conservation of threatened and endangered species, and 3) ensure that appropriate steps are taken to achieve the purposes of the treaties and conventions established in the Act. Threatened and endangered species of plants and animals occurring or potentially occurring on the Hanford Site are listed in Table F.1.

Identification of candidate species can assist environmental planning efforts by providing advance notice of potential listing as a threatened or endangered species, allowing resource managers to alleviate threats and thereby possibly remove the need to list species as endangered or threatened. Even if a candidate species is subsequently listed, the early notice could result in fewer restrictions on human activities in the environment by prompting candidate conservation measures to alleviate threats to the species. Washington State candidate animal species potentially found on the Hanford Site are listed in Table F.2. Plant species not listed as threatened or endangered but considered "candidates" for listing are identified by Washington State as "species of concern;" those potentially found on the Hanford Site are listed in Table F.3.

Hanford Status

No plants or mammals on the federal list of endangered and threatened species (50 CFR 17) are known to occur on the Hanford Site. There are, however, three species of birds and two fish on the federal list of threatened and endangered species (see Table F.1). In addition, nine species of plants, seven species of birds, and one mammalian species have been listed as either threatened or endangered by Washington State. The National Marine Fisheries Service has the responsibility for the federal listing of anadromous fish (i.e., those which require both saltwater and freshwater to complete a life cycle). Upper-Columbia River steelhead and upper-Columbia River spring-run chinook salmon were listed as endangered in August 1998 and March 1999, respectively.

Several species of both plants and animals are under consideration for formal listing as candidate species by Washington State. There are 19 state-level candidate species of plants and animals (see Table F.2) and 42 plant species of concern (see Table F.3).

Table F.1. Federal- or Washington State-Listed Threatened (T) and Endangered (E) Species Occurring or Potentially Occurring on the Hanford Site

Common Name	Scientific Name	Federal	State
Plants			
Columbia milkvetch	*Astragalus columbianus*		T
Columbia yellowcress	*Rorippa columbiae*		T
Dwarf evening primrose	*Camissonia (= Oenothera) pygmaea*		T
Hoover's desert parsley	*Lomatium tuberosum*		T
Loeflingia	*Loeflingia squarrosa var. squarrosa*		T
Northern wormwood[a]	*Artemisia campestris borealis* var. *wormskioldii*		E
Umtanum desert buckwheat	*Eriogonum codium*		E
White Bluffs bladderpod	*Lesquerella tuplashensis*		E
White eatonella	*Eatonella nivea*		T
Fish			
Spring-run chinook	*Oncorhynchus tshawytscha*	E	
Steelhead	*Oncorhynchus mykiss*	E	
Birds			
Aleutian Canada goose[b]	*Branta canadensis leucopareia*	T	T
American white pelican	*Pelecanus erythrorhychos*		E
Bald eagle	*Haliaeetus leucocephalus*	T	T
Ferruginous hawk	*Buteo regalis*		T
Peregrine falcon[b]	*Falco peregrinus*	E	E
Sandhill crane	*Grus canadensis*		E
Western sage grouse[a]	*Centrocercus urophasianus phaios*		T
Mammals			
Pygmy rabbit[a]	*Brachylagus idahoensis*		E

(a) Potentially occurring.
(b) Incidental occurrence.

Table F.2. Washington State Candidate Animal Species Potentially Found on the Hanford Site

Common Name	Scientific Name
Molluscs	
Columbia pebble snail	*Fluminicola (= Lithoglyphus) columbiana*
Shortfaced lanx	*Fisherola (= Lanx) nuttalli*
Insects	
Columbia River tiger beetle[a]	*Cicindela columbica*
Juniper hairstreak	*Mitoura siva*
Silver-bordered bog fritillary	*Boloria selene atrocastalis*
Birds	
Burrowing owl	*Athene cunicularia*
Common loon	*Gavia immer*
Flammulated owl[b]	*Otus flammeolus*
Golden eagle	*Aquila chrysaetos*
Lewis' woodpecker[b]	*Melanerpes lewis*
Loggerhead shrike	*Lanius ludovicianus*
Merlin	*Falco columbarius*
Northern goshawk[b]	*Accipter gentilis*
Sage sparrow	*Amphispiza belli*
Sage thrasher	*Oreoscoptes montanus*
Reptiles	
Striped whipsnake[b]	*Masticophis taeniatus*
Mammals	
Merriam's shrew	*Sorex merriami*
Townsend's big-eared bat[a]	*Coryhorhinus townsendii*[c]
Washington ground squirrel[b]	*Spermophilus washingtoni*

(a) Probable, but not observed, on the Hanford Site.
(b) Reported, but seldom observed, on the Hanford Site.
(c) Formally known as *Plecotus townsendii*.

Table F.3. Washington State Plant Species of Concern Occurring on the Hanford Site

Common Name	Scientific Name	State Listing[a]
Annual paintbrush	*Castilleja exilis*	R1
Awned half chaff sedge	*Lipocarpha (= Hemicarpha) aristulata*	R1
Basalt milk-vetch	*Astragalus conjunctus var. rickardii*	R1
Bristly combseed	*Pectocarya setosa*	W
Brittle prickly-pear	*Opuntia fragilis*	R1
Canadian St. John's wort	*Hypericum majus*	S
Chaffweed	*Centunculus minimus*	R1
Columbia River mugwort	*Artemesia lindleyana*	W
Crouching milkvetch	*Astragalus succumbens*	W
Desert dodder	*Cuscuta denticulata*	S
Desert evening-primrose	*Oenothera cespitosa*	S
False pimpernel	*Lindernia dubia anagallidea*	R2
Fuzzytongue penstemon	*Penstemon eriantherus whitedii*	R1
Geyer's milkvetch	*Astragalus geyeri*	S
Grand redstem	*Ammannia robusta*	R1
Gray cryptantha	*Cryptantha leucophaea*	S
Great Basin gilia	*Gilia leptomeria*	R1
Hedge hog cactus	*Pediocactus simpsonii var. robustio nigrispinus*	R1
Kittitas larkspur	*Delphinium multiplex*	W
Miner's candle	*Cryptantha scoparia*	R1
Palouse thistle	*Cirsium brevifolium*	W
Piper's daisy	*Erigeron piperianus*	S
Robinson's onion	*Allium robinsonii*	W
Rosy balsamroot	*Balsamorhiza rosea*	W
Rosy pussypaws	*Calyptridium roseum*	S
Scilla onion	*Allium scilloides*	W
Shining flatsedge	*Cyperus bipartitus (rivularis)*	S
Small-flowered evening-primrose	*Camissonia (= Oenothera) minor*	R1
Small-flowered nama	*Nama densum var. parviflorum*	R1
Smooth cliffbrake	*Pellaea glabella simplex*	W
Snake River cryptantha	*Cryptantha spiculifera (= C. interrupta)*	S
Southern mudwort	*Limosella acaulis*	W
Stalked-pod milkvetch	*Astragalus sclerocarpus*	W
Suksdorf's monkey flower	*Mimulus suksdorfii*	S
Toothcup	*Rotala ramosior*	R1
Winged combseed	*Pectocarya linearis*	R1

The following species have been reported as occurring on the Hanford Site, but the known collections are questionable in terms of location or identification, and have not been recently collected on the Hanford Site.

Coyote tobacco	*Nicotiana attenuata*	S
Dense sedge	*Carex densa*	S
Few-flowered collinsia	*Collinsia sparsiflora var. bruciae*	S
Medic milkvetch	*Astragalus speirocarpus*	W
Palouse milkvetch	*Astragalus arrectus*	S
Thompson's sandwort	*Arenaria franklinii thompsonii*	R2

(a) S = Sensitive (i.e., taxa vulnerable or declining) and could become endangered or threatened without active management or removal of threats.
R1 = Taxa for which there are insufficient data to support listing as threatened, endangered, or sensitive (formerly monitor group 1).
R2 = Taxa with unresolved taxanomic questions (formerly monitor group 2).
W = Taxa that are more abundant and/or less threatened than previously assumed (formerly monitor group 3).

References

50 CFR 17. U.S. Fish and Wildlife Service, Department of the Interior. "Endangered and Threatened Wildlife and Plants." *Code of Federal Regulations.*

Endangered Species Act. 1973. Public Laws 93-205 through 100-707.

Washington Natural Heritage Program. 1997. *Rare Plant Species County List.* Washington State Department of Natural Resources, Olympia, Washington. Available URL: http://www.wa.gov/dnr/htdocs/fr/nhp/plantco.html

Washington State Department of Fish and Wildlife. 1996. *Priority Habitats and Species List.* Olympia, Washington. Available URL: http://www.wa.gov/wdfw/hab/phspage.htm

PNNL-12088
UC-602

Distribution

No. of
Copies

OFFSITE

M. T. Adams, MS-T8-D14
U.S. Nuclear Regulatory Commission
Washington, DC 20555

L. Albin
Division of Radiation Protection
Washington State Department of Health
P.O. Box 47827
Olympia, WA 98504-7827

T. Allgood
Environmental Action Program
Coeur d'Alene Tribal Council
P.O. Box 408
Plummer, ID 83851

M. Arnett
Westinghouse Savannah River Company
Building 735-11A
Savannah River Site
Aiken, SC 29808

M. R. Ault
US Ecology, Inc.
P.O. Box 638
Richland, WA 99352

H. Babad
2540 Cordoba Court
Richland, WA 99352

No. of
Copies

J. Bargar, MS-69
Stanford Synchrotron Radiation Laboratory
P.O. Box 4349
Stanford, CA 94309-0210

J. Bartel, MS 9221
Sandia National Laboratories
P.O. Box 969
Livermore, CA 94550

Basin City Branch of Mid-Columbia Library
50-A N. Canal Blvd.
Basin City, WA 99343

Benton City Branch of the Mid-Columbia
Library
City Hall
Benton City, WA 99320

Benton Clean Air Authority
650 George Washington Way
Richland, WA 99352

T. Berkompas
Yakama Indian Agency
P.O. Box 632
Toppenish, WA 98948-0632

R. P. Berube
Principal Deputy Assistant Secretary
Office of Environment, Safety, and Health
U.S. Department of Energy, EH-4
1000 Independence Avenue S.E.
Washington, DC 20585

No. of
Copies

M. L. Blazek
Manager, Radioactive Materials Department
Oregon Department of Energy
625 Marion Street N.E.
Salem, OR 97310

2 C. M. Borgstrom
Director, Office of NEPA Project Assistance
U.S. Department of Energy, EH-42
1000 Independence Avenue S.E.
Washington, DC 20585

L. Bowman
Benton County Commissioner
P.O. Box 190
Prosser, WA 99350

B. Boyum
Washington State Department of Natural Resources, Southeast Region
713 E. Bowers Road
Ellensburg, WA 98926

M. S. Broido
Director, Environmental Sciences Division
U.S. Department of Energy, ER-74
19901 Germantown Road
Germantown, MD 20876-1290

D. F. Brown
COESP Manager
4503 Fairbrook Drive
Yakima, WA 98908

M. Brown
Brown and Guis Farms
Star Route 1
Royal City, WA 99357

No. of
Copies

Burbank Community Library
50 Maple
Burbank, WA 99323

Bureau of Land Management
Spokane District Office
1103 N. Fancher
Spokane, WA 99212

N. Buske
1528 W. 6th Avenue #3
Spokane, WA 99204

C. Cannon
ATG, Inc.
P.O. Box 969
Richland, WA 99352

P. Charp
Agency for Toxic Substances and Disease Registry, E-56
1600 Clifton Road
Atlanta, GA 30333

C. Clarke, RA-140
Regional Administrator
U.S. Environmental Protection Agency
1200 6th Avenue
Seattle, WA 98101

J. Clements, Tribal Chairman
Confederated Tribes of the Warm Springs Reservation
P.O. Box 1299
Warm Springs, OR 97761

A. W. Conklin
Division of Radiation Protection
Washington State Department of Health
P.O. Box 47827
Olympia, WA 98504-7827

No. of
Copies

Connell Branch of the Mid-Columbia Library
130 Columbia
Connell, WA 99326

S. Cox
U.S. Geological Survey
1201 Pacific Avenue, Suite 600
Tacoma, WA 98402

J. R. Craig, Director
U.S. Department of Energy
P.O. Box 538705
Cincinnati, OH 45253-8705

A. Danielson
Washington State Department of Health
2 South 45th Avenue
Yakima, WA 98908

M. Davis
Columbia-Cascades Office
National Park Service
909 First Avenue
Seattle, WA 98104

R. Day
Office of Operating Experience, Analysis and Feedback
U.S. Department of Energy, EH-33
19901 Germantown Road
Germantown, MD 20874-1290

G. deBruler
Columbia River United
P.O. Box 912
Bingen, WA 98605

D. Delistraty
Washington State Department of Ecology
N. 4601 Monroe, Suite 202
Spokane, WA 99205-1295

No. of
Copies

L. DeWitt
COESP Manager
312 S. Columbia Center Blvd.
Kennewick, WA 99336

R. W. Donovan
Technological Hazards Branch Chief
Region X, Federal Regional Center
Federal Emergency Management Agency
130 228th Street S.W.
Bothell, WA 98021-9796

T. Droppo
COESP Manager
3621 W. Sylvester
Pasco, WA 99301

B. Drost
U.S. Geological Survey
1201 Pacific Avenue, Suite 600
Tacoma, WA 98402

M. M. Dunkelman
Division of Radiation Protection
Washington State Department of Health
P.O. Box 47827
Olympia, WA 98504-7827

L. Eno
Biological Technician
Bureau of Land Management
1808 N. Third Street
Coeur d'Alene, ID 83814

3 J. L. Erickson, Director, MS-7827
Division of Radiation Protection
Washington State Department of Health
P. O. Box 47827
Olympia, WA 98504-7827

No. of
Copies

R. B. Evans
ESRF
250 Troy Avenue
Idaho Falls, ID 84302

C. Fink, MS 0854
Sandia National Laboratories
P.O. Box 5800
Albuquerque, NM 87185-0854

E. A. Flores
Environmental Sciences Division
Brookhaven National Laboratory
P.O. Box 5000
Upton, NY 11973-5000

B. Floyd
Economic Development Coordinator
Benton County Commissioners
P.O. Box 190
Prosser, WA 99350

H. Foster
Seattle Post-Intelligencer Newsroom
101 Elliott Avenue West
Seattle, WA 98111

N. W. Golchert
Argonne National Laboratory
9700 So. Cass Avenue, Bldg. 330
Argonne, IL 60439

The Honorable Slade Gorton
United States Senate
730 Hart Senate Office Building
Washington, DC 20510

2 W. C. Griffith
Department of Environmental Health
P.O. Box 354695
Seattle, WA 98195

No. of
Copies

D. M. Hamby
School of Public Health
University of Michigan
626 Madison Place
Ann Arbor, MI 48103

R. Harrach, L-629
Lawrence Livermore National Laboratory
P.O. Box 808
Livermore, CA 94551

The Honorable Richard (Doc) Hastings
House of Representatives
1229 Longworth House Office Building
Washington, DC 20515

R. Hirsch
Office of Health and Environmental Research
U.S. Department of Energy, ER-73
19901 Germantown Road
Germantown, MD 20874-1290

B. J. Hodges, MD-964L
Energy Northwest
P.O. Box 968
Richland, WA 99352

M. Hunacek
Dade, Moeller, and Associates
1845 Terminal Drive, Suite 140
Richland, WA 99352

T. A. Ikenberry
Dade, Moeller, and Associates
1845 Terminal Drive, Suite 140
Richland, WA 99352

No. of
Copies

T. Jannik
Environmental Dosimetry Department
Westinghouse Savannah River Company
Savannah River Technology Center
Building 773-42A, Room A-1004
Aiken, SC 29808

R. E. Jaquish
1232 Vintage Avenue
Richland, WA 99352

D. R. Johns
COESP Alternate Manager
59406 E. Main PR, SE
Benton City, WA 99320

J. Johnston, MS-M887
Ecology Group ESH20
Los Alamos National Laboratory
Los Alamos, NM 87545

K. Jones
COESP Alternate Manager
P.O. Box 481
Benton City, WA 99320

B. S. Jonker, Branch Chief, MS 1146
Radiological and Environmental Sciences Laboratory
Idaho Operations Office
U.S. Department of Energy
785 DOE Place
Idaho Falls, ID 83401-1562

T. Joseph
Oak Ridge Operations Office
U.S. Department of Energy
P.O. Box 2001
Oak Ridge, TN 37831

No. of
Copies

Kahlotus Branch of the Mid-Columbia Library
255 E. Weston
Kahlotus, WA 99335

Kennewick Branch of the Mid-Columbia Library
1620 S. Union Street
Kennewick, WA 99338

W. A. Kiel, MD-PE-20
Energy Northwest
P.O. Box 968
Richland, WA 99352

Knight Library
Serials Department
1299 University of Oregon
Eugene, OR 97403-1299

K. Koontz
Executive Director
Southwest Washington Health District
P.O. Box 1870
Vancouver, WA 98668-1870

R. A. Landvoy
COESP Alternate Manager
P.O. Box 1443
Toppenish, WA 98948

M. Lee
Tri-City Herald
107 N. Cascade
Kennewick, WA 99336

2 J. M. Leitch, OAQ-107
U.S. Environmental Protection Agency
1200 6th Avenue
Seattle, WA 98101

No. of
Copies

D. E. Linehan
Mid-Columbia River Complex
U.S. Fish and Wildlife Service
P.O. Box 700
Umatilla, OR 97882

S. Livenick, MS-MLV082
Bechtel-Nevada
P.O. Box 98521
Las Vegas, NV 89193-8521

The Honorable Gary Locke
Governor of the State of Washington
P.O. Box 40002
Olympia, WA 98504-0002

J. Long
c/o The Oregonian
1320 S.W. Broadway
Portland, OR 97201

R. Lorenz
Westinghouse Savannah River Site
Aiken, SC 29808

The Honorable Valoria Loveland
Washington State Senate
412-B Legislative Building
Olympia, WA 98504

T. K. Lyall
COESP
29249 Road O Southwest
Mattawa, WA 99345

L. Maas
Siemens Power Corporation
P.O. Box 130
Richland, WA 99352

No. of
Copies

M. P. Madison
COESP Manager
1715 N. 18th Avenue
Pasco, WA 99301

J. Maizkillie
Dames & Moore
1201 Jadwin Avenue, Suite 102
Richland, WA 99352

A. R. Mamatey
Westinghouse Savannah River Company
Savannah River Site
Building 735-16A
Aiken, SC 29808

T. Martin
Hanford Education Action League
1718 W. Broadway, Suite 230
Spokane, WA 99201

The Honorable Dave Mastin
Washington State House of Representatives
13 1/2 East Main #211
Walla Walla, WA 99362

S. May
Division of Radiation Protection
Washington State Department of Health
P.O. Box 47827
Olympia, WA 98504-7827

D. McBaugh, Head, MS-7827
Environmental Radiation Section
Division of Radiation Protection
Washington State Department of Health
P.O. Box 47827
Olympia, WA 98504-7827

No. of
Copies

J. E. McDonald, MD-1025
Environmental Scientist
Energy Northwest
P.O. Box 968
Richland, WA 99352

N. McDuffie
1745 S.W. Whiteside Drive
Corvallis, OR 97333

K. McEachen
COESP Alternate Manager
160 Basin Drive
Mesa, WA 99343

G. McNeill, MS-505
Nevada Operations Office
U.S. Department of Energy
P.O. Box 98518
North Las Vegas, NV 89030

Merrill's Corner Branch of the Mid-Columbia Library
5240 Eltopia Way
Eltopia, WA 99330

C. B. Miller
Laboratory Infrastructure Division
U.S. Department of Energy, ER-82
19901 Germantown Road
Germantown, MD 20874-1290

M. Mills
Energy Facility Site Evaluation Council
P.O. Box 43172
Olympia, WA 98504-3172

No. of
Copies

R. G. Mitchell
Environmental Science and Research Foundation
P.O. Box 51838
Idaho Falls, ID 83405-1838

J. Monley
Richland City Manager
P.O. Box 190
Richland, WA 99352

E. B. Moore, Jr.
2323 Greenbrook Boulevard
Richland, WA 99352

J. Murphy
Oak Ridge National Laboratory
P.O. Box 2008
Oak Ridge, TN 37831-6198

The Honorable Patty Murray
United States Senate
302 Hart Senate Office Building
Washington, DC 20510

J. R. Naidu
Safety and Environmental Protection Division
Brookhaven National Laboratory
Building 535 A
Upton, NY 11973-5000

3 R. L. Natoli
Office of Environmental Policy and Assessment
U.S. Department of Energy, EH-41
1000 Independence Avenue S.W.
Washington, DC 20585

No. of
Copies

2 C. Olson
Environmental Science Division
U.S. Department of Energy, ER-74
19901 Germantown Road
Germantown, MD 20874-1290

C. O'Neale
9106 Boulder Lane S.E.
Olympia, WA 98501

J. O'Neill
COESP Alternate Manager
P.O. Box 3067
Pasco, WA 99302

J. Oord
COESP Manager
1028 E. Oak
Othello, WA 99344

C. Palmer
Department of Natural Resources
Yakama Indian Nation
P.O. Box 151
Toppenish, WA 98948

Pasco Branch of the Mid-Columbia Library
1320 W. Hopkins
Pasco, WA 99301

A. Patrinos
Associate Director, Biological and Environmental Research
U.S. Department of Energy, ER-70
19901 Germantown Road
Germantown, MD 20874-1290

The Honorable Julia Patterson
Washington State House of Representatives
Legislative Building
Olympia, WA 98504

No. of
Copies

R. Pelletier
Director, Environmental Guidance Division
U.S. Department of Energy, EH-41
1000 Independence Avenue S.E.
Washington, DC 20545

J. Phillips
US Ecology, Inc.
P.O. Box 638
Richland, WA 99352

R. Pixler
CRESP Library Coordinator
Department of Environmental Health
University of Washington
4225 Roosevelt Avenue N.E., #300
Seattle, WA 98105

G. Podonsky
Deputy Assistant Secretary of Oversight
U.S. Department of Energy, EH-2/CC270
19901 Germantown Road
Germantown, MD 20874-1290

L. Poe
807 E. Rollingwood
Aiken, SC 29801

D. Powaukee
Environmental Restoration/Waste Management Program, Cultural Resources
Nez Perce Tribe
P.O. Box 365
Lapwai, ID 83540

G. Powers
Badger Mountain Vineyard
110 Jurupa
Kennewick, WA 99337

No. of
Copies

R. F. Reddick
Battelle
2000 Randolph Road S.E., Suite 105
Albuquerque, NM 87106

J. Reising
U.S. Department of Energy
P.O. Box 538705
Cincinnati, OH 45253-8705

D. Rhodes
Community Development Department
City of Richland
P.O. Box 190
Richland, WA 99352

B. Richards
Natural Resource Manager
Western Project
U.S. Army Corps of Engineers
Route 6, Box 693
Pasco, WA 99301

Richland Public Library
955 Northgate
Richland, WA 99352

N. Rienhart
Senate Committee Services
327 Cherberg Building
Olympia, WA 98504

L. K. Rogers, MS-31
Fluor Daniel Fernald
P.O. Box 538704
Cincinnati, OH 45239-8704

Roza Branch of the Mid-Columbia Library
Johnson and Hinzerling Roads
Prosser, WA 99350

No. of
Copies

M. Sampson
Tribal Councilman
Yakama Indian Nation
370 N. Broun Road
Wapato, WA 98951

C. Sawyer
SAIC
20201 Century Building
Germantown, MD 20874

J. W. Schmidt, H6-23
Washington State Department of Health
3011 W. Hood Avenue
Kennewick, WA 99336

G. Schroeder
Brookhaven National Laboratory
Building 535A
Upton, NY 11973

Seattle Times
P.O. Box 70
Seattle, WA 98111

L. Seelatsee
Grant County P.U.D.
P.O. Box 878
Ephrata, WA 98823

A. M. Shine
U.S. Fish and Wildlife Service
McNary National Wildlife Refuge
P.O. Box 544
Burbank, WA 99323

No. of
Copies

S. Sobczyk
Manager, Environmental Restoration and Waste Management
Nez Perce Tribe
P.O. Box 365
Lapwai, ID 83540

Spokesman Review
W. 999 Riverside Avenue
Spokane, WA 99201

M. D. Squeochs
Department of Natural Resources Environmental Program
Yakama Indian Nation
P.O. Box 151
Toppenish, WA 98948

R. Stanley
Nuclear Waste Programs
Washington State Department of Ecology
P.O. Box 47600
Olympia, WA 98504-7600

C. L. Stevenson
COESP Manager
70 Canal Drive
Mesa, WA 99343

T. R. Strong, MS 7827
Division of Radiation Protection
Washington State Department of Health
P.O. Box 47827
Olympia, WA 98504-7827

Tacoma News Tribune
P.O. Box 11000
Tacoma, WA 98411-0008

No. of
Copies

K. Tanaka
Safety and Security Department
Siemens Power Corporation
2101 Horn Rapids Road
Richland, WA 99352

B. Taylor
COESP Alternate Manager
1013 Sundance Road
Othello, WA 99344

Technical Services
Walla Walla College Library
105 Southwest Adams
College Place, WA 99324-2295

J. Thomas
Short, Cressman, & Burgess
999 Third Avenue, Suite 3000
Seattle, WA 98104-4088

K. A. Thomas
COESP Alternate Manager
6521 W. Argent
Pasco, WA 99301

L. Treichel
U.S. Department of Energy, EM-44
Cloverleaf Building 2116
19901 Germantown Road
Germantown, MD 20874-1290

Tri-City Herald
107 N. Cascade
Kennewick, WA 99336

No. of Copies	
5	J. C. Tseng Associate Deputy Assistant Secretary for Environment U.S. Department of Energy, EM-36 Germantown/Trevion II 19901 Germantown Road Germantown, MD 20874-1290
	U.S. Geological Survey Library Special Attn: Exchange, Mail Stop 950 National Center Reston, VA 22092
	Vancouver Columbian P.O. Box 180 Vancouver, WA 98666-0180
	C. A. Wagner COESP Manager 1528 Hunt Avenue Richland, WA 99352
	A. Wallo, III, Division Director Air, Water, and Radiation Division Office of Environment U.S. Department of Energy 1000 Independence Avenue S.W. Washington, DC 20585
	Washington State Department of Ecology Library, PV-11 P.O. Box 47600 Olympia, WA 98504-7600
	D. Weberling COESP Manager 23745 Boulder Lane Mattawa, WA 99349

No. of Copies	
	P. J. Weeden U.S. Environmental Protection Agency P.O. Box 98517 Las Vegas, NV 89193-8517
	D. Wells INEEL Oversight Program 900 N. Skyline Drive, Suite C Idaho Falls, ID 83402
	West Richland Branch of the Mid-Columbia Library 5456 Van Giesen West Richland, WA 99352
3	J. R. Wilkinson Special Science and Resource Program Department of Natural Resources P.O. Box 638 Pendleton, OR 97801
	A. J. Williamson COESP Manager 254 Rockwood Drive Richland, WA 99352
	K. F. Wolk Radiation Safety Officer P.N. Services, Inc. 2939 Richardson Road Richland, WA 99352
	R. Won U.S. Department of Energy, EM-72 Cloverleaf Building 2083 19901 Germantown Road Germantown, MD 20874-1290

No. of
Copies

J. Wrzeski
Puget Sound Naval Shipyard
Code 2310
1400 Farragut Avenue
Bremerton, WA 98314-5001

Yakima Herald-Republic
P.O. Box 9668
Yakima, WA 98909

C. Zwiener-Thomas
COESP Alternate Manager
65006 E. Sunset View Pr. S.E.
Benton City, WA 99320

FOREIGN

J. Korkisch
Institute of Analytical Chemistry
University of Vienna
A-1090 Vienna, Wahringerstrasse 38
AUSTRIA

ONSITE

117 **DOE Richland Operations Office**

R. F. Brich	K8-50
C. R. Briggs	A1-61
R. M. Carosino	A4-52
S. S. Clark	A5-15
K. V. Clarke	A7-75
A. J. Colburn	A5-18
P.F.X. Dunigan	A5-15
L. Erickson	A0-21
T. W. Ferns (20)	H0-12
M. S. French	S7-55
M. J. Furman	H0-12
R. E. Gerton	H0-12
W. M. Glines	A5-11

No. of
Copies

R. F. Guercia	S7-55
C. C. Haass	R2-89
J. B. Hall	A5-15
R. D. Hildebrand	H0-12
J. D. Kautzky	A5-58
K. A. Klein	A5-15
P. M. Knollmeyer	A5-11
R. N. Krekel	A5-15
P. J. Krupin	A5-15
P. W. Kruger	A5-54
D. W. Lloyd	A5-15
R. W. Lober	A2-22
G. M. McClure	A7-75
D. J. Ortiz	A2-45
J. L. Polehn (HQ)	A4-81
J. E. Rasmussen	A5-15
S. N. Saget	K8-50
W. B. Scott	A5-54
G. L. Sinton	S7-55
K. M. Thompson	H0-12
R. R. Tibbatts	A7-29
D. C. Ward (60)	A5-15
J. W. Wiley	K8-50
J. H. Zeisloft	H0-12
DOE Public Reading Room (2)	H2-53

9 **B&W Hanford Company**

J. M. Barnett	L1-05
A. Clark	H5-31
T. A. Dillhoff	S5-03
S. J. Gray	N2-13
G. D. Hendricks	R3-56
G. J. LeBaron	S4-49
B. B. Nelson-Maki	T5-54
W. E. Starkey	N2-34
E. C. Vogt	R3-56

No. of Copies		
11	**Bechtel Hanford, Inc.**	
	R. L. Biggerstaff	H0-02
	L. A. Dietz	H0-20
	R. L. Donahoe	H0-17
	K. R. Fecht	H0-02
	G. E. Fitzgibbon	H0-09
	K. A. Gano	H0-23
	J. W. Handy	H0-16
	R. J. Landon	H0-02
	G. S. Robinson	H0-02
	D. D. Teel	H0-23
	J. G. Woolard	H0-02
9	**CH2M Hill Hanford, Inc.**	
	S. W. Clark	H9-03
	E. T. Coenenberg	H9-03
	S. J. Ingle	H9-01
	I. D. Jacques	X9-06
	L. M. Johnson	H9-01
	R. E. Peterson	H9-03
	V. J. Rohay	H0-19
	J. J. Sharpe	H9-03
	S. G. Weiss	H9-01
2	**COGEMA Engineering Corporation**	
	L. A. Fort	H3-28
	R. B. Morson	B3-27
3	**DE&S Hanford, Inc.**	
	W. D. Adair	H6-21
	R. G. Gant	X3-79
	T. L. McConnell	H5-30

No. of Copies		
7	**DynCorp Tri-Cities Services, Inc.**	
	B. J. Dixon	G3-26
	R. S. Frix	H5-33
	H. B. Hathway	G3-07
	L. M. Kelly	S2-21
	D. A. Marsh	G3-07
	R. L. Smithwick	A0-20
	P. M. Srubek	A0-20
21	**Fluor Daniel Hanford, Inc.**	
	R. C. Brunke	H6-21
	J. R. Culmer	H6-23
	T. A. Demitruk	A3-02
	D. P. Ellingson	S7-05
	R. D. Hanson	H5-20
	J. J. Kapadia	H6-23
	O. S. Kramer	H8-67
	S. K. Marozik	L1-01
	J. E. Miller	S5-02
	K. A. Peterson	H6-23
	S. M. Price	H6-23
	T. A. Quayle	H6-23
	D. G. Ranade	H6-23
	F. A. Ruck	H6-23
	C. P. Strand	H6-23
	J. M. Swindoll	T1-27
	S. A. Szendre	H6-23
	S. A. Thompson	H6-23
	K. E. Weeks	T4-51
	J. D. Williams	H0-21
	V. E. Wolff	H6-32
2	**Fluor Daniel Northwest, Inc.**	
	F. M. Mann	H0-31
	R. L. Smith	B7-50

No. of Copies		
	Hanford Environmental Health Foundation	
	J. J. Maher	H1-04
	IT Corporation	
	W. W. Ballard	B2-68
6	**Lockheed Martin Hanford Corporation**	
	V. C. Boyles	R2-11
	D. J. Carrell	R1-51
	M. P. DeLozier	H7-07
	M. L. Dexter	R1-51
	S. M. O'Toole	R2-89
	P. A. Powell	R1-51
6	**Lockheed Martin Services, Inc.**	
	D. E. Brunson	G3-51
	D. L. Liddell	G3-51
	R. H. Russell	H8-05
	EDMC (2)	H6-08
	LMSI Central Files	A3-88
2	**MACTEC-ERS**	
	J. F. Bertsch	B1-42
	R. G. McCain	B1-42
	Numatec Hanford Corporation	
	X. J. Hubert	H5-25
	Protection Technology Hanford	
	B. G. Essary	G3-40

No. of Copies		
	SAIC	
	S. Sweetser	H0-50
57	**Waste Management Federal Services of Hanford, Inc.**	
	S. G. Arnold	T4-56
	E. S. Aromi	H6-10
	D. G. Black (5)	H6-20
	R. C. Bowman	H6-24
	H. C. Boynton	T4-52
	S. B. Clifford	H6-26
	B. L. Curn	H6-36
	L. P. Diediker (15)	H6-36
	R. H. Engelmann (13)	H6-26
	E. M. Greager	H6-36
	D. L. Hagel	T3-04
	R. D. Haggard	H6-25
	J. S. Hill	H6-25
	P. H. Jacobsen	T3-06
	M. T. Jansky	H6-20
	R. E. Johnson	H6-25
	S. S. Lowe	H6-06
	D. E. McKenney	H6-30
	D. H. Nichols	H6-06
	P. M. Olson	S6-72
	J. O. Skolrud	H6-20
	D. B. Van Leuven	H5-20
	G. J. Warwick	T6-14
	R. T. Wilde	H6-10
	J. A. Winterhalder	H6-21
	M. I. Wood	H6-06
	D. E. Zaloudek	H6-20
8	**Waste Management Federal Services, Inc., Northwest Operations**	
	P. K. Brockman	H1-11
	J. J. Dorian	H1-13

No. of Copies		
	A. R. Johnson	H1-13
	S. E. Kos	H1-11
	B. M. Markes	H1-11
	S. M. McKinney	H1-11
	R. M. Mitchell	H1-11
	C. J. Perkins	H1-11
284	**Pacific Northwest National Laboratory**	
	R. L. Aaberg	K3-54
	K. M. Airhart	K5-22
	A. R. Ankrum	K8-28
	E. J. Antonio	K3-54
	J. F. Bagley (4)	BWO
	D. B. Barnett	K6-81
	L. L. Belt	K6-75
	M. P. Bergeron	K9-36
	C. P. Beus	K9-80
	G. R. Bilyard	K8-03
	L. E. Bisping	K6-75
	W. J. Bjorklund	K3-75
	M. L. Blanton	K6-75
	S. L. Blanton	K6-85
	C. A. Brandt	K6-85
	R. W. Bryce	K6-75
	J. W. Buck	K6-80
	A. L. Bunn	K6-85
	L. L. Burger	P7-25
	L. L. Cadwell	K6-85
	S. D. Cannon	K9-13
	J. R. Christensen	P7-55
	S. F. Conley	K6-75
	D. D. Dauble	K6-85
	F. L. DeCoria	P8-08
	R. L. Dirkes	K6-75
	J. L. Downs	K6-85
	P. E. Dresel	K6-96
	J. G. Droppo	K6-80
	T. H. Dunning	K9-44
	R. M. Ecker	Sequim

No. of Copies		
	T. O. Eschbach	K6-75
	W. T. Farris	K9-04
	L. L. Fassbender	K8-07
	J. J. Fix	K3-55
	M. D. Freshley	K9-36
	D. R. Geist	K6-85
	R. E. Gephart	K9-76
	R. O. Gilbert	BWO
	B. M. Gillespie	K6-96
	C. S. Glantz	K6-80
	L. L. Glaspell	K6-75
	R. W. Goles	K6-24
	R. W. Hanf (177)	K6-75
	M. J. Hartman	K6-96
	D. W. Harvey	K6-75
	J. O. Heaberlin	K8-02
	P. L. Hendrickson	K8-03
	P. S. Henry	K6-75
	D. J. Hoitink	K9-30
	L. R. Huesties (2)	K6-75
	G. V. Last	K6-81
	E. A. Lepel	P8-08
	S. P. Luttrell	K6-96
	W. J. Madia	K1-46
	S. A. Mann	P7-28
	L. F. Morasch	K6-86
	E. M. Murphy	K3-61
	B. A. Napier	K3-54
	K. R. Neiderhiser	K6-90
	P. L. Nelson	P7-25
	D. R. Newcomer	K9-96
	G. P. O'Connor	K6-86
	B. E. Opitz	K6-75
	T. L. Page	K9-18
	G. W. Patton	K6-75
	T. M. Poston	K6-75
	K. R. Price	K6-75
	K. M. Probasco	K3-56
	K. H. Pryor	P7-78
	E. L. Radford	P7-55

No. of Copies		No. of Copies	
J. V. Ramsdell	K9-30	D. J. Strom	K3-56
K. Rhoads	K3-54	M. J. Sula	Sequim
S. B. Saslow	P7-75	P. D. Thorne	K9-33
A. J. Schmidt	K2-12	H. T. Tilden II	P7-79
P. K. Schuette (4)	K1-38	B. L. Tiller	K6-85
R. J. Serne	K6-81	R. S. Weeks	P7-79
R. W. Sheets	P7-28	B. A. Williams	K6-81
B. D. Shipp	K9-01	R. K. Woodruff	P7-68
M. A. Simmons	K6-85	M. K. Wright	K6-75
R. M. Smith	K6-96	S. K. Wurstner	K9-36
P. S. Stansbury	K3-54	Historical File—T. M. Poston	K6-75
R. D. Stenner	K3-54	Information Release Office (7)	K1-06

☆ U.S. GOVERNMENT PRINTING OFFICE: 1999 — 793-049 / R7743 Region No. 10