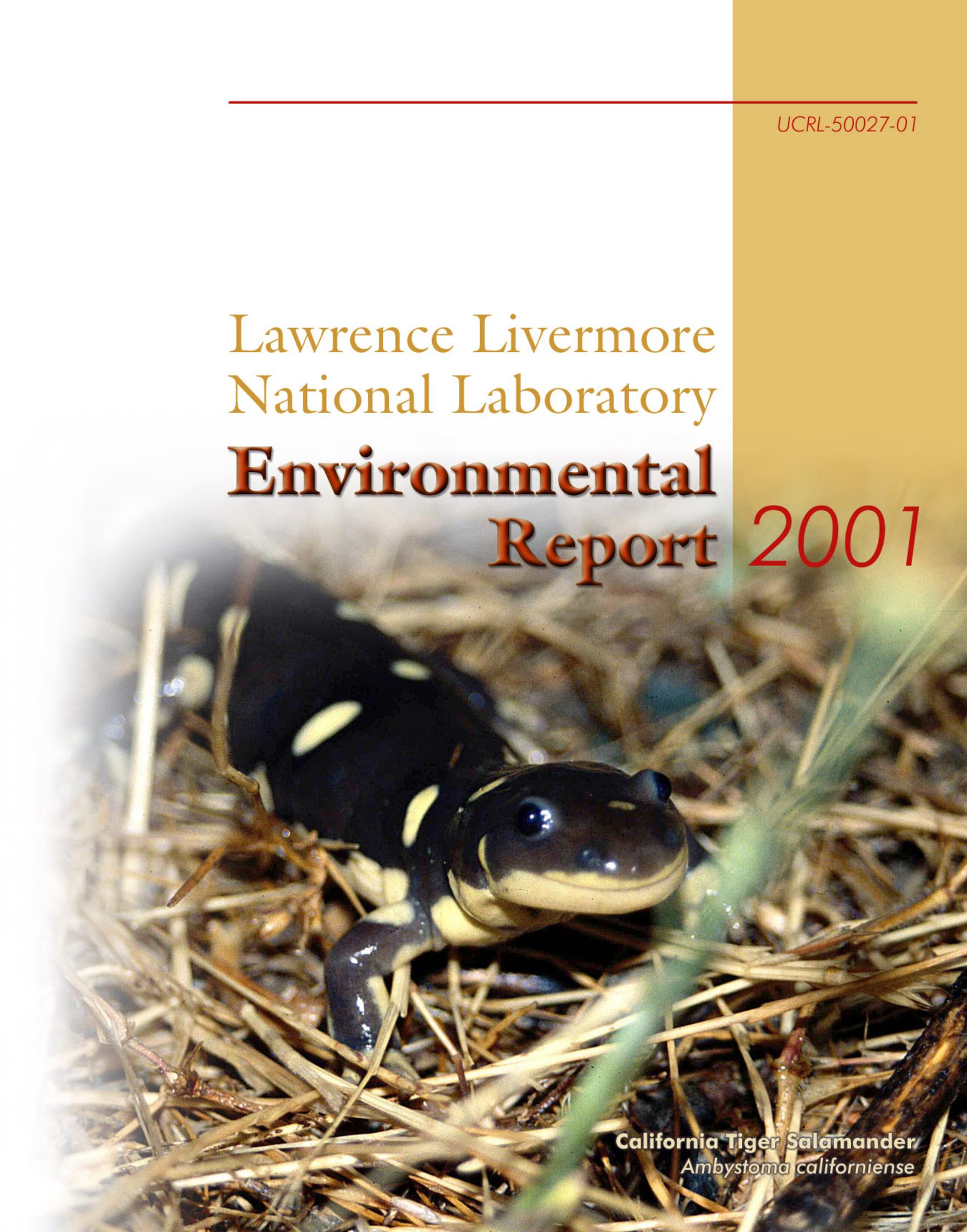


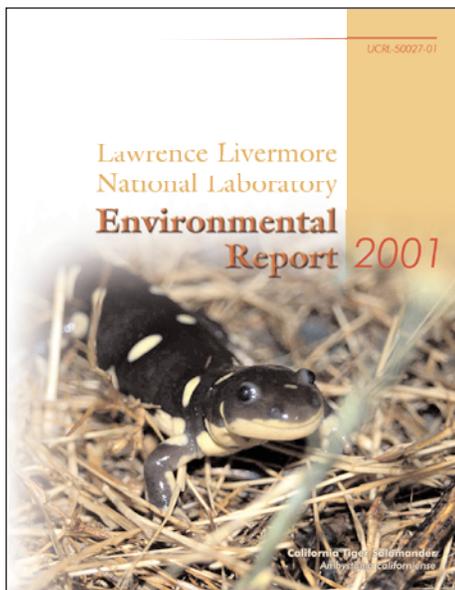
UCRL-50027-01

Lawrence Livermore
National Laboratory
Environmental
Report

2001

A photograph of a California Tiger Salamander (Ambystoma californiense) resting on a bed of dry pine needles. The salamander has a dark, almost black body with bright yellow spots and a yellowish-orange stripe along its side. It is looking towards the camera.

California Tiger Salamander
Ambystoma californiense



Composition

Beverly L. Chamberlain

Art and Design

Brett S. Clark

For further information about this report contact: Bert Heffner, LLNL Public Affairs Department, P.O. Box 808, Livermore, CA 94551, (925) 424-4026. This report can be accessed on the Internet at <http://www.llnl.gov/saer>. It is also available to DOE employees and DOE contractors from: Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831 and to the public from: National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161.

Cover

The California tiger salamander (*Ambystoma californiense*) is endemic to the state of California and geographically isolated from other *Ambystomatid* salamanders (Shaffer and McKnight 1996). The California tiger salamander represents a small but important component of the spectacular diversity found in California's grassland communities. California tiger salamanders breed in ephemeral pools at Site 300 and have been observed within close proximity to the Livermore site.

Distribution, Habitat and Ecology

The California tiger salamander is a large salamander (15 to 22 centimeters long), historically found in the Central Valley and adjacent foothills and coastal grasslands of California, areas with a Mediterranean climate of cool wet winters and hot dry summers (Loredo and Van Vuren 1996). Juveniles and adults live under ground, inhabiting the burrows of California ground squirrels (*Spermophilus beecheyi*) and pocket gophers (*Thomomys bottae*), and are rarely observed on the soil surface except during the winter breeding season when desiccation is not limiting. California tiger salamanders breed in fish-free (Petranka 1998), seasonally ephemeral pools and are considered an obligate vernal pool species (Morey 1996). Migrations to and from the ponds occur from November through April, although most breeding occurs from December through March (Petranka 1998). Males arrive first at the breeding pond followed by the females. Females attach their eggs singly, or in rare instances in groups of two to four on submergent or emergent vegetation, or other suitable substrates. Eggs hatch within 2 to 4 weeks after they are deposited and the larval stage lasts 3 to 6 months. Metamorphosis occurs during the dry summer months, and metamorphs typically migrate from the ponds at night during dry weather. The first night after leaving the breeding pond, metamorphs may move 6 to 57 meters from the pond (Loredo, Van Vuren, and Morrison 1996), with the total distance moved being unknown. The underground ecology of the California tiger salamanders, which constitutes over 90% of the species life history, is completely unknown.

Status

The California tiger salamander is a state Species of Special Concern and Federal Candidate for listing (i.e., warranted but precluded). Within California, there are seven distinct population segments of the California tiger salamander. Two of the seven populations (Sonoma and Santa Barbara Counties) now receive federal protection, both under Emergency Rule, pursuant to the Endangered Species Act of 1973, as amended. Intensive human alteration of habitat over the past 150 years has resulted in the loss of greater than 90% of California's historic vernal pool habitats and extensive fragmentation of that which remains (Holland and Jain 1978). Additional significant population threats include predation by introduced species such as fish (Shaffer, Fisher, and Stanley 1993) and bullfrogs (*Rana catesbeiana*) (Shaffer and Stanley 1991), vehicle-related mortality during breeding migrations (Gibbs 1998), and rodent control programs (Loredo et al. 1994). Within the remaining range of the species, populations are considered fragmented and at risk of extinction; federal protection of the remaining populations appears inevitable at this time.

Michael van Hatten, LLNL Wildlife Biologist, provided the cover photo and information.

Environmental Report 2001

Authors

Gretchen M. Gallegos

Paris E. Althouse
Nicholas A. Bertoldo
Richard G. Blake
Shari L. Brigdon
Richard A. Brown
Chris G. Campbell
Eric Christofferson
Lucinda M. Clark
Allen R. Grayson

Robert J. Harrach
Henry E. Jones
Donald H. MacQueen
Sandra Mathews
S. Ring Peterson
Michael A. Revelli
Lily Sanchez
Michael J. Taffet
Paula J. Tate
Rebecca Ward
Robert A. Williams

Editors

Nancy J. Woods
Jim Kohl

September 1, 2002

**Lawrence Livermore
National Laboratory
UCRL-50027-01**

Distribution Category UC-702





Department of Energy
National Nuclear Security Administration
1301 Clay Street
Oakland, California 94612-5208

SEP 24 2002

Distribution:

Subject: 2001 Annual Site Environmental Report (ASER) for the Lawrence Livermore National Laboratory (LLNL)

This report, prepared by LLNL for the Department of Energy, National Nuclear Security Administration (NNSA), provides a comprehensive summary of the environmental program activities at LLNL for calendar year 2001. The ASER is prepared annually for all Department of Energy sites with significant environmental activities, and distributed to relevant regulatory agencies and other interested organizations or individuals.

The information in this report has been reviewed by NNSA and LLNL personnel for accuracy. The review was based on quality assurance protocols applied to monitoring and data analyses at LLNL. There is a continuing downward trend of specific emissions, ambient concentrations, and groundwater contaminants of radiological and non-radiological substances. This is the result of LLNL's environmental compliance and protection programs, demonstrating NNSA's commitment to protecting public health and the environment.

A reader survey form is provided with the ASER to provide comments or suggestions for future versions of the report. Your response is appreciated.

Sincerely,

A handwritten signature in blue ink, appearing to read "Ray J. Corey".

Ray J. Corey
Deputy Assistant Manager
for National Security

PREFACE

The *Environmental Report 2001* is prepared for the U.S. Department of Energy (DOE), as required by DOE Order 5400.1 and DOE Order 231.1, by the Environmental Protection Department at Lawrence Livermore National Laboratory (LLNL). The results of LLNL's environmental monitoring and compliance efforts and an assessment of the impact of LLNL operations on the public and the environment are presented in this publication.

To increase the readability and usefulness of this document for our diverse readers, which include regulators, scientists and engineers, educators, the media, public interest groups, and interested citizens, this report is divided into two volumes: the main volume and the Data Supplement. The main volume describes LLNL's environmental impact and compliance activities and features descriptive and explanatory text, summary data tables, and plots showing data trends. The summary data include measures of the central tendency of the data (i.e., mean and median), their spread or variability, and their extreme values. The main volume contains the Executive Summary, the Compliance Summary, and other summary information, but it primarily features individual chapters on monitoring of air, sewage, surface water, groundwater, soil and sediment, vegetation and foodstuff, environmental radiation, as well as chapters on the subjects of groundwater remediation, radiological dose assessment, and quality assurance. Information on both the Livermore site and Site 300 is presented in each chapter. The main volume contains the information of interest to most of our

readers. The Data Supplement provides individual data points, where applicable, some summary data, and more detailed accounts of sample collection and analytical methods.

The primary methods of distribution of the *Environmental Report 2001* are electronic. The document will be physically distributed by compact disc (CD), and accessible on the Internet at the LLNL SAER homepage: <http://www.llnl.gov/saer>. Both the main volume and data supplement volume of each individual report can be viewed in its most up-to-date form. Environmental reports covering calendar years 1994 through 2001, and corrections to them, can be accessed at this same Internet address.

In the *Environmental Report 2001*, we continue our practice, begun with the 1991 report, of using *Système International* units. This is consistent with the federal law stated in the Metric Conversion Action of 1975 (15 United States Code 205a et seq.) and Presidential Executive Order 12770, Metric Usage in Federal government programs (July 25, 1991). Although many readers in the United States are not as familiar with metric units as with the U.S. customary units, we are all increasingly citizens of the world, as evidenced by the broad distribution of the *Environmental Report 2001* afforded by the Internet, and we continue to believe it is appropriate to use metric units in this report. The previous discussion notwithstanding, and to ease the transition for the reader parallel units are provided in the Executive Summary and

the first chapter. For ease of comparison to the environmental reports issued prior to 1991, dose values and many radiological measurements are presented in both metric and U.S. customary units throughout the report. Finally, a conversion table is provided in the Glossary under the heading of “metric units.”

This document is the responsibility of LLNL’s Operations and Regulatory Affairs Division of the Environmental Protection Department. Monitoring data were obtained through the combined efforts of the Operations and Regulatory Affairs Division, Environmental Restoration Division, the Chemistry and Materials Science Environmental Services Laboratories, and the Hazards Control Department. Special recognition is deserved for the dedication and professionalism of the technicians who carried out environmental and effluent monitoring—Gary A. Bear, David J. Castro, Steven Hall, David Macedo, Renee Needens, Terrance W. Poole, Donald G. Ramsey, Sterling Sawyer, Robert Williams, and Kent R. Wilson—and to the data management personnel—Kimberly A. Stanford, Beth Schad, Suzanne Chamberlain, Della Burruss, Susan Lambaren, Nancy Montez, and Lisa Graves. Judy Kelly provided secretarial support and collated and distributed drafts.

Special thanks go to Art Biermann for his strong support of the project and careful and timely reviews of all the drafts; C. Susi Jackson and Charlene Grandfield for reviewing the chapters; and Karen Folks and Paul McGuff for their comments and coordination efforts. In addition, the following people contributed significantly to this report: Keith V. Gilbert, Albert L. Lamarre, Duane W. Rueppel, Nona Sanford, Carol Stoker, and Kim Heyward.

Chapter Summaries

The chapter summaries demonstrate the breadth of the environmental activities at LLNL. There are 14 chapters in this report: 3 chapters provide general information about the LLNL sites, regulatory activities, and the structure of environmental programs at LLNL; 10 chapters provide environmental monitoring measurements and analyses; and 1 chapter describes the quality assurance program and quality control activities that ensure the validity of the data. Brief descriptions of the contents of each of the individual chapters are presented here.

Chapter 1, Introduction, describes the physical setting of the two LLNL sites. The description includes information about the topography, geology, and meteorology of the sites and clearly states the differences between them despite their proximity.

Chapter 2, Compliance Summary, summarizes information about LLNL’s substantial compliance activities, including compliance with the major federal, state, and local environmental initiatives. The major topics covered are the Clean Air Act, the Clean Water Act and related state programs, the Comprehensive Environmental Response, Compensation and Liability Act the Resource Conservation and Recovery Act and state and local hazardous waste regulations, the National Environmental Policy Act and the California Environmental Quality Act, the Endangered Species Act, the National Historic Preservation Act, and the Antiquities Act.

Chapter 3, Environmental Program Information, describes the organization of LLNL’s Environmental Protection Department and its divisions, giving the responsibilities of each organization for compliance and monitoring.

Chapter 4, *Air Effluent Monitoring*, summarizes the facilities that have continuous air monitoring for their operations, including a summary of the results of the monitoring data collected for the sources.

Chapter 5, *Air Surveillance Monitoring*, describes the purpose of the air particulate and tritium ambient air monitoring programs and provides analyses of the measurements taken in calendar year 2001. The chapter provides dose estimates from exposure to radiological materials in the ambient air.

Chapter 6, *Sewer Monitoring*, describes the extensive real-time and routine sampling efforts undertaken to characterize the radiological and nonradiological materials in the sewer effluent leaving the LLNL Livermore site.

Chapter 7, *Surface Water Monitoring*, is a compendium of data from many types of surface water, including storm water runoff, rainwater, drinking water, the Livermore site Drainage Retention Basin, and cooling tower water. Monitoring of discharges occurring during maintenance of Arroyo Las Positas is also discussed.

Chapter 8, *Groundwater Remediation*, summarizes CERCLA activities undertaken at the Livermore site and Site 300 during calendar year 2001. It is a summary of reports prepared for CERCLA compliance and contains many maps delineating the extent of contaminant transport in groundwater.

Chapter 9, *Groundwater Monitoring*, contains information about monitoring undertaken to confirm that no new additional sources of contamination of groundwater exist, and to demonstrate compliance with RCRA-permitted closure of disposal areas at Site 300.

Chapter 10, *Soil and Sediment Monitoring*, provides the data collected in the annual soils monitoring program, including plots of historic medians for contaminants of interest, such as plutonium and uranium.

Chapter 11, *Vegetation and Foodstuff Monitoring*, summarizes the data collected in the quarterly vegetation sampling and the annual sampling of local wines for tritium. The chapter provides dose estimates, including estimates for organically bound tritium, for exposures to vegetation and wine produced in the vicinity of LLNL.

Chapter 12, *Environmental Radiation*, describes the direct environmental radiation measurements obtained for the Livermore site and Site 300. The measurement method and results are explained.

Chapter 13, *Radiation Dose Assessment*, discusses sources of potential emissions of radionuclides, principal public receptors, and dose modeling assumptions. The chapter presents the dose impacts of operations conducted in 2001. It also includes an intercomparison of modeled and monitored concentrations.

Chapter 14, *Quality Assurance*, describes the extensive quality assurance program and quality control efforts that LLNL undertakes each year to ensure that samples are collected and handled properly. It also describes how data reported and summarized.

TABLE OF CONTENTS

Executive Summary	EX-1
Radiological Monitoring.....	EX-2
Nonradiological Monitoring.....	EX-6
Superfund Activities.....	EX-6
Regulatory Permitting and Compliance	EX-8
Conclusion.....	EX-10
Site Overview	1-1
Introduction.....	1-1
Operations	1-1
Location.....	1-2
Meteorology	1-3
Topography	1-4
Hydrogeology	1-5
Livermore Site	1-5
Site 300.....	1-7
Summary.....	1-7
Compliance Summary	2-1
Introduction.....	2-1
Comprehensive Environmental Response, Compensation and Liability Act	2-1
Livermore Site Groundwater Project.....	2-2
Documentation.....	2-2
Milestones and Activities.....	2-2
Treatment Facilities.....	2-3
Community Relations	2-3
Site 300 CERCLA Project	2-3
Documentation.....	2-3
Milestones and Activities.....	2-4
Treatment Facilities	2-4
Community Relations	2-4
Site Evaluations Prior to Construction	2-4
Agency for Toxic Substances and Disease Registry Assessment	2-4
Superfund Amendment and Reauthorization Act, Title III.....	2-5
Clean Air Act—Air Quality Management Activities	2-5
National Emission Standards for Hazardous Air Pollutants, Radionuclides	2-6
Clean Water Act and Related State Programs	2-8
Groundwater and Surface Water	2-13
Sewerable Water	2-13

Streambed Alteration Agreements and Nationwide Permits	2-14
Tank Management.....	2-15
Resource Conservation and Recovery Act and Related State Laws	2-15
Hazardous Waste Permits	2-15
Livermore Site	2-15
Site 300	2-17
Hazardous Waste Reports.....	2-17
Hazardous Waste Transport Registration	2-18
Waste Accumulation Areas.....	2-18
California Medical Waste Management Act.....	2-18
Federal Facility Compliance Act.....	2-18
Toxic Substances Control Act.....	2-18
National Environmental Policy Act	2-19
California Environmental Quality Act	2-19
National Historic Preservation Act.....	2-19
Endangered Species Acts and Sensitive Natural Resources.....	2-20
Antiquities Act (of 1906): Paleontological Resources	2-23
Environmental Occurrences.....	2-23
Contributing Authors Acknowledgment	2-23
Environmental Program Information	3-1
Introduction.....	3-1
Integrated Environment, Safety, and Health Management System	3-1
Work Smart Standards	3-2
Environmental Protection Department	3-3
Operations and Regulatory Affairs Division	3-4
Hazardous Waste Management Division	3-4
Environmental Restoration Division.....	3-5
Environmental Training.....	3-5
Performance Measures Summary	3-6
DOE Pollution Prevention Goals.....	3-6
Pollution Prevention Reporting	3-9
Waste Minimization/Pollution Prevention.....	3-9
Nonhazardous Solid Waste Minimization.....	3-10
Diverted Waste	3-11
Source Reduction and Pollution Prevention	3-12
Current Return-on-Investment Projects	3-12
Review of New Processes or Experiments.....	3-12
Design for Environment	3-12
Implementing P2 Employee Training and Awareness Programs	3-14
ChemTrack	3-14
Response to Spills and Other Environmental Emergencies	3-14
LLNL's Other Environmental Programs.....	3-15
Contributing Authors Acknowledgment	3-15
Air Effluent Monitoring	4-1
Introduction.....	4-1
Air Quality Laws.....	4-1

Monitored Emissions	4-2
Operation of Monitoring Systems	4-2
Methods.....	4-3
Measured Radioactive Air Emissions	4-5
Livermore Site	4-5
Site 300.....	4-6
All Potential Sources of Radioactive Air Emissions	4-6
Nonradioactive Air Emissions	4-7
Environmental Impact	4-8
Contributing Authors Acknowledgment	4-8
Air Surveillance Monitoring	5-1
Introduction.....	5-1
Methods.....	5-2
Air Particulate Sampling Locations.....	5-2
Air Tritium Sampling Locations	5-5
Radiological Analysis	5-6
Results	5-7
Livermore Site	5-7
Airborne Radioactivity	5-7
Beryllium in Air	5-14
Site 300.....	5-15
Airborne Radioactivity	5-15
Beryllium in Air	5-16
Environmental Impact	5-16
Nonradioactive Materials	5-17
Sewerable Water Monitoring.....	6-1
Introduction.....	6-1
Preventive Measures	6-3
Monitoring.....	6-3
Monitoring at the Sewer Monitoring Station.....	6-3
Monitoring at the Upstream pH Monitoring Station.....	6-4
Diversion System	6-4
Pretreatment Discharges.....	6-4
Categorical Discharges	6-6
Discharges of Treated Groundwater.....	6-6
Radioactive Pollutants in Sewage	6-7
Monitoring Results.....	6-7
Environmental Impact	6-8
Nonradioactive Pollutants in Sewage	6-12
Monitoring Results.....	6-12
Environmental Impact	6-16
Surface Water Monitoring.....	7-1
Overview.....	7-1
Storm Water.....	7-1
General Information	7-2
Permits	7-2
Constituent Criteria	7-2

Inspections	7-3
Sampling	7-4
Methods	7-8
Results.....	7-9
Inspections	7-9
Livermore Sampling.....	7-10
Site 300 Sampling.....	7-19
Rainfall.....	7-20
General Information	7-20
Livermore Site and Livermore Valley.....	7-20
Site 300	7-20
Methods.....	7-20
Results.....	7-20
Livermore Site and Livermore Valley.....	7-20
Site 300	7-22
Livermore Site Drainage Retention Basin.....	7-22
General Information	7-22
Methods.....	7-25
Results.....	7-25
Chemical and Physical Monitoring.....	7-26
Biological Monitoring.....	7-28
Site 300 Cooling Towers	7-28
General Information	7-28
Methods.....	7-29
Results.....	7-30
Site 300 Drinking Water System Discharges.....	7-32
General Information	7-32
Methods.....	7-33
Results.....	7-33
Other Waters.....	7-33
General Information	7-33
Methods.....	7-33
Results.....	7-33
Arroyo Las Positas Maintenance Project.....	7-36
General Information	7-36
Methods.....	7-37
Results.....	7-38
Environmental Impacts.....	7-39
Storm Water	7-39
Rainfall	7-40
Drainage Retention Basin	7-40
Cooling Towers.....	7-40
Site 300 Drinking Water System Discharges.....	7-40
Other Waters.....	7-40
Arroyo Las Positas Maintenance Project.....	7-40
Groundwater Investigation and Remediation	8-1
Introduction.....	8-1
Livermore Site Groundwater Project.....	8-1

Physiographic Setting	8-1
Hydrogeology	8-2
Background	8-2
Remedial Activities	8-2
Treatment Facility A	8-5
Treatment Facility B	8-6
Treatment Facility C	8-13
Treatment Facility D	8-13
Treatment Facility E	8-14
Treatment Facility G-1	8-15
Treatment Facility 406	8-15
Groundwater Treatment Facility 518	8-16
Vapor Treatment Facility 518	8-17
Treatment Facility 5475	8-17
Vapor Treatment Facility 5475	8-19
Groundwater Flow and Transport Modeling	8-19
HSU 1B /2 Model	8-19
Deeper HSU Models	8-20
Electroosmosis Modeling	8-20
Environmental Impact	8-20
Site 300 CERCLA Project	8-22
Geology of Site 300	8-22
Hydrogeology of Site 300	8-22
Operable Unit Highlights and Activities	8-25
General Services Area Operable Unit	8-27
Building 834 Operable Unit	8-31
High Explosives Process Area Operable Unit	8-32
Building 850/Pits 3 and 5 Operable Unit	8-34
Building 854 Operable Unit	8-35
Pit 6 Operable Unit	8-38
Building 832 Canyon Operable Unit	8-39
Site 300 Operable Unit	8-39
Environmental Remediation at Site 300	8-41
General Services Area	8-41
Building 834 Complex	8-43
High Explosives Process Area	8-44
Building 854 Area	8-46
Building 832 Canyon	8-47
Building 850/Pits 3 and 5 Operable Unit	8-47
Groundwater Monitoring	9-1
Introduction	9-1
Surveillance Monitoring	9-1
Surveillance Monitoring of Livermore Site and Environs	9-3
Livermore Valley	9-3
Livermore Site Perimeter	9-3
Livermore Site	9-4
Surveillance and Compliance Monitoring of Site 300	9-6
Elk Ravine Drainage Area	9-8

Corral Hollow Creek Drainage Area.....	9-11
Sampling and Analytical Methods	9-18
Results	9-19
Livermore Site and Environs	9-19
Livermore Valley.....	9-19
Livermore Site Perimeter	9-19
Livermore Site	9-21
Site 300.....	9-21
Elk Ravine Drainage Area	9-21
Corral Hollow Creek Drainage Area.....	9-24
Environmental Impacts.....	9-26
Livermore Site and Environs	9-26
Site 300.....	9-27
Soil and Sediment Monitoring	10-1
Introduction.....	10-1
Sampling Locations	10-2
Methods.....	10-3
Livermore Valley Surface Soil Results	10-5
Livermore Site Sediment Results	10-8
Livermore Site Vadose Zone Soil Results	10-9
Site 300 Results	10-10
Environmental Impact	10-11
Livermore Site	10-11
Site 300.....	10-12
Vegetation and Foodstuff Monitoring.....	11-1
Introduction.....	11-1
Methods.....	11-2
Vegetation.....	11-2
Wine	11-3
Results	11-4
Livermore Site	11-4
Vegetation	11-4
Wine.....	11-5
Site 300.....	11-8
Vegetation	11-8
Environmental Impact	11-10
Livermore Site Vegetation	11-10
Livermore Site Wine	11-12
Summary	11-12
Site 300.....	11-12
Environmental Radiation Monitoring.....	12-1
Introduction.....	12-1
Cosmic Radiation Component.....	12-1
Terrestrial Radiation Component.....	12-1
General Methods.....	12-2
Monitoring Locations.....	12-2
Results of Gamma Monitoring.....	12-2

Livermore Site	12-2
Site 300.....	12-4
Environmental Impact	12-5
Radiological Dose Assessment	13-1
Introduction.....	13-1
Background Information	13-1
Releases of Radioactivity to Air	13-2
Air Dispersion and Dose Models.....	13-2
Radiation Protection Standards.....	13-3
Air Emission Sources and Data	13-4
Sources.....	13-4
2001 Air Monitoring.....	13-4
Continuous Stack Air Effluent Monitoring.....	13-4
Air Surveillance Monitoring for Radioactive Particles and Gases.....	13-5
Radionuclide Usage Inventory Update.....	13-6
Dose Assessment Methods and Concepts.....	13-7
Principal Modeling Approaches.....	13-7
Identification of Key Receptors.....	13-7
Summary of Input Parameters to CAP88-PC	13-9
General Model Inputs.....	13-9
Meteorological Data	13-9
Surrogate Radionuclides	13-9
Population Inputs	13-9
Land Use and Agricultural Inputs	13-9
Source Specification	13-10
Special Modeling Challenges.....	13-10
Modeling Dose from Tritium.....	13-11
Reporting the Contribution of Tritium to Total Dose.....	13-12
Results of 2001 Radiological Dose Assessment	13-12
Total Dose to Site-Wide Maximally Exposed Individuals.....	13-12
Doses from Unplanned Releases	13-15
Population Doses.....	13-15
Effect of Silica Gel Correction Factors on Modeling vs. Monitoring Comparison	13-16
Doses to the Public Placed in Perspective	13-16
Estimate of Dose to Biota	13-17
Summary and Conclusion	13-19
Quality Assurance.....	14-1
Introduction.....	14-1
Quality Assurance Activities	14-2
Analytical Laboratories	14-2
Participation in Laboratory Intercomparison Studies	14-5
Duplicate Analyses.....	14-6
Radiation Units	14-10
Radiological Data	14-10
Nonradiological Data.....	14-11
Statistical Comparisons	14-11
Summary Statistics	14-11
Data Presentation	14-11

Quality Assurance Process for the Environmental Report	14-12
Appendix A. Methods of Dose Calculations	A-1
Appendix B. Environmental DOE Orders in Work Smart Standards.....	B-1
Appendix C. Reports for Regulatory Agencies	C-1
Appendix D. Supplementary Topics on Radiological Dose	D-1
D-1: Radiation Basics	D-1
D-2: Radiation Control Measures at LLNL	D-4
Appendix E. Errata	E-1
References	R-1
Acronyms and Abbreviations	AC-1
Glossary.....	GL-1
External Distribution.....	ED-1

LIST OF FIGURES

Figure EX-1. Annual median tritium (HTO) concentrations for samples of ambient air and vegetation decline with the declining emissions of HTO	EX-3
Figure EX-2. Concentrations of plutonium-239+240 in air (nBq/m ³) at three locations throughout the United States, and a perimeter and downwind LLNL Livermore site location	EX-4
Figure EX-3. Historical trend in tritium concentration in LLNL sewage	EX-5
Figure EX-4. Successful reduction of the PCE plume at the western and southern boundaries of the LLNL Livermore site.....	EX-7
Figure EX-5. Successful reduction of the TCE plume at the southeastern boundary of LLNL's Site 300	EX-8
Figure 1-1. Locations of LLNL Livermore site and Site 300	1-2
Figure 1-2. Wind rose showing the frequency of occurrence for wind speed and direction at the Livermore site, 2001.....	1-4
Figure 1-3. Wind rose showing the frequency of occurrence for wind speed and direction at Site 300, 2001.....	1-5
Figure 1-4. 2001 approximate groundwater and surface elevation contours, Livermore site and vicinity.....	1-6
Figure 1-5. 2001 approximate groundwater elevations in the principal continuous water-bearing zone at Site 300	1-8
Figure 4-1. Facilities at the Livermore site with air monitoring systems for effluent gas streams during all or part of 2001	4-3
Figure 4-2. Tritium Facility combined HTO and HT emissions from 1981 through 2001.....	4-6
Figure 5-1. Air particulate and tritium sampling locations on the Livermore site, 2001.....	5-4
Figure 5-2. Air particulate and tritium sampling locations in the Livermore Valley, 2001.....	5-5
Figure 5-3. Air particulate and tritium sampling locations at Site 300 and off-site, 2001.....	5-6
Figure 5-4. Two-year history of the median gross alpha and gross beta activities for all particulate samples grouped by area, 2000-2001	5-8
Figure 5-5. Monthly median concentrations of plutonium-239+240 in air particulate samples, 2001.....	5-11
Figure 5-6. Calculated annual median concentrations of plutonium-239+240 for SALV and FCC with current detection limit and DCG identified, 2001	5-12
Figure 5-7. Monthly median concentration of beryllium in air particulate samples	5-14
Figure 5-8. Median concentration of beryllium in air particulate samples taken at the Livermore site perimeter, 1975–2001	5-15
Figure 6-1. LLNL sanitary sewer system, monitoring stations, and diversion facility	6-2
Figure 6-2. Historical trend in tritium concentration in LLNL sewage	6-9
Figure 6-3. Historical trends in average monthly plutonium and cesium concentrations in LLNL sewage.....	6-11
Figure 6-4. Monthly 24-hour composite sample concentrations for eight of the nine regulated metals in LLNL sanitary sewer effluent showing trends from 1994 to 2001.....	6-14

Figure 6-5.	Results as percentages of effluent pollutant limits (EPLs) for eight of the nine regulated metals in LLNL sewage, 2001	6-15
Figure 7-1.	Surface waterways in the vicinity of the Livermore site.....	7-6
Figure 7-2.	Storm water runoff and Drainage Retention Basin sampling locations, Livermore site, 2001	7-7
Figure 7-3.	Storm water sampling locations for NIF construction project	7-8
Figure 7-4.	Storm water and rainwater sampling locations at Site 300, 2001	7-9
Figure 7-5.	Diuron concentrations in Arroyo Las Positas storm water 1997–2001	7-13
Figure 7-6.	Tritium activity in Livermore storm water samples from the Arroyo Las Positas (location WPDC) 1992–2001	7-14
Figure 7-7.	Sampling locations for the special tritium studies performed at Livermore site	7-15
Figure 7-8.	Tritium activities in storm water samples from the downstream storm drain location 3729 near the Tritium Facility	7-16
Figure 7-9.	Tritium activities in storm water samples from the storm drains near Building 343.....	7-16
Figure 7-10.	Rain sampling locations, Livermore site and Livermore Valley, 2001	7-21
Figure 7-11.	Mean tritium activities (detections only) in rain at locations in the Livermore vicinity grouped by direction from the Tritium Facility, 1990-2001.....	7-23
Figure 7-12.	Sampling locations within the Drainage Retention Basin, 2001	7-25
Figure 7-13.	Monthly chlorophyll-a in the Drainage Retention Basin, 2001	7-28
Figure 7-14.	Transparency in Drainage Retention Basin, 1994–2001	7-29
Figure 7-15.	Nutrient levels in the Drainage Retention Basin, 2001	7-30
Figure 7-16.	Cooling tower locations and receiving water monitoring locations, Site 300, 2001	7-31
Figure 7-17.	Site 300 surface waters, drinking water tanks, and receiving water monitoring locations.....	7-34
Figure 7-18.	Surface and drinking water sampling locations, Livermore Valley, 2001	7-35
Figure 7-19.	Annual median tritium activity in Livermore Valley surface and drinking water, 1988 to 2001	7-37
Figure 7-20.	Arroyo Las Positas maintenance zones.....	7-38
Figure 8-1.	Map and cross section of the Livermore site showing hydrostratigraphic units and the locations of the treatment facilities.....	8-3
Figure 8-2.	Total VOC mass removed from the subsurface of the Livermore site, 1989–2001	8-6
Figure 8-3.	Isoconcentration contour map of total VOCs within HSU 1B, 2001	8-7
Figure 8-4.	Isoconcentration contour map of total VOCs within HSU 2, 2001	8-8
Figure 8-5.	Isoconcentration contour map of total VOCs within HSU 3A, 2001.....	8-9
Figure 8-6.	Isoconcentration contour map of total VOCs within HSU 3B, 2001.....	8-10
Figure 8-7.	Isoconcentration contour map of total VOCs within HSU 4, 2001	8-11
Figure 8-8.	Isoconcentration contour map of total VOCs within HSU 5, 2001	8-12
Figure 8-9.	Environmental restoration operable units at Site 300.....	8-23
Figure 8-10.	Site 300 stratigraphy (Webster-Scholten 1994)	8-25
Figure 8-11.	Approximate groundwater elevations in the principal continuous water-bearing zone at Site 300.....	8-26
Figure 8-12.	Extent of groundwater contamination at Site 300	8-28
Figure 8-13.	Total VOC concentrations in groundwater in the eastern GSA and vicinity (4th quarter, 2001).....	8-30
Figure 8-14.	Total VOC concentrations in groundwater in the central GSA (4th quarter, 2001). Monitoring wells are completed in the Qt-Tnsc ₁ hydrologic unit.....	8-31
Figure 8-15.	Isoconcentration contours for total VOCs in groundwater in the Qt-Tp _{sg} hydrologic unit at the Building 834 complex (4th quarter, 2001).....	8-33

Figure 8-16. Isoconcentration contour map of trichloroethene (TCE) in groundwater in the Tnbs ₂ aquifer in the HE Process Area (2nd quarter, 2001)	8-35
Figure 8-17. Distribution of tritium in groundwater in the first water-bearing zone in the Building 850/Pits 3 and 5 Operable Unit (2nd quarter, 2001)	8-36
Figure 8-18. Distribution of TCE in groundwater in the Tnbs ₁ aquifer in the Building 854 area (4th quarter, 2001).....	8-37
Figure 8-19. Distribution of TCE and tritium in groundwater in the Pit 6 area (4th quarter, 2001).....	8-38
Figure 8-20. Distribution of TCE in groundwater in the Building 832 Canyon (4th quarter, 2001).....	8-40
Figure 9-1. Locations of off-site tritium monitoring wells in the Livermore Valley	9-4
Figure 9-2. Locations of routine surveillance groundwater monitoring wells at the Livermore site.....	9-5
Figure 9-3. Locations of surveillance groundwater wells, Barcads, and springs at Site 300	9-7
Figure 9-4. Locations of Pit 7 compliance groundwater monitoring wells	9-9
Figure 9-5. Locations of Pit 1 compliance and Pit 2 surveillance groundwater monitoring wells.....	9-9
Figure 9-6. Locations of Pit 8 surveillance groundwater monitoring wells.....	9-11
Figure 9-7. Locations of Pit 9 surveillance groundwater monitoring wells.....	9-11
Figure 9-8. Locations of Pit 6 compliance groundwater monitoring wells	9-13
Figure 9-9. Locations of Building 829 closed burn pit compliance groundwater monitoring wells	9-14
Figure 9-10. Locations of compliance groundwater monitoring wells in the Explosives Process Area 16	
Figure 9-11. Sewage evaporation and percolation ponds, compliance groundwater monitoring wells, and wastewater monitoring locations	9-17
Figure 9-12. Trend of tritium activity in Livermore Valley wells, 1988 to 2001. The drinking water MCL of 740 Bq/L is also shown.	9-19
Figure 10-1. Surface soil sampling locations, Livermore Valley, 2001	10-3
Figure 10-2. Site 300 surface soil sampling locations, 2001	10-4
Figure 10-3. Sediment and vadose zone sampling locations on or near the Livermore site, 2001.....	10-5
Figure 10-4. Median plutonium-239+240 activities in surface soils, 1976–2001. Upwind and downwind designations are relative to the center of the Livermore site.....	10-8
Figure 10-5. Median uranium-238 concentrations in surface soils, 1976–2001. Upwind and downwind designations are relative to the center of the Livermore site.	10-11
Figure 11-1. Livermore site and Livermore Valley vegetation sampling locations, 2001	11-3
Figure 11-2. Site 300 vegetation sampling locations, 2001	11-4
Figure 11-3. Median tritium concentrations in Livermore site and Livermore Valley plant water samples, 1971–2001. When median values are below detection limits, values are plotted arbitrarily as 1 Bq/L.....	11-7
Figure 11-4. Median tritium concentrations in retail wines decay-corrected from the sampling year to the vintage year	11-9
Figure 11-5. Median tritium concentrations in plant water at Site 300 sampling locations, 1971–2001. When the median values are below detection limits, values are plotted arbitrarily as 1 Bq/L.....	11-10
Figure 12-1. Gamma dosimeter locations, Livermore site, 2001	12-3
Figure 12-2. Gamma dosimeter locations, Livermore Valley, 2001	12-4
Figure 12-3. Gamma dosimeter locations, Site 300 and vicinity, 2001	12-5
Figure 12-4. Quarterly mean gamma dose measurements at the Livermore site perimeter, Livermore Valley, and Site 300, 1988–2001.....	12-6

Figure 13-1. Location of the sitewide maximally exposed individual (SW-MEI) at the Livermore site, 2001 13-8

Figure 13-2. Location of the sitewide maximally exposed individual (SW-MEI) at Site 300, 2001 13-8

Figure 14-1. Gross beta concentrations from collocated samples. These samples lie close to a line with slope equal to 1 and intercept equal to 0..... 14-9

Figure 14-2. Runoff barium concentrations from collocated samples showing an outlier 14-10

Figure 14-3. Runoff nickel concentrations from collocated samples showing a lot of scatter 14-10

LIST OF TABLES

Table 2-1.	Summary of LLNL compliance with EPCRA in 2001	2-6
Table 2-2.	Livermore site, SARA, Title III, Section 311, Chemical List, 2001	2-7
Table 2-3.	Site 300, SARA, Title III, Section 311, Chemical List, 2001	2-9
Table 2-4.	Inspections and tours of the Livermore site and Site 300 by external agencies in 2001 ...	2-10
Table 2-5.	Summary of permits active in 2001	2-11
Table 2-6.	Summary of NPDES permit nonconformance	2-14
Table 2-7.	Summary of nonconformance with LWRP permit limits for discharges to the sanitary sewer	2-14
Table 2-8.	Summary of streambed alteration agreements, Nationwide Permits, and Waste Discharge Requirements	2-15
Table 2-9.	Summary of in-service tanks, December 31, 2001	2-16
Table 2-10.	Environmental occurrences reported under the Occurrence Reporting (OR) System, 2001	2-24
Table 3-1.	UC Contract 48 environmental protection performance measures for environmental performance in FY2001	3-7
Table 3-2.	Pollution prevention and energy efficiency leadership goals at Department of Energy facilities	3-8
Table 3-3.	Routine waste reduction, FY 2001	3-10
Table 3-4.	Total nonhazardous waste sent to landfills, FY 2001	3-11
Table 3-5.	Diverted waste summary, FY 2001	3-11
Table 3-6.	P2 Award Nominations	3-13
Table 3-7.	High return-on-investment projects, 2001	3-13
Table 4-1.	Air effluent sampling locations and sampling systems	4-4
Table 4-2.	Nonradioactive air emissions, Livermore site and Site 300, 2001	4-7
Table 5-1.	Sampling locations and type and frequency of analyses for ambient air	5-3
Table 5-2.	Beryllium-7 activity in air particulate samples for the Livermore site and Site 300 composites, 2001	5-9
Table 5-3.	Summary of uranium mass concentration in air samples, 2001	5-13
Table 5-4.	Tritium in air samples, 2001	5-13
Table 6-1.	Permit discharge limits for nonradioactive pollutants in LLNL wastewaters	6-5
Table 6-2.	Estimated total radioactivity in LLNL sanitary sewer effluent, 2001	6-7
Table 6-3.	Tritium in sanitary sewer effluents, LLNL and LWRP, 2001	6-8
Table 6-4.	Cesium and plutonium in sanitary sewer effluents, LLNL and LWRP, 2001	6-10
Table 6-5.	Radioactive liquid effluent releases from the Livermore site, 1992–2001	6-12
Table 6-6.	Average monthly results for regulated metals in LLNL sanitary sewer effluent (mg/L), 2001	6-13
Table 6-7.	Monthly monitoring results for physical and chemical characteristics of the LLNL sanitary sewer effluent, 2001	6-17
Table 7-1.	Analyses conducted on storm water samples, 2001	7-3

Table 7-2.	Threshold comparison criteria for selected water quality parameters. The sources of values above these are examined to determine if any action is necessary.	7-4
Table 7-3.	Fish chronic toxicity test results, Livermore site, January 2001	7-11
Table 7-4.	Algae chronic toxicity test results, Livermore site, January 2001	7-11
Table 7-5.	Chronic algae toxicity test results in Arroyo Las Positas storm water on February 12, 2001	7-12
Table 7-6.	Radioactivity in storm water from the Livermore site, 2001.....	7-13
Table 7-7.	Water quality parameters above the threshold comparison criteria shown in Table 7-2 from both the Livermore site and Site 300 in 2001	7-17
Table 7-8.	Total suspended solids in storm water samples from Site 300 in 2001	7-19
Table 7-9.	Tritium activities in rainfall for the Livermore site, Livermore Valley, and Site 300, 2001	7-22
Table 7-10.	Summary of Drainage Retention Basin monitoring not meeting management action levels.....	7-27
Table 7-11.	Summary data from monitoring of primary cooling towers, Site 300, 2001	7-32
Table 7-12.	Radioactivity in surface and drinking water in the Livermore Valley, 2001	7-36
Table 7-13.	Arroyo Las Positas maintenance project monitoring data, 2001	7-39
Table 8-1.	2001 extraction wells and extraction rates	8-4
Table 8-2.	Volatile organic compounds (VOCs) removed from groundwater and soil at the Livermore site	8-5
Table 8-3.	Wells installed in 2001	8-13
Table 8-4.	Major contaminants of concern found in soil, rock, and groundwater at Site 300	8-24
Table 8-5.	Volatile organic compounds (VOCs) removed from groundwater and soil vapor at Site 300	8-42
Table 8-6.	General Services Area groundwater treatment system surface discharge permit requirements	8-44
Table 9-1.	Concentration ranges for three major anions in shallow background and western perimeter monitoring wells	9-20
Table 10-1.	Plutonium activity concentrations in Livermore Valley soil, 2001	10-6
Table 10-2.	Plutonium and americium activity concentrations in LWRP soil, 2001	10-7
Table 10-3.	Plutonium and tritium activity concentrations in surface sediment, 2001	10-9
Table 10-4.	Uranium and beryllium concentration in Site 300 soil, 2001	10-10
Table 10-5.	Special soil studies	10-12
Table 11-1.	Concentrations of tritium in plant water (Bq/L) collected quarterly from various sampling locations, 2001	11-6
Table 11-2.	Tritium in retail wine (Bq/L), 2001	11-8
Table 12-1.	Summary of dose calculations for gamma-monitoring locations (mSv) at all LLNL sites, 2001	12-6
Table 12-2.	Annual dose by year at the Livermore site perimeter caused by direct gamma radiation	12-7
Table 13-1.	List of facilities or sources whose emissions accounted for more than 90% of the SW-MEI doses for the Livermore site and Site 300 in 2001	13-13
Table 13-2.	Doses (in μ Sv) calculated for the sitewide maximally exposed individual (SW-MEI) for the Livermore site and Site 300, 1990 to 2001	13-14
Table 13-3.	Annual dose to the SW-MEI from explosives experiments on firing tables at Site 300, 1990–2001, related to the total quantity of depleted uranium used in the experiments and the total quantity of high explosives driving the detonations	13-15

Table 13-4. Uncorrected (upper) and corrected (lower) ratios of predicted-to-observed air concentrations of tritiated water at Livermore site perimeter locations and ZON7, 1997-2001	13-17
Table 13-5. Comparison of background (natural and man-made) and LLNL radiation doses, 2001	13-18
Table 14-1. Sampling completeness in 2001 for the Livermore site and Site 300	14-3
Table 14-2. Quality assurance collocated sampling. Summary statistics for analytes with more than eight pairs in which both results were above the detection limit	14-7
Table 14-3. Quality assurance collocated sampling. Summary statistics for selected analytes with eight or fewer pairs in which both results were above the detection limit	14-8
Table 14-4. Quality assurance collocated sampling. Summary statistics for analytes with at least four pairs in which one or both results were below the detection limit	14-9



EXECUTIVE SUMMARY

Lawrence Livermore National Laboratory (LLNL) is a U.S. Department of Energy national laboratory operated by the University of California. LLNL has two sites—the Livermore site located in Livermore, California, and the Experimental Test Site (Site 300) located approximately 20 km (12 mi) east of Livermore, near Tracy, California.

When it was founded in September 1952, LLNL's purpose was to support the Nation's nuclear weapons program by providing innovative design and engineering. Since that time, LLNL has grown to become one of the world's premier scientific centers, with additional substantial research efforts directed toward laser fusion energy, computation, non-nuclear energy, biomedicine, and environmental science.

Although LLNL's mission has been fundamentally one of scientific research, as an institution it has been ever mindful of its responsibilities for protecting the environment and the health and safety of its employees. As stated in the *Environment, Safety and Health Manual*, "It is the Laboratory's environment, safety, and health (ES&H) policy to perform work in a manner that protects the health and safety of employees and the public, preserves the quality of the environment, and prevents property damage. The environment, safety, and

health are to be priority considerations in the planning and execution of all work activities at the Laboratory. Furthermore, it is the policy of LLNL to comply with applicable ES&H laws, regulations, and requirements."

To meet these requirements, LLNL currently monitors the ambient air, water, and soil, and air and liquid effluents for numerous radiological and non-radiological materials. LLNL complies with all federal, state, and local environmental permitting requirements, including the requirements imposed by listing as a Superfund site on the National Priorities List.





This summary is a brief overview of environmental compliance and monitoring activities undertaken by LLNL in calendar year 2001.

Radiological Monitoring

The emissions most often associated with LLNL, especially the Livermore site, are the emissions of tritium (which is the radioactive isotope of hydrogen) to the atmosphere. Tritium emissions occur in two chemical forms: tritium gas (HT) and tritiated water (HTO). The HT and HTO emissions from the most significant programmatic source of tritium, the Tritium Facility, are monitored continuously. In addition, samples of ambient air, vegetation, sewer effluent, storm water, rainwater, groundwater, sediment, and wine are collected and analyzed for HTO. **Figure EX-1** shows the HTO emissions from LLNL Livermore site operations, including the emissions from Sandia/California, a neighboring Department of Energy laboratory that used tritium in its operations from 1979 to 1995. The figure also shows the measured quantities of HTO in ambient air at two locations and in vegetation from a collocated sampling location. The figure illustrates that ambient environmental measurements decline with emissions, that the ambient measurement also declines with distance (ZON7 location is farther downwind from the Livermore site than VIS), and that measurements by environmental media are correlated. Although not shown in the figure, measurements of tritium in wine, rainwater, surface water, and sewer effluent show the same downward trend.

The Department of Energy (DOE) primary radiation protection standard for protection of the public is 1 mSv/y (100 mrem/y). To enable the determination of whether concentrations of radionuclides in the air or water may cause an exposure greater than the standard, DOE developed Derived Concentration Guides. The Derived Concentration

Guides specify the concentrations of radionuclides that an individual could consume, inhale, or be immersed in continuously 365 days a year without receiving a dose greater than 1 mSv/y (100 mrem/y). The Derived Concentration Guide for HTO in air is 3700 Bq/m³ (100,000 pCi/m³). All measurements of HTO in air in 2001 were less than 5 Bq/m³ (135 pCi/m³), that is, less than 0.2% of the Derived Concentration Guide. Although there are no standards for levels of tritium in vegetation or wine, the wine measurements can be compared to the drinking water standard of 740 Bq/L (20,000 pCi/L). The highest measured value for a Livermore Valley wine for the samples collected in calendar year 2001 is 2.6 Bq/L (70 pCi/L), less than 0.4% of the drinking water standard.

Another radioisotope often associated with LLNL operations is plutonium. Current measurements of plutonium at the perimeter of the Livermore site arise from the resuspension of soil contaminated by the operation of solar evaporators of plutonium-containing liquid waste in the early 1970s.

Figure EX-2 shows the measurement of plutonium in ambient air from a Livermore site perimeter location (VIS) and a downwind location (ZON7) as well as three other locations from around the United States. From this figure it can be seen that measurements at the Livermore site are very similar to measurements in other parts of the United States. These measurements result from global fallout from nuclear weapons tests by various nations over the last 50 years. For example, the People's Republic of China conducted eight atmospheric weapons tests of various explosive yields from June 1974 to October 1980. The debris from the tests, including fission products, made a number of passes around the globe before declining to undetectable quantities. The LLNL values at the downwind location, ZON7, are consistent with other measurements of global fallout throughout the United States. The

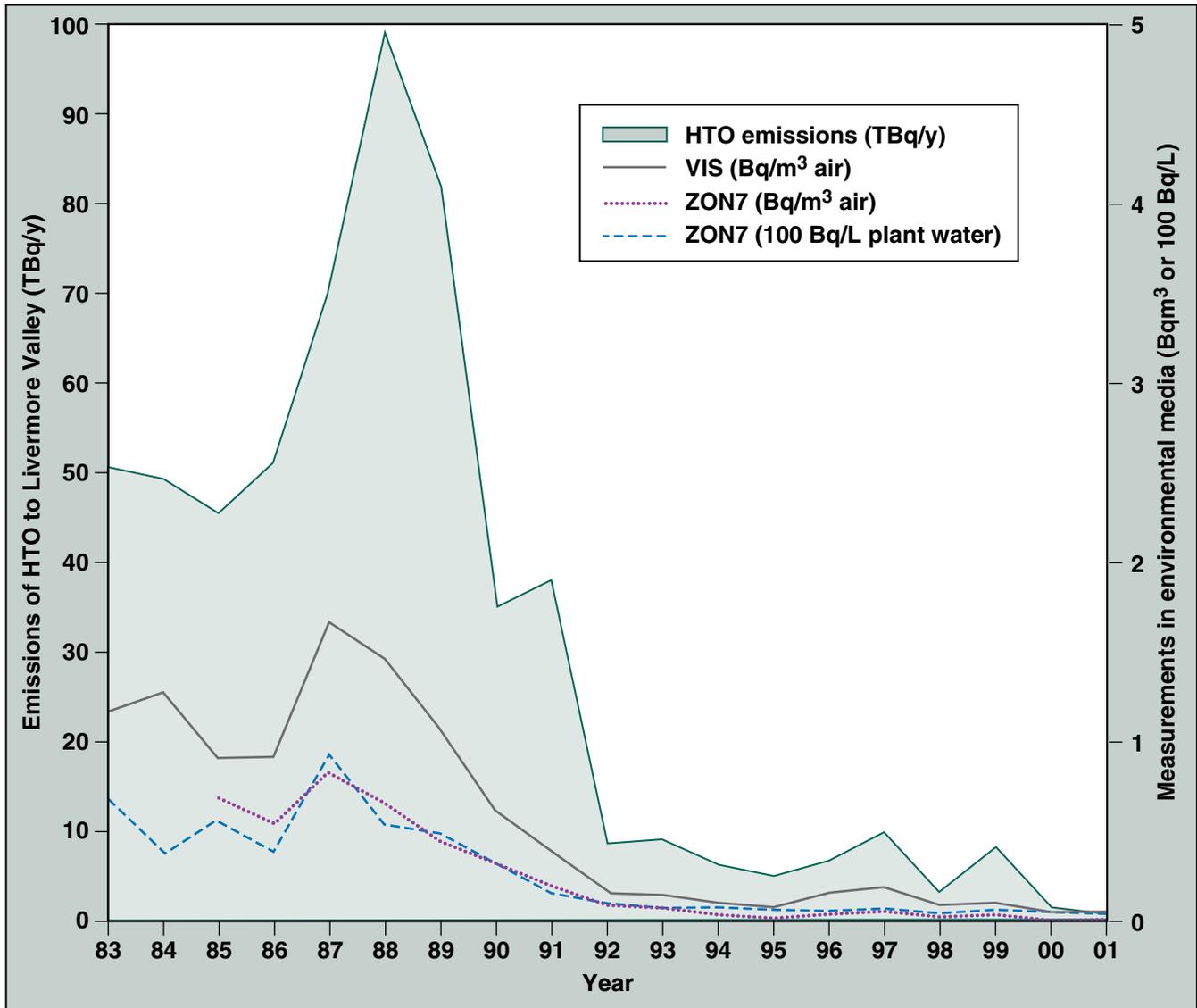
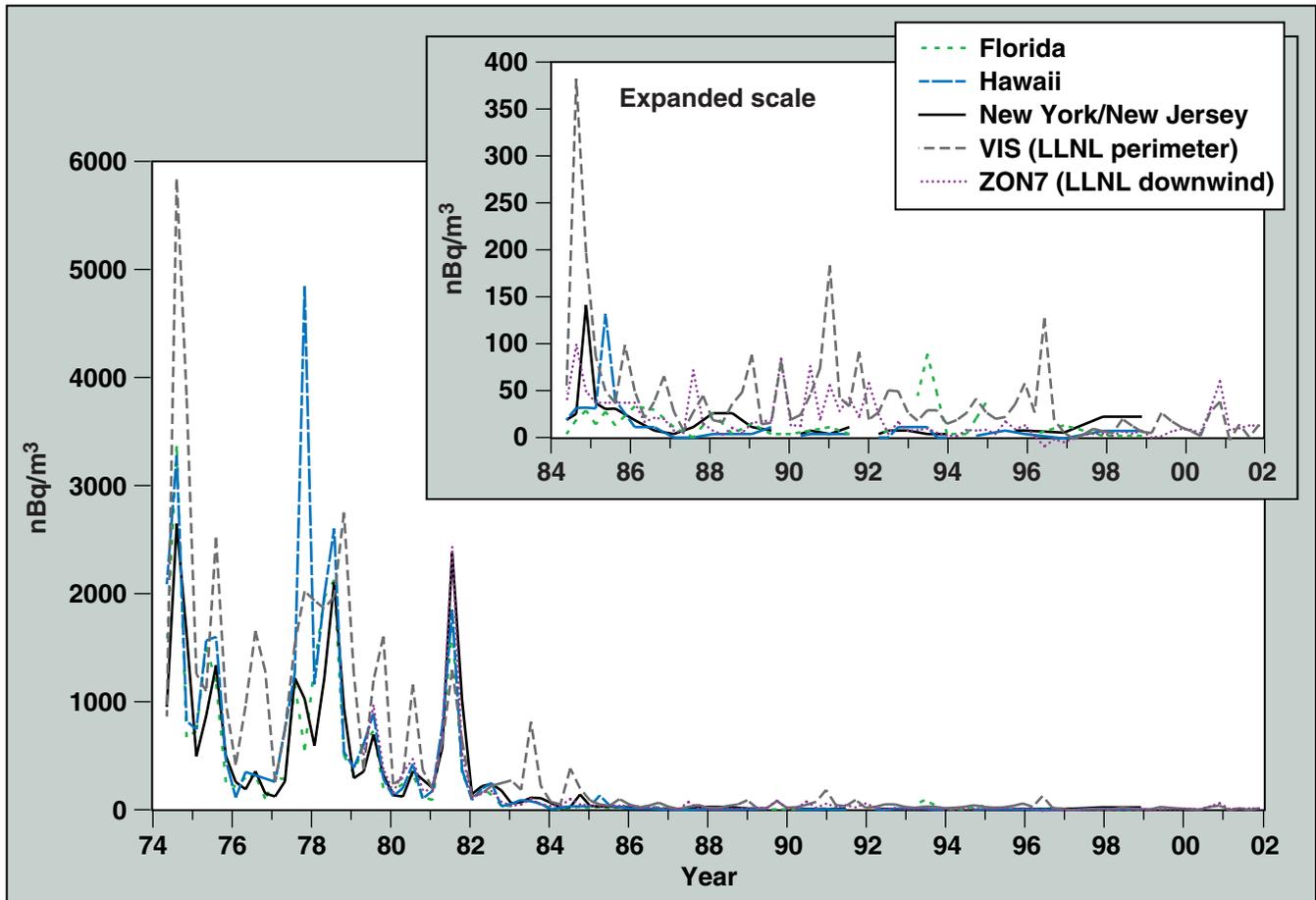


Figure EX-1. Annual median tritium (HTO) concentrations for samples of ambient air and vegetation decline with the declining emissions of HTO

measurements at sampling location VIS show the contributions of resuspension of plutonium-contaminated soil. By the early 1990s, the concentrations at all locations shown in [Figure EX-2](#) declined to a level where most analytical results are non-detections.

The Derived Concentration Guide for plutonium in air is 0.00074 Bq/m^3 (0.02 pCi/m^3); the highest measured value in 2001 for LLNL sampling locations for plutonium $9.5 \times 10^{-7} \text{ Bq/m}^3$ ($2.6 \times 10^{-5} \text{ pCi/m}^3$), only 0.13% the Derived Concentration Guide.



Sources: 1974 to 1985, U.S. Department of Energy Environmental Measurements Laboratory; 1985 to 1999, U.S. Environmental Protection Agency, National Air and Radiation Environmental Laboratory. The samples for Florida were collected in Miami; the samples for Hawaii, in Mauna Loa for 1974 to 1985 and in Honolulu for 1986 to 1999; the samples for New York/New Jersey, in New York City from 1974 to 1990, and in Trenton, New Jersey for 1991 to 1999.

Figure EX-2. Concentrations of plutonium-239+240 in air (nBq/m³) at three locations throughout the United States, and a perimeter and downwind LLNL Livermore site location

Substantial efforts are also undertaken by LLNL to characterize the contribution of operations to the sewer effluent leaving the site. During 2001, no permitted discharge limit for radioactive materials was exceeded in the sewer effluent. Nonradiological permit limits were exceeded only once during 2001, when lead was discharged at a concentration of 1.4 mg/L on May 11.

The sewer effluent is monitored continuously for gamma radioactivity, flow rate, pH, and metals. Effluent samples are analyzed daily for gross alpha, gross beta, and tritium radioactivity. Monthly composites of daily sewer samples are analyzed for tritium, plutonium, and cesium radioactivity. **Figure EX-3** shows the monthly average tritium activity in the sewer effluent since 1982. As can be seen in this figure, the amount of tritium released has declined significantly. During 2001, the monthly tritium activity averages were mostly

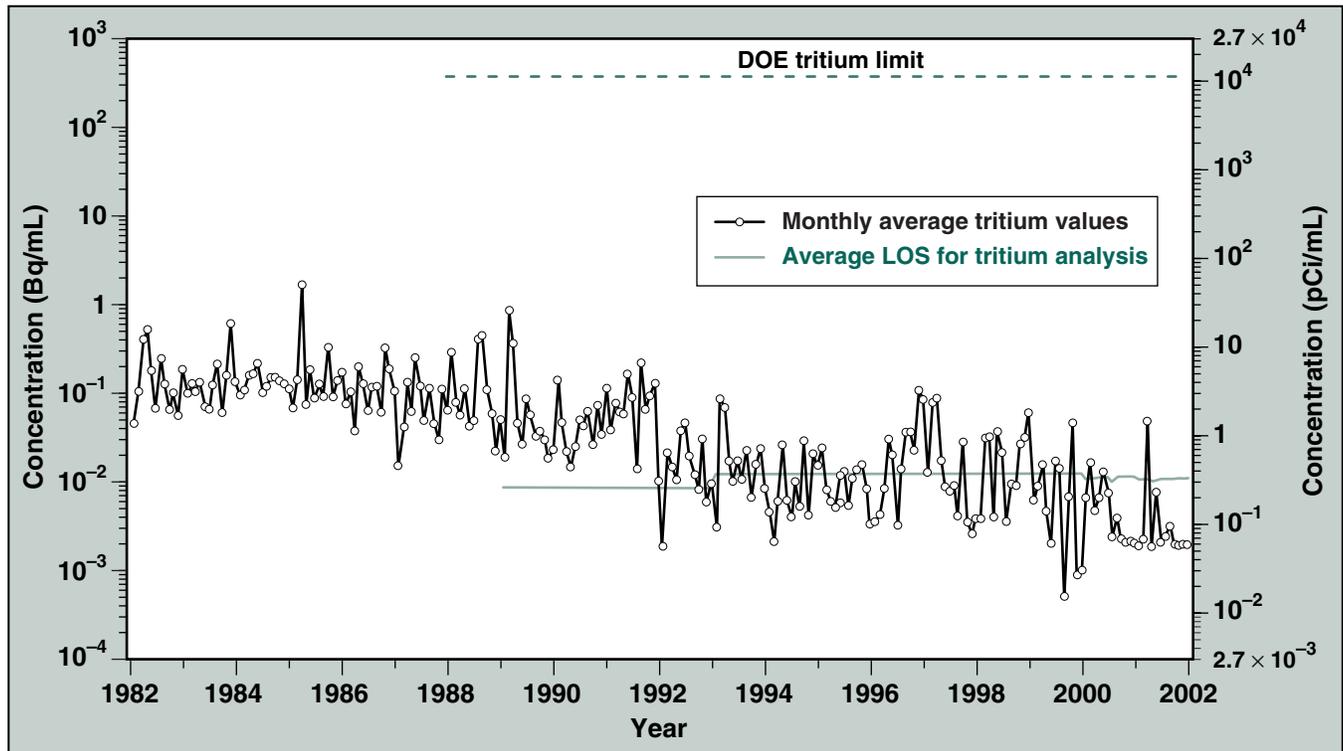


Figure EX-3. Historical trend in tritium concentration in LLNL sewage

below the limit of sensitivity of the analytical method used. The median monthly tritium release was 0.002 Bq/mL (0.05 pCi/mL), or 0.0005% of the Derived Concentration Guide of 370 Bq/mL (10,000 pCi/mL). Similarly, the annual discharges of cesium-137 and plutonium-239 were small percentages, 5.7×10^{-4} and 9.5×10^{-5} , respectively, of their Derived Concentrations Guides.

The measurements of radionuclides in soil and the direct measurements of gamma radiation using thermoluminescent dosimeters (TLDs) provide further confirmation of the low level of effects of LLNL's radiological operations on the environment. Most radionuclides in soil were detected at background concentrations. The highest measured value for plutonium-239+240 in soil occurred in a sample from an area of known contamination at the Livermore Water Reclamation Plant. The

contamination is the result of an estimated 1.2×10^9 Bq (32 mCi) release of plutonium to the sanitary sewer in 1967 and earlier releases. The measured value for 2001, 6.5 mBq/dry g (0.18 pCi/dry g), is 1.4% of the National Council on Radiation Protection (NCRP) recommended screening level of 0.470 Bq/dry g (12.7 pCi) for property used for commercial purposes. The highest measured value for uranium-238 was 18 μ g/dry g and was from a sample collected at Site 300, in an area where tests containing depleted uranium have been conducted; the measured value is well below the NCRP screening level of 313 μ g/dry g for commercial sites.

TLDs absorb gamma radiation from all sources, including terrestrial sources such as naturally occurring radioactive isotopes of uranium, thorium, radium, and radon present in the soil, cosmic



radiation originating from beyond the solar system, as well as any man-made gamma radiation arising from LLNL operations. The TLD measurements for 2001 yielded an annual dose of 0.55 mSv (55 mrem), a value consistent with the National Council on Radiation Protection and Measurements (NCRP) estimate of the annual average U.S. personal dose from terrestrial and cosmogenic sources of 0.58 mSv (58 mrem); these estimates are published in NCRP Report No. 93, *Ionizing Radiation Exposure of the Population of the United States*.

Nonradiological Monitoring

Most of the nonradiological monitoring is performed on samples of groundwater, surface water, and storm water runoff. Although water samples are analyzed for various radioisotopes, their chemical contents are also of concern to regulators, especially where the water is or contributes to a drinking water source or supports aquatic life. Water monitoring at both LLNL sites is conducted to meet general DOE environmental protection requirements, to meet state and federal permit requirements, and to meet Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) requirements. Water monitoring locations include wells, springs, ponds, streams, and drinking water reservoirs. With the exception of volatile organic compounds in wells monitored for CERCLA compliance, the constituents of all off-site samples collected in 2001 were within regulatory or permit limits. The groundwater containing contaminants in excess of standards is being remediated in compliance with Federal agency cleanup agreements.

Superfund Activities

Two of the most substantial LLNL environmental activities are the investigations and cleanup of groundwater that are being conducted at the

Livermore site and at Site 300. The groundwater contaminants at the Livermore site are primarily the volatile organic compounds, trichloroethene (TCE) and tetrachloroethene (PCE). The original source of these contaminants dates from the time that the Livermore site was a Naval Air Station during World War II, when aircraft repair and servicing took place on the site. TCE and PCE were solvents used in cleaning airplane parts.

For the most part, the groundwater contaminants remain within the Livermore site boundary; however, they do extend beyond the boundary to the west and south of the site. Maps showing the extent of PCE contamination in 1988 before cleanup of the PCE plume began, and the current extent of PCE contamination are shown in [Figure EX-4](#). These maps show the progress that has been made in the PCE cleanup. Since remediation began in 1989, approximately 6.5 billion liters (1.7 billion gallons) of groundwater and over 934,000 cubic meters (33 million cubic feet) of vapor have been treated, removing more than 1238 kilograms (2,735 pounds) of volatile organic compounds from all remediation sites.

Volatile organic compounds are also the main groundwater contaminants at Site 300. The sites are also similar in that the contamination is, for the most part, confined to the site. The sites differ in that Site 300, with an area of 30.3 km² (11.8 mi²), is much larger than the Livermore site, and has been divided into eight operable units based on the nature and extent of contamination, and topographic and hydrologic considerations. The Livermore site at 3.28 km² (1.3 mi²) is effectively one operable unit. Site 300 has additional contaminants, including organosilicate oil, nitrate, high explosives, perchlorate, tritium, and depleted uranium. Many of these contaminants are present in the groundwater at Site 300 because of the historic practice of burying debris from high-explosives tests.

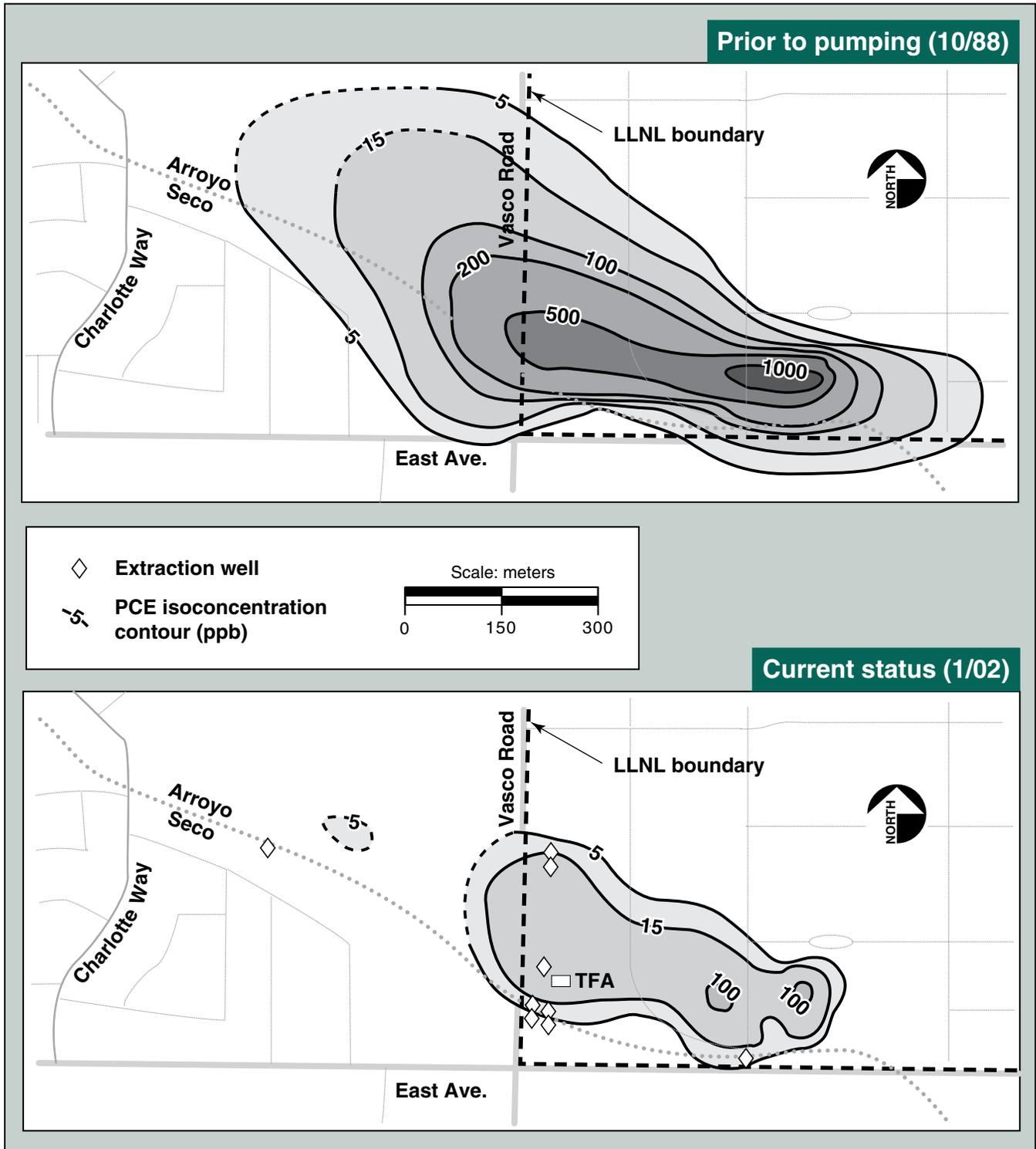


Figure EX-4. Successful reduction of the PCE plume at the western and southern boundaries of the LLNL Livermore site



LLNL has made substantial progress in cleanup at Site 300. For example, before treatment commenced in 1991, the contaminant plume as shown by monitoring of groundwater wells at the eastern General Services Area (GSA) operable unit, extended more than a mile down the Corral Hollow Creek channel. Now, TCE concentrations have been decreased to below drinking water standards in groundwater from all off-site wells. The reduction in this plume is illustrated in [Figure EX-5](#). Overall, since remediation efforts began in 1990, more than 772 million liters (200 million gallons) of groundwater and

approximately 3.13 million cubic meters (110 million cubic feet) of vapor have been treated, yielding about 198.3 kilograms (438.2 pounds) of removed VOCs.

Regulatory Permitting and Compliance

LLNL undertakes substantial activities to comply with the many federal, state and local environmental laws. The major permitting and regulatory activities that LLNL conducts are required by the Clean Air Act, the Clean Water Act and related

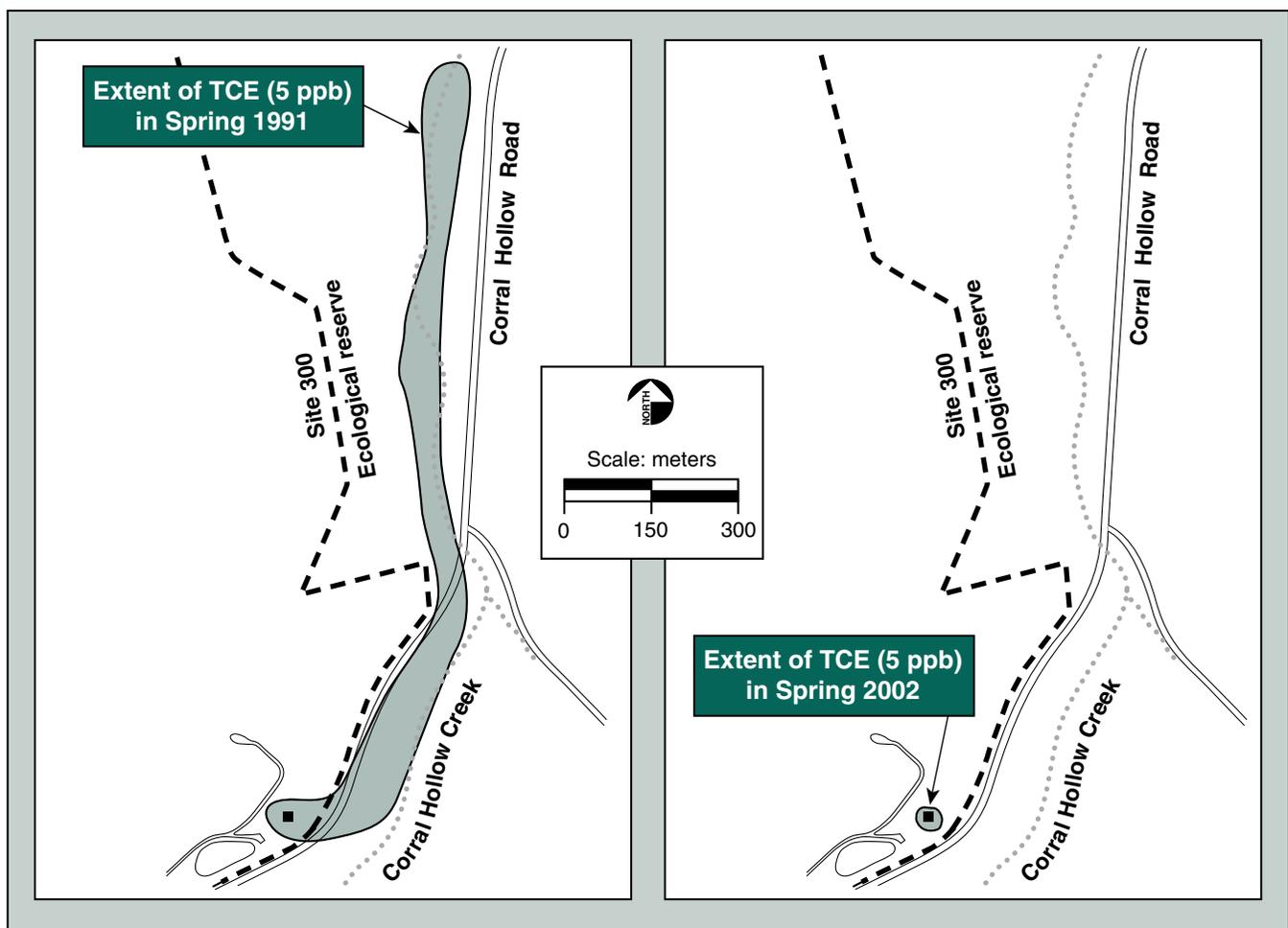


Figure EX-5. Successful reduction of the TCE plume at the southeastern boundary of LLNL's Site 300



state programs, the Resource Conservation and Recovery Act and state and local hazardous waste regulations, the National Environmental Policy Act (NEPA) and the California Environmental Quality Act (CEQA), the Endangered Species Act, the National Historic Preservation Act, the Antiquities Act, and the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA, which is more commonly known as the Superfund Act).

LLNL has numerous environmental permits from a variety of regulatory agencies in all levels of government. Some of these permits cover individual pieces of equipment (for example, air permits for boilers, emergency generators, degreasers, printing presses, or tank permits for product or waste storage). During the years 1990 to 2001, LLNL obtained 150 to 250 air permits, depending on operations. However, for the same time period, the number of permitted tanks has steadily declined from 80 to 16 tanks, as the tanks have been permanently closed or replaced with aboveground tanks. Other permits cover classes of emissions, such as the Regional Water Quality Control Board controls on discharges of industrial or construction-site storm water and treated groundwater to surface water. Similarly, the sewer permits cover all discharges from the Livermore site to the municipal sewage system, setting emissions limits for acidity or alkalinity, metals, and radioactivity. Hazardous waste permits, likewise, cover all operations in which the various physical forms of hazardous, radioactive, mixed, and medical waste are handled or stored.

Permitting is not the only type of compliance activity. Another significant compliance activity is reporting, and generating data to support the reports. Some reporting can occur as frequently as monthly, for example, sanitary sewer reports, or annually, for example, the waste minimization reports; however, reporting may be virtually any

period determined by the regulatory agency. Reports cover subjects as varied as hazardous materials business plans; NEPA and CEQA evaluations of new projects, experiments and construction; waste management reports; stormwater pollution prevention plans and reports; antiquities and cultural evaluations; and endangered species surveys.

One report of public interest provides an estimate of the radionuclide dose to a hypothetical maximally exposed individual member of the public. This report is the annual report submitted to the U.S. Environmental Protection Agency (EPA) in compliance with the National Emissions Standards for Hazardous Air Pollutants (NESHAPs) section of the federal Clean Air Act. NESHAPs specifically regulates the emissions of radionuclides to air and their dose consequences. NESHAPs limits the annual dose to members of the public caused by operations to 100 μSv (10 mrem). The regulations specify the methods by which airborne emissions and their impacts must be evaluated. The total dose is calculated using the conservative assumptions about emissions of radionuclides from unmonitored sources required by the U.S. EPA, as well as stack monitoring and ambient air modeling, where available. The total dose for 2001 was 0.17 μSv (0.017 mrem) for the Livermore site and 0.54 μSv (0.054 mrem) for Site 300. These doses are well below the 100 μSv (10 mrem) standard. These modeling calculations provide a separate mechanism for evaluating the magnitude of the impacts of LLNL operations and confirm that the impacts of LLNL operations are very small.

A final important method by which LLNL complies with environmental regulations is to conduct surveys of and undertake measures to protect endangered and threatened species, as required by the U.S. Endangered Species Act and the California Endangered Species Act. Both the Livermore site and Site 300 have populations of



rare or endangered species. Livermore site populations of the California red-legged frog (*Rana aurora draytonii*) were monitored and were the subject of special protective measures during the Arroyo Las Positas maintenance project. Also at the Livermore site, one pair of white-tailed kites (*Elanus leucurus*) successfully fledged three young and a pair of red-shoulder hawks (*Bute lineatus*) fledged two young.

At Site 300, three occupied American badger (*Taxidea taxus*) dens and eight western burrowing owl (*Speotyto cunicularia hypugaea*) dens were identified. Site 300 also has populations of the California red-legged frog and the California tiger salamander (*Ambystoma californiense*). In addition, Site 300 is home to four rare plant species: the large-flowered fiddleneck (*Amsinckia grandiflora*), the big tarplant (*Blepharizonia plumosa*), the diamond-petaled poppy (*Eschscholzia rhombipetala*), and the gypsum-loving larkspur (*Delphinium gypsophilium* ssp. *gypsophilium*). The first three of these species were the subject of detailed monitoring and restoration activities in 2001; future periodic monitoring will be conducted for the gypsum-loving larkspur.

Conclusion

The current techniques LLNL uses for environmental monitoring are very sensitive, allowing detection of extremely low levels of constituents. The combination of surveillance and effluent monitoring, source characterization, and dose assessment shows that radiological dose to the public caused by LLNL operations is less than 1% of regulatory standards and is about 0.01% of the dose received from natural background radiation. The analytical results and evaluations generally show continuing low contaminant levels, reflecting the responsiveness of the Laboratory in controlling pollutants.

In addition, LLNL's extensive environmental compliance activities related to water, air, endangered species, waste, and waste reduction provided further controls on LLNL's effects on the environment.

In summary, the results of the 2001 environmental programs demonstrate that LLNL is committed to protecting the environment and ensuring that its operations are conducted in accordance with applicable federal, state, and local laws and regulations. The environmental impacts of LLNL operations are minimal and pose no threat to public health or the environment.



SITE OVERVIEW

Introduction

Meteorology and geography play primary roles in how the environment is affected by human actions. Dispersal of particles in air, for example, is influenced by the wind and rain, which in turn are influenced by geographical characteristics. Similarly, the movement of groundwater is constrained by the particular geology of a site. Thus, knowledge of wind, rainfall, geology, and geographical characteristics is used to understand the effects that operations at Lawrence Livermore National Laboratory might have on the surrounding environment. Some history and a description of these characteristics help us understand the importance of the Laboratory's meteorological and geographic setting.

Operations

The Laboratory's mission is to apply science and technology in the national interest, with a focus on global security, global ecology, and bioscience. Laboratory employees are working with industrial and academic partners to increase national economic competitiveness and improve science education. The Laboratory's mission is dynamic and has changed over the years to meet new national needs.

LLNL is a full-service research laboratory with the infrastructure—engineering, maintenance, and waste management activities, as well as security, fire, health and safety, and medical departments—necessary to support its operations and about 9000 personnel.





Location

LLNL consists of two sites—the Livermore site located in Livermore, California (Livermore site) in Alameda County, and the Experimental Test Site

(Site 300) located near Tracy, California, in San Joaquin and Alameda counties (**Figure 1-1**). Each site is unique, requiring a different approach for environmental monitoring and protection.

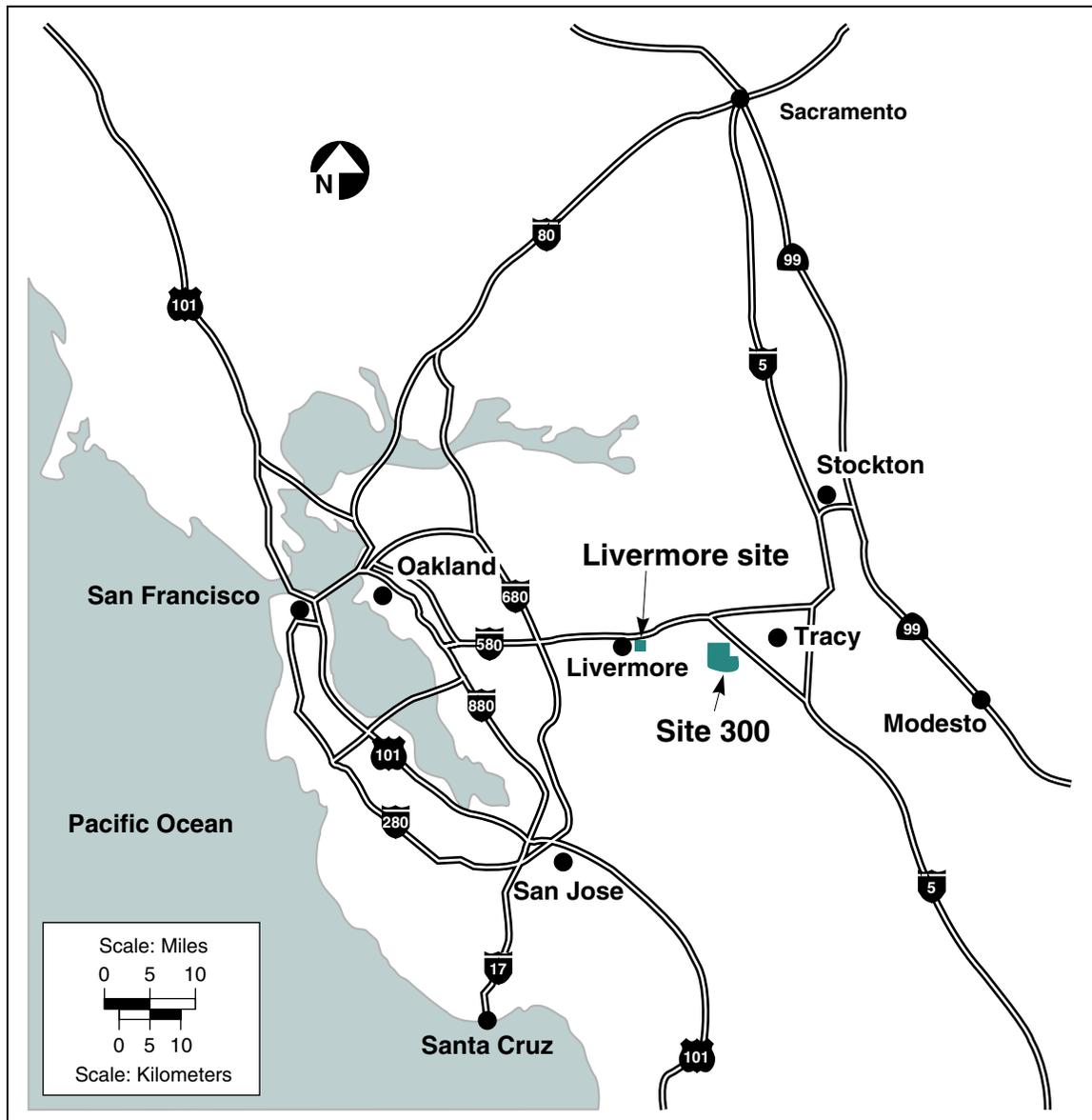


Figure 1-1. Locations of LLNL Livermore site and Site 300



LLNL was founded at the Livermore site in 1952 at a former U.S. Navy training base. At that time the location was relatively isolated, being approximately 1.6 km (1 mi) from the Livermore city limits. Over time, Livermore evolved from a small town of fewer than 7000 people when the Laboratory began to its present population which is about 75,200 (State of California 2001). The economy, which had been primarily agricultural, diversified to include light industry and business parks. Within the last few years, single-family residential developments have begun to fill the formerly vacant fields immediately to the west of the Lab. Livermore residences are now near LLNL's western boundary.

LLNL's Livermore site occupies an area of 3.28 km² (1.3 mi²), including the land that serves as a buffer zone around the site. Immediately to the south is Sandia National Laboratories/California (Sandia/California), operated by Lockheed-Martin under Department of Energy (DOE) contract. Sandia/California engages in research and development associated with nuclear weapons systems engineering as well as related national security tasks. Although their primary missions are similar, LLNL and Sandia/California are separate entities, each with its own management and each reporting to a different DOE operations office.

To the south of LLNL, there are also some low-density residential areas and agricultural areas devoted to grazing, orchards, and vineyards. A business park lies to the southwest. Farther south, property is primarily open space and ranchettes, with some agricultural use. Single-family dwellings and apartments lie immediately to the west. A very small amount of low-density residential development lies to the east of the Livermore site, and agricultural land extends to the foothills that define the eastern margin of the Livermore Valley. A business park is located to the north, and a 200-hectare (500-acre) parcel of open space to the northeast has been rezoned to allow development of light industry.

Major population centers near Livermore include the nearby communities of Pleasanton and Tracy, and the more distant metropolitan areas of Oakland, San Jose, and San Francisco, as well as Stockton in the San Joaquin Valley. There are 6.9 million residents within an 80-km (50-mi) radius of the Livermore site.

Site 300, LLNL's Experimental Test Facility, is located 20 km (12 mi) east of the Livermore site in San Joaquin and Alameda counties in the Altamont Hills of the Diablo Range; it occupies an area of 30.3 km² (11.8 mi²). SRI International operates a testing site located approximately 1 km (0.62 mi) south of Site 300. Property immediately to the east of Site 300 is owned by Fireworks America, which uses it for packaging and storing fireworks displays. The Carnegie State Vehicular Recreation Area is located south of the western portion of Site 300, and wind turbine generators line the hills to the northwest. The remainder of the surrounding area is in agricultural use, primarily as grazing land for cattle and sheep. The nearest residential area is the town of Tracy, population 61,200 (State of California 2001), located 10 km (6 mi) to the northeast. Within 80 km (50 mi) of Site 300, there are 6 million residents, many of whom are located in the metropolitan areas of Oakland, San Jose, and Stockton.

Meteorology

Meteorological data (including wind speed, wind direction, rainfall, humidity, solar radiation, and air temperature) are continuously gathered at both the Livermore site and Site 300. Mild, rainy winters and warm, dry summers characterize the climate. A detailed review of the climatology for LLNL can be found in *Climatology of Lawrence Livermore National Laboratory* (Gouveia and Chapman 1989). The mean annual temperature for the Livermore site in 2001 was 14.7°C (58.5°F). The mean annual temperature for Site 300 in 2001 was



15°C (59°F). Temperatures range from -5°C (23°F) during some predawn winter mornings to 40°C (104°F) during some summer afternoons.

Both rainfall and wind exhibit strong seasonal patterns. These wind patterns tend to be dominated by the thermal draw of the warm San Joaquin Valley that results in wind blowing from the cool ocean toward the warm valley, increasing in intensity as the valley heats up. The wind blows from the northeast primarily during the winter storm season. Most precipitation occurs between October and April, with very little rainfall during the warmer months.

Annual wind data for the Livermore site are given in [Figure 1-2](#). These data show that about 50% of the wind comes from the southwest to westerly direction. This prevailing pattern occurs primarily during the summer. During the winter, the wind often blows from the northeast. Based on a ten-year record, the highest and lowest annual rainfalls were 541 and 211 mm (21 and 7.2 in.), and the average annual rainfall was 360 mm (14 in.). In 2001, the Livermore site received 339 mm (13.2 in.) of rain.

The meteorological conditions at Site 300, while generally similar to those at the Livermore site, are modified by higher elevation and more pronounced topological relief. The complex topography of the site significantly influences local wind and temperature patterns. Annual wind data are presented in [Figure 1-3](#). The data show that winds are more consistently from one wind direction, the west-southwest, and reach greater speeds than at the Livermore site. Rainfall for 2001 was 247 mm (9.6 in.) at Site 300. As in the case for the Livermore site, precipitation is seasonal, with most rainfall occurring between October and April.

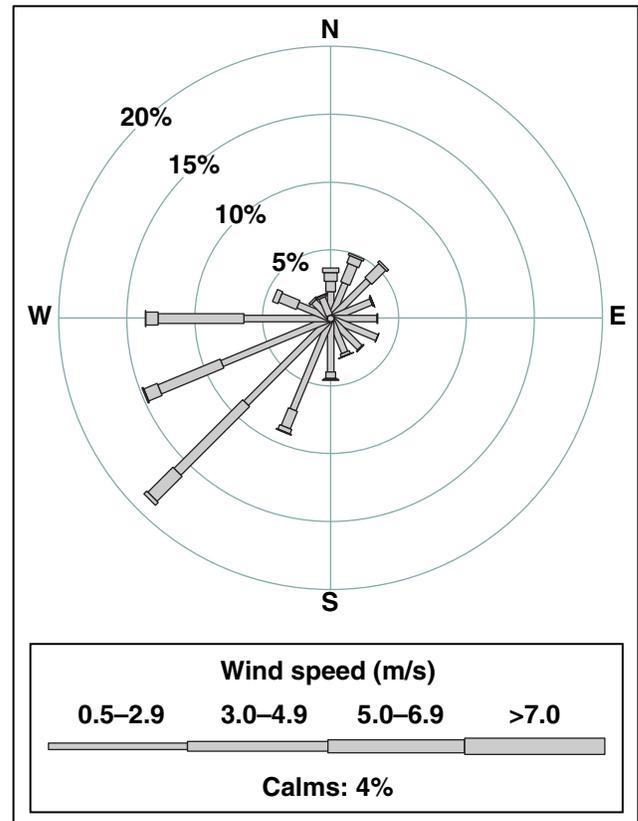


Figure 1-2. Wind rose showing the frequency of occurrence for wind speed and direction at the Livermore site, 2001

Topography

The Livermore site is located in the southeastern portion of the Livermore Valley, a topographic and structural depression oriented east-west within the Diablo Range of the California Coast Range Province. The Livermore Valley, the most prominent valley in the Diablo Range, is an east-west trending structural and topographic trough that is bounded on the west by Pleasanton Ridge and on the east by the Altamont Hills. The valley floor is covered by alluvial, lake, and swamp deposits consisting of gravels, sands, silts, and clays, at an average thickness of about 100 m (325 ft). The valley is approximately 25-km (16-mi) long and averages 11-km (6.8-mi) in width. The valley floor

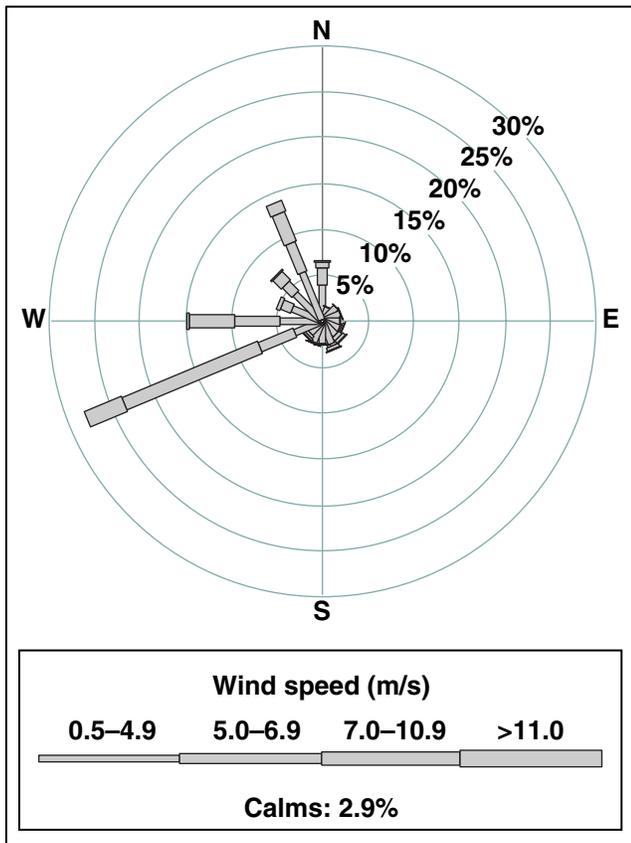


Figure 1-3. Wind rose showing the frequency of occurrence for wind speed and direction at Site 300, 2001

is at its highest elevation of 220 m (720 ft) above sea level along the eastern margin and gradually dips to 92 m (300 ft) at the southwest corner. The major streams passing through the Livermore Valley are Arroyo del Valle and Arroyo Mocho, which drain the southern highlands and flow intermittently. Major arroyos are depicted in Chapter 7 (Figure 7-1).

The topography of Site 300 is much more irregular than that of the Livermore site; a series of steep hills and ridges is oriented along a generally north-west-southeast trend and is separated by intervening ravines. The Altamont Hills, where Site 300 is located, are part of the California Coast Range Province and separate the Livermore Valley to the west from the San Joaquin Valley to the east. The

elevation ranges from approximately 538 m (1765 ft) above sea level at the northwestern corner of the site to approximately 150 m (490 ft) in the southeast portion.

Hydrogeology

Livermore Site

The hydrogeology and movement of groundwater in the vicinity of the Livermore site have been the subjects of several investigations (Stone and Ruggieri 1983; Carpenter et al. 1984; Webster-Scholten and Hall 1988; Blake et al. 1995; Thorpe et al. 1990). This section has been summarized from the reports of these investigations and from data supplied by Alameda County Flood Control and Water Conservation District Zone 7, the agency responsible for groundwater management in the Livermore Valley basin (SFBRWQCB 1982a,b).

The Livermore Formation (and overlying alluvial deposits) contains the aquifers of the Livermore Valley groundwater basin, an important water-bearing formation. Natural recharge occurs primarily along the fringes of the basin and through the arroyos during periods of winter flow. Artificial recharge, if needed to maintain groundwater levels, is accomplished by releasing water from Lake Del Valle or from the South Bay Aqueduct into arroyo channels in the east. Groundwater flow in the valley generally moves toward the central east-west axis of the valley and then westward through the central basin. Groundwater flow in the basin is primarily horizontal, although a significant vertical component probably exists in fringe areas, under localized sources of recharge, and in the vicinity of heavily used extraction (production) wells.

Beneath the Livermore site, the water table varies in depth from the surface from about 10 to 40 m (30 to 130 ft). Figure 1-4 shows a contour map of water table elevations (meters above mean sea



level) for the Livermore site area. Although water table elevations vary slightly with seasonal and year-to-year differences in both natural and artificial recharge, the qualitative patterns shown in **Figure 1-4** are generally maintained. At the eastern edge of the Livermore site, groundwater gradients (change in vertical elevation per unit of horizontal distance) are relatively steep, but under most of the site and farther to the west, the contours flatten to a gradient of approximately 0.003.

Groundwater flow under most of the site is southwesterly. This flow direction diverges from the generally westward regional flow and from flow

patterns demonstrated for the site in the 1980s. This shift in flow direction is a consequence of groundwater recovery and remediation in the southwest portion of the site and agricultural pumping. Aquifer tests on monitoring wells in the vicinity of the Livermore site indicate that the hydraulic conductivity (a measure of the rate of flow) of the permeable sediments ranges from 1 to 16 m/day (3.3 to 52 ft/day) (Isherwood et al. 1991). This, in combination with the observed water table gradients, yields an estimated average groundwater velocity of 20 m/y (66 ft/y) (Thorpe

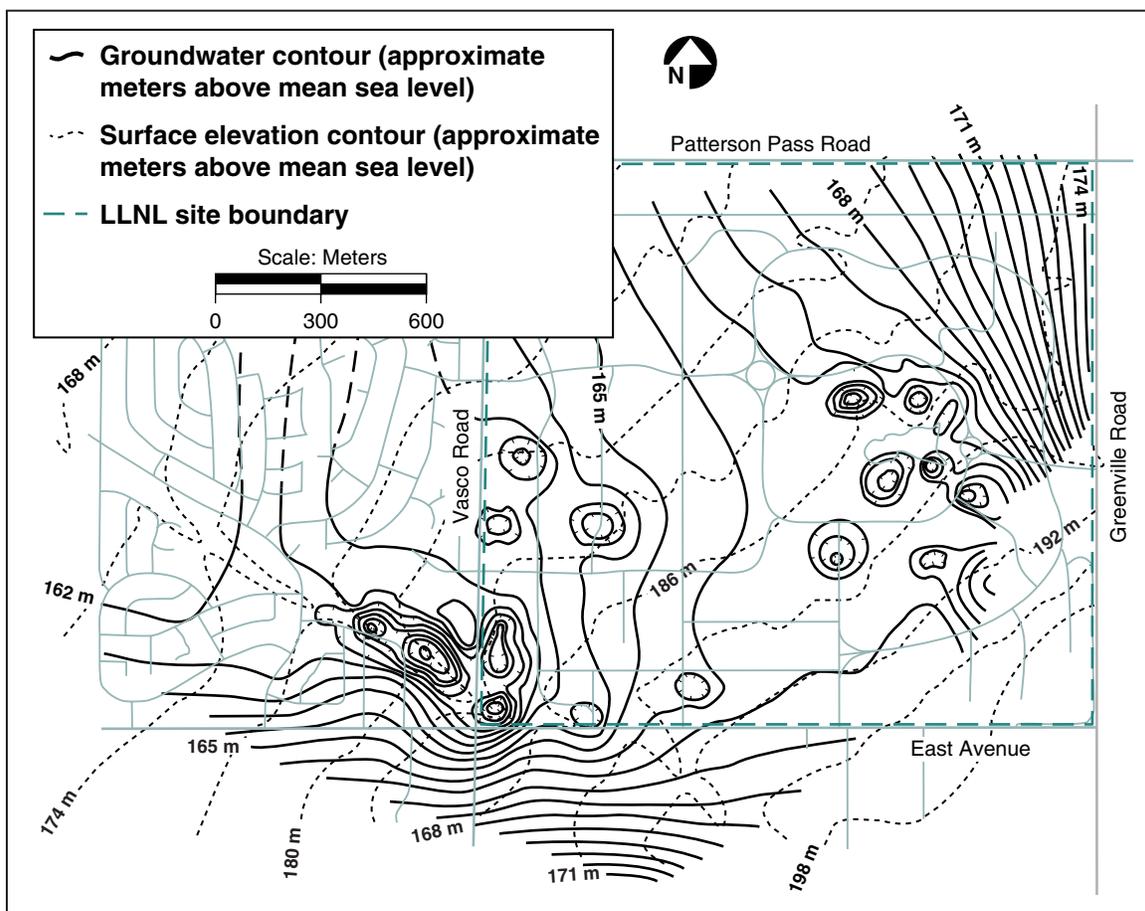


Figure 1-4. 2001 approximate groundwater and surface elevation contours, Livermore site and vicinity



et al. 1990). The range in these values reflects the heterogeneity typical of the more permeable alluvial sediments that underlie the area.

Site 300

Gently dipping sedimentary bedrock dissected by steep ravines generally underlies Site 300. The bedrock is made up primarily of interbedded sandstone, siltstone, and claystone. Most groundwater occurs in the Neroly Formation upper and lower blue sandstone aquifers. Significant groundwater is also locally present in permeable Quaternary alluvium valley fill. Much less groundwater is present within perched aquifers in the unnamed Pliocene nonmarine unit. Perched aquifers contain unconfined water separated from an underlying main body of water by impermeable layers; normally they are discontinuous and highly localized. Because water quality generally is poor and yields are low, these perched water-bearing zones do not meet the State of California criteria for aquifers that are potential water supplies.

Fine-grained siltstone and claystone interbeds may confine the groundwater and act as aquitards, confining layers, or perching horizons. Groundwater is present under confined conditions in parts of the deeper bedrock aquifers but is generally unconfined elsewhere.

Groundwater flow in most aquifers follows the attitude of the bedrock. In the northwest part of Site 300, groundwater in bedrock generally flows northeast except where it is locally influenced by the geometry of alluvium-filled ravines. In the southern half of Site 300, groundwater in bedrock flows roughly south-southeast, approximately coincident with the attitude of bedrock strata.

The thick Neroly lower blue sandstone, stratigraphically near the base of the formation, generally contains confined water. Wells located in the

western part of the General Services Area (GSA) are completed in this aquifer and are used to supply drinking and process water.

Figure 1-5 shows the elevation contours for groundwater in the regional aquifer at Site 300. This map of the piezometric surface (the elevation at which water stabilizes in a well that penetrates a confined or unconfined aquifer) is based primarily on water levels in the Neroly lower blue sandstone aquifer.

Recharge occurs predominantly in locations where saturated alluvial valley fill is in contact with underlying permeable bedrock or where permeable bedrock strata crop out because of structure or topography. Local recharge also occurs on hilltops, creating some perched water-bearing zones. Low rainfall, high evapotranspiration, steep topography, and intervening aquitards generally preclude direct vertical recharge of the bedrock aquifers.

Further information on the hydrology of both the Livermore site and Site 300 can be found in the groundwater monitoring and remediation information in [Chapters 8 and 9](#).

Summary

LLNL recognizes the importance of our geology, hydrogeology, climate, and geographical relationships with our neighbors in assessing potential impacts of operations at the Livermore site and Site 300. Each year we gain additional information that allows us to better predict, interpret, and avoid potential impacts. Each environmental medium that is discussed in this document—air, soil, water, vegetation, and foodstuff—may be affected differently. The environmental scientists at LLNL take into account the unique locations of the Livermore site and Site 300 to tailor sampling and analysis programs for each method used to monitor the environment.

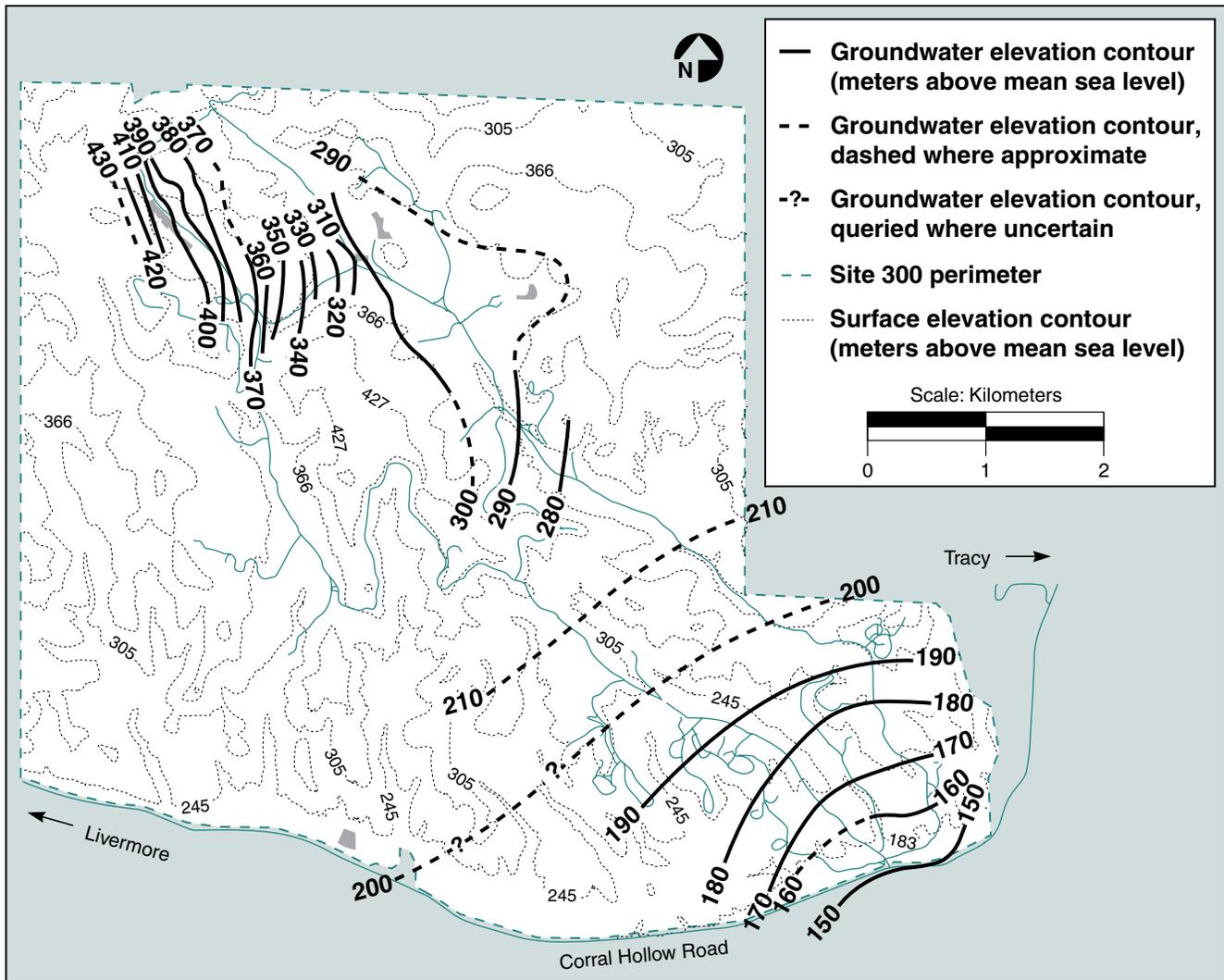


Figure 1-5. 2001 approximate groundwater elevations in the principal continuous water-bearing zone at Site 300

We acknowledge the work of Richard Blake, Gretchen Gallegos, Frank Gouveia, Donald MacQueen, Ring Peterson, and Michael Taffet, in preparing this chapter.

COMPLIANCE SUMMARY

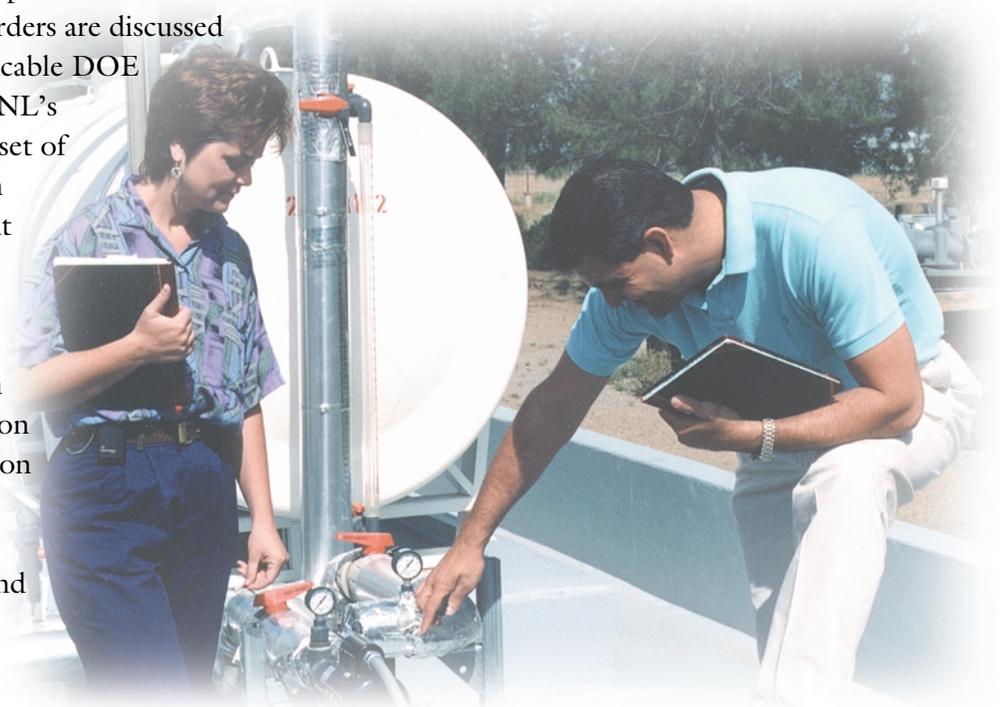
Introduction

During 2001, Lawrence Livermore National Laboratory participated in numerous activities to comply with federal, state, and local environmental regulations as well as internal requirements and applicable Department of Energy (DOE) orders. This chapter, which is organized according to the various laws and regulations that drive LLNL's compliance activities, describes those activities the Laboratory carried out related to air, water, waste, waste reduction, community "right to know," protection of sensitive resources, and other environmental issues at the Livermore site and Site 300. A wide range of compliance activities is summarized in this chapter. Compliance activities specific to the applicable DOE orders are discussed in the chapters that follow. Applicable DOE orders are those identified in LLNL's Work Smart Standards (WSS), a set of environmental, safety, and health standards specific to operations at the Laboratory (see [Chapter 3](#)). Other environmental program information, including the Environment, Safety, and Health Management System and pollution prevention and waste minimization activities, is also discussed in [Chapter 3](#). Many documents concerned with these activities and other environmental topics are

available for public viewing at the LLNL Visitors Center, the Livermore and Tracy public libraries, or on the Internet at <http://www-envirinfo.llnl.gov>.

Comprehensive Environmental Response, Compensation and Liability Act

The Livermore Site Groundwater Project (GWP) and the Site 300 CERCLA Project are under the jurisdiction of the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA)/Superfund Amendments and Reauthorization Act, Title 1. As part of work on these





projects, DOE and LLNL also continued with environmental restoration and community relations activities. These projects and activities are described in the following sections.

Livermore Site Groundwater Project

The GWP at the Livermore site complies with provisions specified in a federal facility agreement (FFA) entered into by the U.S. Environmental Protection Agency (EPA), DOE, the California EPA's Department of Toxic Substances Control (DTSC), and the San Francisco Bay Regional Water Quality Control Board (SFBRWQCB). As required by the FFA, the project addresses compliance issues by investigating potential contamination source areas (such as suspected old release sites, solvent-handling areas, and leaking underground tank systems), by continuous monitoring, and by remediation of groundwater.

The groundwater contaminants (constituents of concern) are volatile organic compounds (VOCs), primarily trichloroethene (TCE) and tetrachloroethene (PCE). For the most part, these contaminants are present within the site boundary, but are present to some extent beyond the boundary, mainly to the west and south of the site (see [Figures 8-3 to 8-8](#)). In 2001, GWP activities included preparing the required CERCLA documents, meeting milestones, operating groundwater treatment facilities, and maintaining liaison with community groups.

In 2001, DOE and LLNL submitted documents required by the CERCLA and the Livermore Site FFA. In addition, DOE and LLNL continued environmental restoration and community activities as discussed below.

Documentation

As required by the FFA, DOE and LLNL issued the *Ground Water Project 2000 Annual Report* (Aarons et al. 2001) on schedule on March 31, 2001. DOE and LLNL also issued six final Remedial Project Managers' (RPMs') meeting summaries. Quarterly self-monitoring data were reported in letter reports (Bainer and Abbott 2001; Bainer and Joma 2001a, 2001b, 2002a).

Milestones and Activities

Three milestones were completed ahead of schedule and one was delayed three months with regulatory concurrence because new work was not authorized by the Federal budget at the beginning of fiscal year 2001. The commencement of operation of the Treatment Facility E Southeast miniature treatment unit (MTU) was delayed until March 19, 2001. The three completed milestones were achieved by beginning operation of the Treatment Facility E West MTU on April 26, 2001, beginning operation of the Treatment Facility D Marina Pipeline on July 25, 2001, and beginning Phase 3 of the Treatment Facility 5475 catalytic reductive dehalogenation unit on September 19, 2001.

Other activities related to the Livermore CERCLA project included continued implementation of Engineered Plume Collapse (an integration of hydrostratigraphic unit analysis, smart pump and treat, source isolation, and treatment of VOCs in fine-grained sediments), initial testing of electroosmosis in the Treatment Facility D Helipad area, and finalizing a revised Consensus Statement.

LLNL installed and performed a hydraulic test on a new off-site well, and installed a new well to monitor for leaks around the on-site gasoline station. LLNL also provided groundwater level elevations to the Alameda Flood Control and Water Conservation District Zone 7 for use in analyzing water levels in the Mocho 1 Subbasin.



Treatment Facilities

DOE and LLNL operated all facilities in treatment facilities TFA, TFB, TFC, TFD, TFE, TFG, TF406, TF518, and TF5475 areas in 2001. A total of 77 groundwater extraction wells operated at 25 separate locations at an average flow rate of 2,893,000 L/day. Vapor treatment facilities VTF518 and VTF5475 operated at an average flow of 670 m³/day from 2 soil vapor extraction wells. Together, the groundwater and vapor treatment facilities removed approximately 215 kg of VOC mass in 2001 compared to 269 kg in 2000. Since remediation began in 1989, approximately 6.6 billion L of groundwater and over 934,400 m³ of vapor have been treated, removing more than 1238 kg of VOCs. (See [Chapter 8](#) for further information.)

Community Relations

The Community Work Group (CWG) met once in 2001 to discuss the DOE budget, technology deployments, the Consensus Statement, and progress of the Livermore site cleanup. Correspondence and communication continued with CWG members throughout the year. DOE and LLNL met twice with members of Tri-Valley Communities Against a Radioactive Environment (CAREs) and their scientific advisor as part of the activities funded by an Environmental Protection Agency Technical Assistance Grant.

Other Livermore site community relations activities in 2001 included communications and meetings with neighbors, local, regional, and national interest groups, and other community organizations; making public presentations; producing and distributing the Environmental Community Letter; maintaining the Information Repositories and the Administrative Record; conducting tours of the site environmental activities; and responding to public and news media inquiries. In addition, community questions were addressed via e-mail, and project

documents, letters, and public notices were posted on a public website at www-envirinfo.llnl.gov.

Site 300 CERCLA Project

Investigations and remedial activities are ongoing at Site 300, which became a CERCLA/Superfund site in 1991, when it was placed on the National Priorities List. Investigations and remedial activities are conducted under the joint oversight of the EPA, the Central Valley Regional Water Quality Control Board (CVRWQCB), California EPA's DTSC, and the authority of an FFA for the site. (There are separate FFAs for Site 300 and the Livermore site.)

During 2001, LLNL performed all actions stipulated in the FFA and maintained liaison with community groups. Results and status for Site 300 environmental restoration operable units are discussed in [Chapter 8](#). Background information for LLNL environmental characterization and restoration activities at Site 300 can be found in the *Final Site-Wide Remedial Investigation Report, Lawrence Livermore National Laboratory Site 300* (Webster-Scholten 1994).

Documentation

LLNL submitted all required documentation to oversight agencies on time in 2001. The *Draft Final Interim Site-Wide Record of Decision for Lawrence Livermore National Laboratory Site 300* (U.S. DOE 2001), *Five-Year Review Report for the General Services Area Operable Unit* at Lawrence Livermore National Laboratory Site 300 (Ferry et al. 2001a), *Remedial Design Work Plan for Interim Remedies at Lawrence Livermore National Laboratory Site 300* (Ferry et al. 2001b), *Draft Five-Year Review Report for the Building 834 Operable Unit* (Gregory et al. 2001), *Draft Final Interim Remedial Design for the Building 834*



Operable Unit Treatment Facility (Ferry et al. 2001c), quarterly reports, and other work plans were among the documents submitted.

Milestones and Activities

LLNL has completed all the 2001 FFA milestones for Site 300 on or ahead of schedule. For a detailed list of these milestones and corresponding dates, see [Table 8-2](#).

Treatment Facilities

VOCs (primarily TCE) are the main contaminants at Site 300. High explosives, tritium, depleted uranium, organosilicate oil, nitrate, and perchlorate are also found in groundwater. Ten treatment facilities that remove and treat VOCs operated throughout 2001. These facilities are discussed in more detail in [Chapter 8](#). Nineteen wells that extract groundwater only and 24 wells that extract both groundwater and soil vapor operated during 2001, treating about 94.7 million L of groundwater. The 24 wells that extract both vapor and groundwater together removed 922,000 m³ of vapor. In 2001, the Site 300 treatment facilities removed approximately 36.1 kg of VOCs. Since remediation efforts began in 1990, more than 772 million L of groundwater and approximately 3.13 million m³ of vapor have been treated, to yield about 198.3 kg of removed VOCs. See [Chapter 8](#) for maps of the operable units and details of the distribution of all contaminants in groundwater at Site 300.

Community Relations

The Site 300 CERCLA project maintains proactive communication with the surrounding communities of Tracy and Livermore. Community relations activities in 2001 included maintenance of the information repositories and administrative records; off-site, private well-sampling activities; mailings to stakeholders; and interviews with the news media. Meetings were held with Tri-Valley

CAREs, which receives an annual technical assistance grant from EPA to independently evaluate CERCLA activities at Site 300.

On April 17, 2001, and August 15, 2001, at the request of the public, LLNL conducted two tours of Site 300 investigation areas and treatment facilities.

On May 15, 2001, the remedial project managers held a public workshop to present and explain to the community the overall plan and schedule for implementing environmental remedies as outlined in the *Site-Wide Remedial Design Work Plan* (Ferry et al. 2001c).

Site Evaluations Prior to Construction

Before any construction begins, the CERCLA Record of Decision (ROD) for the Livermore site requires that the project site be evaluated to determine if soil or rubble (concrete and asphalt) is contaminated. Soil is sampled and analyzed for potential radioactive and/or hazardous contamination. Depending on the analytical results, soil may be reused on site or disposed of according to established procedures. Depending on the potential for radioactive contamination, rubble may be either surveyed or analyzed for radioactivity. During 2001, soil and rubble were evaluated at 66 construction sites.

Agency for Toxic Substances and Disease Registry Assessment

The Agency for Toxic Substances and Disease Registry (ATSDR) is a federal public health agency whose mission is to prevent adverse human health effects and diminished quality of life associated with exposure to hazardous substances from waste sites, unplanned releases, and other sources of pollution in the environment. ATSDR is mandated by Congress to conduct public health



assessments (PHAs) of communities, such as Livermore, that are adjacent to DOE sites undergoing CERCLA cleanup. During the PHA process, at a meeting in April 2000, members of the Livermore community expressed specific concerns related to the environmental monitoring and dose evaluation of tritium, as well as the health impact of past releases. To address these concerns, in 2000 ATSDR convened a panel of five independent experts in the fields of tritium analysis and dosimetry to complete a health consultation on tritium related to LLNL-operations.

Three draft reports were prepared by the expert panel and ATSDR in February, May, and July 2001 and distributed for comment. A Public Health Assessment Site Team Meeting was held November 8, 2001, in Livermore to present the conclusions of the PHA to the public. ATSDR concluded that total tritium doses to the communities surrounding LLNL, including potential contributions from organically bound tritium, tritiated water, and tritiated hydrogen gas, are below levels of public health concern and are adequately assessed by current monitoring and modeling. The report of the expert panel (*Environmental Tritium Evaluations at SRS and LLNL with Emphasis on the Monitoring and Dosimetry of Organically-Bound Tritium*) and the conclusions of ATSDR can be found at http://www.atsdr.cdc.gov:80/HAC/PHA/livermore2/liv_toc.html.

ATSDR also is preparing an exposure assessment of the 1965 and 1970 accidental tritium gas releases from LLNL. Preliminary analysis of reported data plus dispersion and dose modeling suggest that the one-time exposures to the public following these releases cannot be considered public health hazards, nor will any adverse health effects be found.

Public comment on the July draft was extended from October to December. A final report is expected in mid-2002.

Superfund Amendment and Reauthorization Act, Title III

Title III of the Superfund Amendment and Reauthorization Act (SARA) is known as the Emergency Planning and Community Right-to-Know Act (EPCRA). It requires owners or operators of facilities that handle certain hazardous chemicals on site to provide information on the release, storage, and use of those chemicals to organizations responsible for emergency response planning. Executive Order 13148 directs all federal agencies to comply with the requirements of EPCRA, including SARA 313, Toxic Release Inventory Program.

EPCRA requirements and LLNL compliance are summarized in [Table 2-1](#). [Table 2-2](#) and [Table 2-3](#) identify those chemicals and their related hazards reported during 2001 by LLNL for the Livermore site and Site 300, respectively, under Title III, Section 311.

Clean Air Act—Air Quality Management Activities

All activities at LLNL are evaluated to determine the need for air permits and are operated in full compliance with all applicable requirements. Air permits are obtained from the Bay Area Air Quality Management District (BAAQMD) for the Livermore site and from the San Joaquin Valley Unified Air Pollution Control District (SJVUAPCD) for Site 300. In 2001, LLNL operated 110 air emission sources for the Livermore site. BAAQMD inspectors found no deficiencies at the Livermore site (see [Table 2-4](#)). There was no

**Table 2-1. Summary of LLNL compliance with EPCRA in 2001**

EPCRA requirement ^(a)	Brief description ^(a)	Compliance
302 Planning Notification	Operator must notify SERC of presence of extremely hazardous substances. In California, operator must notify CEPRC of presence of extremely hazardous substances above threshold planning quantities.	Originally submitted May 1987.
303 Planning Notification	Operator must designate a facility representative to serve as emergency response coordinator.	Update submitted April 9, 2001.
304 Release Notification	Releases of certain hazardous substances must be reported to SERC and LEPC.	No EPCRA-listed extremely hazardous substances were released above reportable quantities.
311 MSDS/Chemical Inventory	Operator must submit MSDSs or chemical list to SERC, LEPC, and Fire Department.	Tables 2-2 and 2-3. Updated April 9, 2001.
312 MSDS/Chemical Inventory	Operator must submit hazardous chemical inventory to local administering agency (county).	Business plans and chemical inventory submitted to San Joaquin County (January 12, 2001) and Alameda County (February 28, 2001).
313 Toxic Release Inventory	Operator must submit Form R to U.S. EPA and California EPA for toxic chemicals released.	A negative declaration statement dated July 13, 2001, was submitted to DOE; no thresholds were exceeded for TRI reporting year 2000.

^a See [Acronyms and Abbreviations](#) for list of acronyms

action taken by the BAAQMD to process or finalize LLNL's Synthetic Minor Operating Permit in 2001. The Synthetic Minor Operating Permit was applied for in 2000 and is to provide BAAQMD with an accounting of data about the potential to emit regulated pollutants from LLNL operations, a list of the permitted and exempt sources on site, a proposed limit on any regulated pollutant that exceeds the limits set in the regulations, and an explanation of how LLNL will comply with the conditions set forth in the permit. In 2001, SJVUAPCD issued or renewed air permits for 45 air emission sources for Site 300 (see [Table 2-5](#)). At Site 300, SJVUAPCD conducted startup inspections of two sources in accordance with their Authority to Construct permits: the Contained Firing Facility (CFF) and the Central

General Service Area (CGSA) air stripper. SJVUAPCD inspectors found no deficiencies at Site 300 (see [Table 2-4](#)).

National Emission Standards for Hazardous Air Pollutants, Radionuclides

To demonstrate compliance with the National Emissions Standards for Hazardous Air Pollutants (NESHAPs) for radiological emissions (40 Code of Federal Regulations [CFR] 61, Subpart H), LLNL is required to monitor certain air release points and evaluate all potential sources of radionuclide air emissions to determine the possible effective dose equivalent to the maximally exposed individual of the public. These evaluations include modeling (using EPA-sanctioned computer codes) based on

Table 2-2. Livermore site, SARA, Title III, Section 311, Chemical List, 2001

Livermore site chemicals	Physical hazard ^(a)			Health hazard ^(a)	
	Fire	Pressure	Reactivity	Acute	Chronic
Air		•			
Ammonium hydroxide				•	
Argon		•		•	
Carbon, activated	•				
Carbon dioxide		•		•	
Chlorine		•	•	•	
Chromium(III) chloride				•	•
Cobalt	•			•	•
Diesel fuel	•			•	•
Ethyl alcohol	•			•	•
Freon 113				•	
Gasoline	•			•	•
Glass cleaner		•		•	
Helium		•		•	
Hydrofluoric acid		•(b)	•	•	•
Hydrogen peroxide (<52%)			•		
Insulating oil, inhibiting	•			•	
Joint compound				•	
Krypton		•		•	
Lead (bricks, ingots)				•	•
Lithium hydride	•		•	•	
Mineral oil	•			•	
Neodymium oxide				•	
Nitric acid	•		•	•	•
Nitric oxide		•	•	•	
Nitrogen		•		•	
Oil, Diala AX	•			•	
Oil, DTE-26	•				
Oil, vacuum pump	•			•	
Oil, waste	•				
Oxygen	•	•			



Table 2-2. Livermore site, SARA, Title III, Section 311, Chemical List, 2001 (continued)

Livermore site chemicals	Physical hazard ^(a)			Health hazard ^(a)	
	Fire	Pressure	Reactivity	Acute	Chronic
Paint	•	•		•	•
Potassium cyanide				•	
Potassium hydroxide			•	•	•
Potassium phosphate, monobasic				•	
Propane	•	•		•	
Refrigerant 123 SUVA				•	•
Sodium cyanide			•	•	
Sodium hydroxide			•	•	
Sodium hypochlorite				•	
Sulfuric acid			•	•	•
Tantalum				•	
Thinner, lacquer	•			•	•

a Physical and health hazard information obtained primarily from material safety data sheets

b Some containers have a pressure hazard because hydrofluoric acid has the potential to form hydrogen fluoride gas.

radionuclide inventory data, air effluent (source emission) monitoring, or air surveillance monitoring.

The *LLNL NESHAPs 2001 Annual Report* (Harrach et al. 2002), submitted to DOE and EPA, reported that the estimated total sitewide maximally exposed individual radiological doses for the Livermore site and Site 300 were 0.17 μSv (0.017 mrem) and 0.54 μSv (0.054 mrem), respectively, for 2001.

The reported doses include contributions from both point and diffuse sources. The totals were well below the 100 $\mu\text{Sv}/\text{y}$ (10 mrem/y) dose limits defined by the NESHAPs regulations. The details of these data are included in this report (see [Chapter 13](#)).

In 2001, LLNL continuously monitored radionuclide emissions from Building 331 (the Tritium Facility), Building 332 (the Plutonium Building), and portions of five other facilities (see [Chapter 4](#)). There were no unplanned atmospheric releases at the Livermore site or at Site 300 in 2001.

Clean Water Act and Related State Programs

Preserving clean water is one objective of local, state, and federal regulations. The National Pollutant Discharge Elimination System (NPDES) under the Federal Clean Water Act (CWA) establishes permit requirements for discharges into waters of the United States. In addition, the State of California, under the Porter Cologne Water Quality Control Act, requires permits, known as

Table 2-3. Site 300, SARA, Title III, Section 311, Chemical List, 2001

Site 300 chemicals	Physical hazard ^(a)			Health hazard ^(a)	
	Fire	Pressure	Reactivity	Acute	Chronic
Carbon, activated	•				
Chlorine		•	•	•	
Bis(2,2-dinitro-2-fluoroethyl)formal in methylene chloride	__(b)		__(b)	•	•
Diesel fuel	•			•	•
Gasoline	•			•	•
High explosives			•		
Lead (bricks, ingots)				•	•
Nitrogen		•		•	
Oil, hydraulic	•			•	
Oil, inhibited insulating	•				
Oil, Diala Ax	•			•	
Oil, transformer	•				
Roof acrylic coating				•	•
Steam cleaning solution/split equipment cleaner		•		•	•
Sulfuric acid			•	•	•

a Physical and health hazard information obtained primarily from material safety data sheets

b Dangerous fire or explosion risk in neat form (solvent evaporates)

Waste Discharge Requirements (WDRs), for any waste discharges affecting the beneficial uses of waters of the state. The regional water quality control boards are responsible for issuing and enforcing both permits as well as water quality certifications for discharges controlled by Section 401 of the CWA.

Several agencies issue other water-related permits. The Livermore Water Reclamation Plant (LWRP) requires permits for discharges of sewerable water to the city sanitary sewer system. The Army Corps of Engineers (ACOE) issues permits for work in navigable waterways below the ordinary high-water mark and for controlling fill operations in waters of the United States. The State Water Resources Control Board (SWRCB) can issue statewide NPDES permits/WDRs or water quality


Table 2-4. Inspections and tours of the Livermore site and Site 300 by external agencies in 2001

Medium	Description	Agency ^(a)	Date	Finding ^(a)
Livermore Site				
Air	Emission sources	BAAQMD	11/8 12/6	No violations
Sanitary sewer	Annual compliance sampling	LWRP	10/2, 10/8–9	No violations
	Categorical sampling		10/15 10/31	No violations
Waste	Hazardous waste facilities	DTSC	6/20–6/22	Received an Inspection Report and final SOV on 11/6/01 with two minor violations and one violation categorized as “other violation.” All violations were resolved by LLNL before the final SOV was received on 11/6/01.
	Medical waste	ACDEH	9/25	No violations
Water	Arroyo Las Positas	SFBRWQCB	4/23 8/29	No violations
Storage tanks	Compliance with underground storage tank upgrade requirements and operating permits.	ACHCS	6/26, 8/21, 9/4 9/17, 10/17	No violations
HW Transportation	Biennial terminal inspection	CHP	1/5	Three minor deficiencies (short mud flaps, two loose bolts) corrected during inspection
Site 300				
Air	Emission sources Startup inspection of Contained Firing Facility and CGSA air stripper.	SJVUAPCD	3/6	No violations
Water	Permitted operations	CVRWQCB	10/16	No violations
Waste	Permitted Hazardous Waste facilities (EWTF, EWSF, B883 CSA), Waste Accumulation Area B883 North, and Generator Areas.	DTSC	5/16–5/18	Three violations were issued. One violation was issued on 5/18 and two additional violations were issued in an amended inspection report which LLNL received on 8/15. All violations have been corrected.
			8/16–8/17	No violations

^a See [Acronyms and Abbreviations](#) for list of acronyms


Table 2-5. Summary of permits active in 2001^(a,b)

Type of permit	Livermore site	Site 300
Air	<p>BAAQMD issued 110 permits for operation of various types of equipment, including boilers, emergency generators, cold cleaners, ultrasonic cleaners, degreasers, printing press operations, manual wipe-cleaning operations, metal machining and finishing operations, silk-screening operations, silk-screen washers, paint spray booths, adhesives operations, image tube fabrication, optic coating operations, storage tanks containing VOCs in excess of 1.0%, plating tanks, drum crusher, semiconductor operations, diesel air-compressor engines, groundwater air strippers/dryers, ovens, material-handling equipment, sewer diversion system, oil and water separator, fire test cells, gasoline-dispensing operation, paper-pulverizer system, and firing tanks.</p>	<p>SJVUAPCD issued 45 permits for operation of various types of equipment, including boilers, emergency generators, paint spray booth, groundwater air strippers, soil vapor extraction units, woodworking cyclone, gasoline-dispensing operation, explosive waste treatment units, and drying ovens, and the Contained Firing Facility.</p>
Water	<p>WDR Order No. 88-075 for discharges of treated groundwater from Treatment Facility A to percolation pits and recharge basin.</p> <p>WDR Order No. 95-174, NPDES Permit No. CA0030023 for discharges of storm water associated with industrial activities and low-threat nonstorm water discharges to surface waters.</p> <p>WDR Order No. 99-08-DWQ, NPDES California General Construction Activity Permit No. CAS000002, DWTF Site ID No. 201S305140 (terminated July 2001), Soil Reuse Project ID No. 2015305529 and National Ignition Facility, Site ID No. 201S306762, for discharges of storm water associated with construction activities affecting two hectares or more.</p> <p>WDR Order No. 99-086 for the Arroyo Las Positas Maintenance Project.</p> <p>Nationwide Permit 18 for the Arroyo Las Positas Maintenance Project.</p> <p>FFA for groundwater investigation/remediation.</p>	<p>WDR Order No. 99-08-DWQ, NPDES California General Construction Activity Permit No. CAS000002, Contained Firing Facility/ Chemistry Magazine Loop, Site ID No. 5B39S307131 (terminated August 2001) for discharges of storm water associated with construction activities impacting two hectares or more.</p> <p>WDR Order No. 93-100 for post-closure monitoring requirements for two Class I landfills.</p> <p>WDR Order No. 96-248 for operation of two Class II surface impoundments, a domestic sewage lagoon, and percolation pits.</p> <p>WDR Order No. 97-03-DWQ, NPDES California General Industrial Activity General Permit No. CAS000002 for discharge of storm water associated with industrial activities</p> <p>WDR Order No. 97-242, NPDES Permit No. CA0082651 for discharges of treated groundwater from the eastern General Services Area treatment unit.</p> <p>WDR Order No. 5-00-175, NPDES Permit No. CA0082651 for large volume discharges from the drinking water system that reach surface waters.</p> <p>One ongoing project permitted under a stream-bed alteration agreement.</p> <p>FFA for groundwater investigation/remediation.</p> <p>57 registered Class V injection wells.</p>


Table 2-5. Summary of permits active in 2001^(a,b) (continued)

Type of permit	Livermore site	Site 300
Hazardous waste	<p>EPA ID No. CA2890012584.</p> <p>Authorization to mix resin in Unit CE231-1 under conditional exemption tiered permitting.</p> <p>Final Closure Plan submitted to DTSC for the Building 419 interim status unit (February 2001).</p> <p>Authorizations to construct the permitted units of Building 280, Building 695, and additions to Building 693.</p> <p>Authorization under hazardous waste permit to operate 18 waste storage units and 14 waste treatment units.</p> <p>Continued authorization to operate seven waste storage units and eight waste treatment units under interim status. Final Closure Plans submitted to DTSC for the Building 233 and Building 514 interim status units (May 2000).</p> <p>Notified DTSC on 3/31/01 that LLNL will not construct and operate Building 280 as a permitted unit as described in our Hazardous Waste Facility permit.</p>	<p>EPA ID No. CA2890090002.</p> <p>Part B Permit—Container Storage Area (Building 883) and Explosives Waste Storage Facility (issued May 23, 1996).</p> <p>Part B Permit—Explosives Waste Treatment Facility (issued October 9, 1997).</p> <p>Docket HWCA 92/93-031. Closure and Post-Closure Plans for Landfill Pit 6 and the Building 829 Open Burn Facility.</p> <p>Post-Closure Permit Application submitted for Building 829 Open Burn Facility (September 2000). Prepared a Notice of Deficiency (NOD) response document to be submitted to DTSC in February 2002.</p>
Medical waste	<p>One permit for large quantity medical waste generation and treatment covering the Biology and Biotechnology Research Program, Health Services Department, Forensic Science Center, Medical Photonics Lab, and Tissue Culture Lab.</p>	<p>Limited Quantity Hauling Exemption for small quantity medical waste generator.</p>
Sanitary sewer	<p>Discharge Permit No. 1250 (01/02) for discharges of wastewater to the sanitary sewer.</p> <p>Permit 1510G (01) for discharges of sewerable groundwater from CERCLA restoration activities.</p>	
Storage tanks	<p>Eight operating permits covering 11 underground petroleum product and hazardous waste storage tanks: 111-D1U2 Permit No. 6480; 113-D1U2 Permit No. 6482; 152-D1U2 Permit No. 6496; 271-D2U1 Permit No. 6501; 321-D1U2 Permit No. 6491; 322-R2U2 Permit No. 6504; 365-D1U2 Permit No. 6492; and 611-D1U1, 611-G1U1, 611-G2U1, and 611-O1U1 Permit No. 6505.</p>	<p>One operating permit covering five underground petroleum product tanks assigned individual permit numbers: 871-D1U2 Permit No. 008013; 875-D1U2 Permit No. 006549; 879-D1U1 Permit No. 006785; 879-G3U1 Permit No. 007967; and 882-D1U1 Permit No. 006530</p>

a Permit numbers are based on actual permitted units or activities maintained and renewed by LLNL during 2001.

b See [Acronyms and Abbreviations](#) for list of acronyms.

certifications. The California Department of Fish and Game (CDFG), under the Fish and Game Code Section 1601 et seq. requires streambed alteration agreements (SAAs) for any work that may disturb or impact rivers, streams, or lakes. The Safe Drinking Water Act requires registration with the

EPA and management of injection wells to protect underground sources of drinking water. The Clean Water Act also requires facilities meeting specific storage requirements to have and implement Spill Prevention Control and Countermeasure (SPCC) plans for oil-containing equipment and tanks.



Finally, Alameda County Health Care Services (ACHCS) and San Joaquin County Environmental Health Services issue permits for operating underground storage tanks containing hazardous materials or hazardous waste as required under the California Health and Safety Code. Water-related permits are summarized in [Table 2-5](#) and discussed in detail in [Chapters 6, 7, and 9](#).

Groundwater and Surface Water

In 2001, LLNL discharged storm water associated with industrial activities, low-threat equipment wastewater, process wastewater, sanitary sewage, treated groundwater, and domestic drinking water to surface waters, percolation pits, surface impoundments, septic systems, and sewage ponds under six NPDES permits, four WDRs, and agreements developed under CERCLA ([Table 2-5](#)). Details about surface water discharges are found in [Chapter 7](#) of this report and in quarterly and annual compliance monitoring reports. Details about groundwater monitoring and discharges from CERCLA remediation actions are found in [Chapters 8 and 9](#) of this report and in quarterly and annual compliance monitoring and groundwater program reports.

In July 2000, LLNL submitted a Report of Waste Discharge to the CVRWQCB to amend WDR 96-248 to include low-threat discharge going to ground. Previously, these discharges were permitted under WDR 94-131, which was rescinded by the CVRWQCB in August 2000. The low threat discharges include several discharges previously believed to be discharging to surface waters. The CVRWQCB is currently in the process of amending WDR 96-248 to include these discharges. In addition, to simplify the various administrative mechanisms that currently cover wastewater discharges occurring at Site 300, LLNL requested that discharges covered by waivers of WDRs be consolidated into WDR 96-248.

During 2001, LLNL continued construction of two projects that were covered by the California General Construction Activity permit and terminated coverage for two completed projects (see [Table 2-5](#)). Continuing operations included construction of the Soil Reuse Project and the National Ignition Facility (NIF) at the Livermore site. Construction of the Decontamination and Waste Treatment Facility (DWTF) at the Livermore site and the Contained Firing Facility at Site 300 was completed. Documentation for construction projects ongoing as of September 2001 was revised to comply with the SWRCB Resolution 2001-046, which addresses sampling and analysis.

LLNL received no Notices of Violation (NOVs) in 2001 from the regional water quality control boards that issued the NPDES permits and WDRs; however, LLNL identified administrative nonconformances with one of the six NPDES permits (see [Table 2-6](#)). These events are documented in the annual compliance certification required by NPDES CAS000002 and were reported to the SFBRWQCB at its request. In addition, LLNL was unable to comply with prohibitions in WDR 96-248 on four occasions. These discharges were reported to the applicable regional boards and are discussed further in [Chapters 7 and 9](#).

The CVRWQCB inspected the Site 300 permitted facilities in October 2001. No violations were found during these inspections (see [Table 2-4](#)).

Sewerable Water

The Livermore site's sanitary sewer discharges are sampled continuously to satisfy various permit requirements. The monitoring results for the LLNL effluent were reported monthly to the LWRP. In 2001, LLNL had one discharge in violation of the LWRP permit covering wastewater discharges to the sanitary sewer (see [Table 2-7](#)).

**Table 2-6. Summary of NPDES permit nonconformance**

Permit No.	Outfall	Nonconformance	Date(s) of non-conformance ^(a)	Description–solution
CAS000002	Arroyo Las Positas (Livermore site)	National Ignition Facility— Failure to document some rain-event construction inspections and to perform some inspections.	10/00–4/01	Revised inspection program and provided additional training.

^a These dates reflect the construction reporting period of June 2000 through May 2001. The actual nonconformance may not have occurred over the entire time; however, specific nonconformance dates cannot be determined.

Table 2-7. Summary of nonconformance with LWRP permit limits for discharges to the sanitary sewer

Permit No	Nonconformance	Date(s) of nonconformance	Description–solution
1250	Lead in the May daily effluent sample exceeded the permit limit. LWRP issued a notice of violation dated July 30, 2001.	5/11/01	An effluent sample collected May 12, 2001, confirmed LLNL's return to compliance.

Self-monitoring continued during 2001, as required in the permit. One sample collected in 2001 had constituents that exceeded permit effluent limits. The daily effluent sample collected on May 11, 2001, contained 1.4 mg/L of lead, exceeding the discharge limit of 0.2 mg/L. The LWRP issued an NOV for this discharge dated July 30, 2001.

On October 2 and 9, 2001, the LWRP collected split samples of site effluent as part of the annual compliance sampling. Sample results confirmed compliance with effluent discharge limits. LLNL and LWRP also inspected and sampled federally regulated processes and their wastestreams on October 15 and 31. No facility deficiencies were noted during any of the inspections ([Table 2-4](#)).

In addition, LLNL conducts self-monitoring of federally regulated processes and reports results to the LWRP semiannually.

LLNL monitors discharges from groundwater treatment facilities to sanitary sewer under Permit 1510G (2001) as they occur. Data are reported annually to the LWRP. In 2001, LLNL complied with all the terms and conditions of Permit 1510G. Chapter 6 discusses the self-monitoring programs and the analytical results for the site effluent, categorical processes, and discharges from groundwater treatment facilities.

Streambed Alteration Agreements and Nationwide Permits

CDFG, SFBRWQCB, and ACOE all issue permits for work in streambeds ([Table 2-8](#)). In 2001, CDFG Legal Counsel advised LLNL that, because LLNL is a federal facility, LLNL is exempt from SAA requirements for activities conducted in streambeds at the Livermore site and Site 300. To ensure ongoing protection of streambeds, LLNL and CDFG are developing a memorandum of understanding (MOU) regarding LLNL activities that affect streambeds.

Table 2-8. Summary of streambed alteration agreements, Nationwide Permits, and Waste Discharge Requirements

Project	Location	Agency/type of permit ^(a)	Year submitted
Storm-generated debris removal and vegetation management (five-year agreement)	Arroyo Seco	CDFG/SAA	1999
Arroyo Las Positas Maintenance Project (five-year agreement)	Arroyo Las Positas	CDFG/SAA SFBRWQCB/WDR ACOE/NWP 18	1998 1999 2000

^a See [Acronyms and Abbreviations](#) for list of acronyms.

During 2001, LLNL continued operations allowed under a five-year SAA and WDR issued for the Arroyo Las Positas Maintenance Project. Although LLNL's coverage under Nationwide Permit (NWP) 18 was completed in 2000, LLNL continued to comply with reporting required by NWP 18 through 2001. Operations also continued under an SAA issued for vegetation management in Arroyo Seco. No projects at Site 300 required permits from ACOE during 2001.

Tank Management

LLNL manages its underground and aboveground storage tanks through the use of underground tank permits, monitoring programs, operational plans, closure plans and reports, leak reports and follow-up activities, and inspections. At LLNL, underground storage tanks contain diesel fuel, gasoline, waste oil, and process wastewater; aboveground storage tanks contain diesel fuel, insulating oil, and process wastewater. Some wastewater systems are a combination of underground storage tanks and aboveground storage tanks. [Table 2-9](#) shows the status of tanks at the Livermore site and Site 300 as of December 31, 2001. All regulated underground storage tanks at the Livermore site were inspected by the regulating agency in 2001, and no violations were found (see [Table 2-4](#)).

Resource Conservation and Recovery Act and Related State Laws

The Resource Conservation and Recovery Act (RCRA) and its corresponding regulations provide the framework at the federal level for regulating the generation and management of solid wastes, including wastes designated as hazardous. Similarly, the California Hazardous Waste Control Act (HWCA) and the California Code of Regulations (CCR) Title 22, set requirements for managing hazardous wastes in California. RCRA and HWCA also regulate hazardous waste treatment, storage, and disposal facilities, including permit requirements. Because RCRA program authorization was delegated to the State of California in 1992, LLNL works with DTSC on compliance issues and in obtaining hazardous waste permits.

Hazardous Waste Permits

Livermore Site

The hazardous waste management facilities at the Livermore site consist of permitted units (located in Area 612 and Buildings 693 and 695 of the DWTF) and units that operate under interim status (Area 514 Facility and the Building 233 Container Storage Facility). Permitted and interim status waste management units include container storage, tank storage, and various treatment processes (e.g.,



Table 2-9. Summary of in-service tanks, December 31, 2001

Tank type	Livermore site			Site 300		
	Permitted	Permits not required	Total	Permitted	Permits not required	Total
Underground storage tanks						
Diesel fuel	7	0	7	4	0	4
Gasoline	2	0	2	1	0	1
Waste oil	1	0	1	0	0	0
Process wastewater	1	40	41	0	12	12
Subtotal	11	40	51	5	12	17
Aboveground storage tanks						
Diesel fuel	0	27	27	0	6	6
Insulating oil	0	1	1	0	4	4
Process wastewater	10 ^(a)	64	74	0	12	12
Miscellaneous non-waste tanks	0	16	16	0	0	0
Subtotal	10	108	118	0	22	22
Total	21	148	169	5	34	39

^a These 10 tanks are located at the LLNL Treatment and Storage Facility.

wastewater filtration, blending, and size reduction). A final closure plan for the Building 419 Interim Status Facility has been submitted to DTSC for approval.

In accordance with the document *Transition Plan: Transfer of Existing Waste Treatment Units to the Decontamination and Waste Treatment Facility* (EPD 1997), operations in the Area 514 Facility will eventually be replaced by those in the new DWTF, and Area 514 will be closed. The Building 233 Container Storage Facility also will be closed. Final closure plans for the Area 514 Facility and the Building 233 Container Storage Facility were submitted for approval to the DTSC in May 2000.

In May 1999, DTSC signed the hazardous waste permit and issued a Notice of Final Permit Decision for DWTF. In July 1999, Tri-Valley CAREs et al. filed a petition for review to appeal the permit decision. The appeal was denied by the DTSC in November 1999, and the permit immediately became effective.

Tri-Valley CAREs et al. filed a California Environmental Quality Act (CEQA) lawsuit in December 1999 that challenges many of the environmental impact evaluations made in the DTSC initial study, which formed the basis of the CEQA Negative Declaration determination on DTSC. A Settlement Agreement was reached on June 26, 2001, between Tri-Valley CAREs et al. and the Regents of the University of California and DOE. As part of the Settlement Agreement, DTSC, the Regents,

and DOE agreed to comply with all of the items listed under Section 6 (Actions by Respondents) of the Settlement Agreement. The Regents are currently in compliance with their responsibilities described in Section 6. The Regents have delivered all information requested by DTSC to support an evaluation to determine the need for additional permit conditions or modifications. DTSC submitted a status report to Tri-Valley CAREs et al. in December 2001. It provided another status report to them on March 25, 2002.

On June 20–22 2001, DTSC conducted a compliance evaluation inspection of the hazardous waste storage and treatment facilities at the Livermore site. On November 6, 2001, LLNL received notification of an SOV resulting from this inspection. The SOV included two minor violations and one violation categorized as “other violation.” As stated in the SOV, DTSC concurred that all violations were resolved by LLNL (see [Table 2-10](#)).

Site 300

In addition to the four permits active in 2001, a post closure permit application for the Building 829 Open Burn Facility was submitted to DTSC for approval in September 2000. In the last quarter of 2001, LLNL worked on a response to a DTSC notice of deficiency (NOD) letter dated August 29, 2001, and submitted the response document to DTSC in January 2002.

On May 15-18, 2001, DTSC conducted the 2001 compliance evaluation inspection of Site 300 hazardous waste generator areas, Building 883 Waste Accumulation Area (north), Building 883 Container Storage Area, Explosives Waste Storage Facility (EWSF), and the Explosives Waste Treatment Facility (EWTF). As a result of the inspection, DTSC issued an SOV on May 18, 2001, with one violation under the category of “Minor Violations Corrected During the Inspection.”

The minor violation was for five open dry-waste containers. The containers were closed immediately during the inspection.

On August 15, 2001, Site 300 received an amended 2001 inspection report with two additional violations. Violation number one was issued for failure to characterize a solvent waste stream. Violation number two was issued for failure to maintain waste characterization documentation on site for the same solvent waste and an organic acid waste stream, and failure to provide this waste characterization documentation upon request. In response to the violations, LLNL characterized the solvent waste and submitted this information to DTSC on September 14, 2001. The LLNL violation response letter also agreed to maintain the waste characterization documentation on site until closure of the facility and to provide the documentation upon request. This submittal completed all corrective actions required for Site 300 to return to compliance.

Hazardous Waste Reports

LLNL completed two annual hazardous waste reports, one for the Livermore site and the other for Site 300, that address the 2001 transportation, storage, disposal, and recycling of hazardous wastes. The annual reports, required under 22 CCR 66262.41, were completed and submitted to meet DTSC’s April 1, 2001, deadline. These same reports, *2001 Hazardous Waste Report—Mainsite* and *2001 Hazardous Waste Report—Site 300* (Raber and Gilbert 2001a, b), were submitted to the EPA under Sections 3002 and 3004 of RCRA, which requires a biennial reporting of hazardous wastes. DTSC is authorized to receive the reports for EPA.



Hazardous Waste Transport Registration

Transportation of hazardous waste over public roads (e.g., from one LLNL site to another) requires DTSC registration (22 CCR 66263.10). DTSC renewed LLNL's registration in November 2001. Conditions for registration include a biennial inspection of terminals report (BIT Report) by California Highway Patrol (CHP), and special training and annual physical examinations for drivers. The biennial inspection of terminals resulted in a "satisfactory" rating, which is the highest rating possible.

Waste Accumulation Areas

In January 2001, there were 22 waste accumulation areas (WAAs) at the Livermore site. Four temporary WAAs were put into service, and four temporary WAAs were taken out of service. Program representatives conducted inspections at least weekly at all WAAs to ensure that they were operated in compliance with regulatory requirements. Approximately 1184 prescribed WAA inspections were conducted at the Livermore site.

One WAA was in operation at Site 300 during 2001. Program representatives conducted 52 prescribed inspections of the WAA at Site 300.

California Medical Waste Management Act

All LLNL medical waste management operations comply with the California Medical Waste Management Act, Health and Safety Code Sections 117600–118360, Chapters 1–11. The Medical Waste Management Act establishes a comprehensive program for regulating the management, transport, and treatment of medical wastes that contain substances that may potentially infect humans. The program is administered by the State Department

of Health Services (DHS) and is enforced by the Alameda County Department of Environmental Health (ACDEH).

LLNL is registered with the ACDEH as a generator of medical waste and has a treatment permit. The September 2001 ACDEH inspection of buildings at Health Services, the Biology and Biotechnology Research Program, and the Medical Photonics Lab did not result in any compliance issues or violations (see [Table 2-4](#)).

Federal Facility Compliance Act

LLNL is continuing to work with DOE to maintain compliance with the Federal Facilities Compliance Act Site Treatment Plan (STP) for Lawrence Livermore National Laboratory that was signed in February 1997. All milestones for 2001 were completed on time. Reports and certification letters were submitted to DOE as required. An agreement was reached with DTSC to extend all FY02 and FY03 milestones to allow LLNL to concentrate resources on characterizing and disposing of transuranic (TRU) waste. LLNL continued to pursue the use of commercial treatment and disposal facilities that are permitted to accept mixed waste. These facilities provide LLNL greater flexibility in pursuing the goals and milestones set forth in the STP.

Toxic Substances Control Act

The Federal Toxic Substances Control Act (TSCA) and implementing regulations found in 49 CCR 700–789, govern the uses of newly developed chemical substances and TSCA-governed waste by establishing requirements for recordkeeping, reporting, disposal standards, employee protection, compliance and enforcement, and cleanup standards.



In 2001, LLNL generated PCB-containing waste from CERCLA cleanup projects, PCB oil drained from electrical equipment, electrical equipment contaminated with PCBs, liquid PCBs used to calibrate analytical equipment, and TSCA-regulated asbestos from building demolition or renovation projects.

All TSCA-regulated waste was disposed of in accordance with TSCA, state, and local disposal requirements except for radioactively contaminated PCB waste. Radioactive PCB waste, typically known as TRU mixed waste or mixed waste, is currently stored at one of LLNL's hazardous waste storage facilities until the Waste Isolation Pilot Project, or other approved facility, accepts this waste for final disposal.

National Environmental Policy Act

The National Environmental Policy Act (NEPA; 42 U.S. Code [USC] 4321 et seq.) established federal policy for protecting environmental quality. The major method for achieving established NEPA goals is the requirement of preparing an environmental impact statement (EIS) for any major federal or federally funded project that may have significant impact on the quality of the human environment. If the need for an EIS is not clear, or if the project does not meet DOE's criteria for requiring an EIS, an environmental assessment (EA) is prepared. A Finding Of No Significant Impact (FONSI) is issued when an EIS is determined to be unnecessary.

Certain groups of actions that do not have a significant effect on the environment either individually or cumulatively can be categorically excluded from a more in-depth NEPA review (i.e., preparation of either an EA or EIS). DOE NEPA implementing procedures (61 FR 36222 and 57 FR 15122) identify those categorical exclusions and the eligibility criteria for their application. If a proposed project

does not clearly fit one of the exclusion categories, DOE determines which type of assessment document may be needed.

In 2001, no DOE EAs were prepared for LLNL projects. Thirty-five categorical exclusion applications were approved by DOE, and there were no proposed actions at LLNL that required separate DOE floodplain or wetlands assessments under DOE regulations in 10 CFR 1022. In March 1999, DOE issued a *Supplement Analysis* (U.S. DOE 1999) that concluded that the 1992 *Final Environmental Impact Statement and Environmental Impact Report for Continued Operation of Lawrence Livermore National Laboratory and Sandia National Laboratories, Livermore (1992 EIS/EIR)* (U.S. DOE and UC 1992a,b) did not need to be supplemented and remained adequate.

California Environmental Quality Act

In November 1992, the University of California (UC) and LLNL made a commitment to implement 67 mitigation measures identified by the 1992 *EIS/EIR* and to provide annual reports on their implementation. An addendum to the EIR was prepared in 1997. The measures are being implemented in accordance with the approved 1992 Mitigation Monitoring and Reporting Program associated with that joint DOE/UC EIS/EIR. The 1997 and 1998 fiscal year Mitigation Monitoring reports were published in 2001. The 1999–2001 fiscal year Mitigation Monitoring reports will be published in 2002.

National Historic Preservation Act

The National Historic Preservation Act (NHPA) applies to historically important places and things affected by the federal government. LLNL contains resources subject to NHPA consideration. These



range from prehistoric archeological sites to remnants of the Laboratory's own history of scientific and technological endeavor.

The responsibility to comply with the provisions of NHPA rests solely with DOE as a federal agency. The Laboratory, and the University of California as its contractor operator, supports DOE NHPA responsibilities. LLNL does so in a limited manner as directed by DOE.

NHPA contains two primary sections that apply to LLNL: Sections 106 and 110.

Section 106 requires federal agencies to take into account the effects their projects may have on historic properties. The agencies must allow and consider comments of the federal Advisory Council on Historic Preservation. The Section 106 rules outline a five-step review process that is conducted on a project-by-project basis.

Section 110 sets forth broad affirmative responsibilities to balance agency missions with cultural values. Its purpose is to ensure full integration of historic preservation into federal agency programs.

LLNL is working on two approaches to streamline historic preservation efforts and focus on important historic properties. One approach is to construct an agreement among DOE, the federal Advisory Council on Historic Preservation, and the State Historic Preservation Office. This device is called a programmatic agreement (PA). Since 1997, LLNL has drafted several versions of a historic preservation PA. LLNL continued to work on this effort in 2001, but a final agreement has not been signed.

The second approach is to complete an inventory of places that meet a statutory threshold of historic importance. During 2001, LLNL management funded development of historic background infor-

mation, a necessary precursor for the inventory, and also funded an analysis to make recommendations for historic significance determinations at the Livermore site and Site 300.

During 2001, LLNL completed historic evaluations of five buildings (Buildings 222, 412, 415, 490, and 865) and initiated evaluations for six additional buildings. Only Building 865 is eligible for listing in the National Register of Historic Places. Also during 2001, LLNL renovated its archeological collections to meet the federal standard for long-term storage of such materials. These efforts involved development of a catalog, cleaning and storage of artifacts in approved containers, and labeling of artifacts and records.

Endangered Species Acts and Sensitive Natural Resources

LLNL must meet the requirements of the U.S. Endangered Species Act, the California Endangered Species Act, and the California Native Plant Protection Act as they pertain to Endangered or Threatened species and their habitats, other species of special concern, and critical habitats that may exist or are known to exist at the LLNL sites. For example, in implementing the 1992 Mitigation Monitoring and Reporting Program in 2001, biological assessment surveys were performed for special-status species at 45 LLNL Site 300 project construction (ground-disturbing) areas. Presence data for the San Joaquin kit fox (*Vulpes macrotis mutica*), American badger (*Taxidea taxus*), and western burrowing owl (*Speotyto cunicularia hypugaea*) were collected at each project location, and other applicable mitigation measures were implemented where appropriate.

During 2001, at Site 300, no active San Joaquin kit fox dens were discovered, but one potential den was found. Three occupied American badger dens were discovered, and two unoccupied dens were



identified. Eight active burrowing owl dens were discovered and monitored throughout the breeding and wintering season. Site 300 populations of the federally-listed threatened California red-legged frog (*Rana aurora draytonii*) and a federal species of concern, the California tiger salamander (*Ambystoma californiense*), were monitored at wetland locations sitewide.

Livermore site populations of the California red-legged frog (*Rana aurora draytonii*) were monitored in accordance with the 1997 and 1998 amended U.S. Fish and Wildlife Service Biological Opinion for the Arroyo Las Positas Maintenance Project. One-hundred- to three-hundred-foot checkerboard sections in the Arroyo were managed for excess in-stream vegetation and 47 California red-legged frogs were protected from harm in project locations during the maintenance process. The United States Fish and Wildlife Service has designated critical habitat for the California red-legged frog since 2001. The North Buffer Zone and eastern edge of the Livermore site is now considered critical habitat for the California red-legged frog.

In addition, in 2001, a new monitoring strategy for California red-legged frogs was initiated at the Livermore site. Instead of basing population solely on observations of the frog life stage, egg masses were counted and located by global positioning system (GPS). Egg masses are conspicuous, making them a readily available indicator of population. The oviposition site (location and attachment point) was quantified to yield greater insight into what micro-habitat characteristics might be important to California red-legged frog breeding ecology in the Arroyo Las Positas. The results of the survey suggest that the Livermore site Arroyo Las Positas population is small but viable with 37 egg masses counted (roughly the same number of egg masses as the previous year). Because predation is high, the

actual number of frogs produced per egg mass is unknown. Further annual surveys will document the true viability of this population.

Bullfrog control continued in 2001 with the direct removal of both breeding adults and eggs from the Drainage Retention Basin (DRB). The bullfrog control program appears to be reducing the overall numbers after the original introduction and subsequent population explosion. California red-legged frog breeding in the DRB was documented for the first time after draining the basin to remove bullfrog larvae and catfish (both are non-native predators) in January 2001.

Also at the Livermore site, one pair of white-tailed kites (*Elanus leucurus*) successfully fledged three young and a pair of red-shouldered hawks (*Buteo lineatus*) fledged two young.

Four rare plant populations are known to occur at Site 300. These are the large-flowered fiddleneck (*Amsinckia grandiflora*), a federally-listed endangered plant species; the big tarplant (*Blepharizonia plumosa*, also known as *Blepharizonia plumosa* ssp. *plumosa*), listed on the California Native Plant Society Rare Plant 1A List (Tibor 2001); the diamond-petaled poppy (*Eschscholzia rhombipetalata*), a plant thought to be extinct until rediscovered in 1993, now listed on the revised California Native Plant Society 1A list (Tibor 2001); and the gypsum-loving larkspur (*Delphinium gypsophilum* ssp. *gypsophilum*), listed on the California Native Plant Society Rare Plant 4 list (Tibor 2001). Restoration and/or monitoring activities were conducted for three of these species in 2001 (the large-flowered fiddleneck, the big tarplant, and the diamond-petaled poppy), and the results of this work are described in more detail in an annual progress report (Carlsen et al. 2002). Future periodic monitoring will be conducted for the gypsum-loving larkspur.



Two of the three known natural populations of the large-flowered fiddleneck occur at Site 300. A portion of Site 300 has been designated as critical habitat area for the plant. In April 2000, this area was designated the *Amsinckia grandiflora* Reserve through a declaration by Secretary of the U.S. Department of Energy. A memorandum of agreement was signed between the DOE and the U.S. Fish and Wildlife Service concerning activities within the reserve. LLNL has also established an experimental population within the reserve. LLNL is working with the U.S. Fish and Wildlife Service on continued monitoring of native and experimental *Amsinckia* populations, and to further develop habitat restoration and maintenance techniques. The annual progress report prepared by LLNL was submitted to the U.S. Fish and Wildlife Service in April 2002 (Carlsen et al. 2002).

The smaller of the two on-site native populations of fiddleneck appears to have been extirpated in 1997 when the bank containing the population washed away. Although no plants have been observed at this site since 1998, other fiddleneck populations have suffered severe declines in recent years, and the area will continue to be monitored. The number of fiddleneck plants in the larger native population has been at historic lows for the past three years (14 plants were observed in 2001, with 40 plants observed in 2000 and 6 in 1999). The number of fiddleneck plants observed in the original experimental population area (59 plants) is similar to that observed during the past two years (45 plants in 2000 and 42 plants in 1999). The experimental population was expanded in 2000 to investigate more fully the use of fire as a management tool. The existing seed bank from the 148 *Amsinckia grandiflora* plants that flowered in the twenty native bunch-grass-restored plots in 2000 was enhanced between December 2000 and January 2001 with the addition of approximately

250 seeds into the plots. This resulted in a total of 257 *Amsinckia grandiflora* flowering plants in this area in 2001.

The low numbers of *Amsinckia grandiflora* plants observed over the past several years at Site 300 have also been observed in other existing natural and experimental populations of the fiddleneck throughout its existing range. A dramatic increase in seed predation by small rodents was observed in the Site 300 experimental population in 1998 and 1999. However, seed predation was much reduced in 2000. Unfortunately, this did not translate into increased numbers of *Amsinckia grandiflora* in either the native or experimental populations. Seed predation was again on the rise in 2001, but remained below that observed in 1998 and 1999.

Significant expansion of bush lupine (*Lupinus albus*) and gum-plant (*Grindelia camporum*), both native, shrubby forbs, have occurred in the area of the native *Amsinckia grandiflora* population. Bush lupine, a nitrogen fixer, can significantly change vegetation structure, and the overstory canopy of this site is becoming quite closed with large amounts of introduced grasses. Manual clipping and removal of some of the overstory to encourage *Amsinckia grandiflora* germination and establishment is being discussed with the U.S. Fish and Wildlife Service. Bush lupine expansion is known to be cyclical, and some evidence of natural dieback is beginning to appear.

Monitoring of the big tarplant (*Blepharizonia plumosa*), and the diamond-petaled poppy (*Eschscholzia rhombipetala*) continued in 2001. The big tarplant remained widespread throughout Site 300, with the number and size of the populations similar to that observed in 2000. Detailed monitoring of populations located in areas undergoing controlled burning is also being conducted to determine the impacts of fire on the population dynamics of this species. A total of 189 diamond-



petaled poppy plants were observed in 2001 (down somewhat from the 273 plants observed in 2000, but still significantly higher than the 9 plants observed in 1999). The majority of these plants produced seed-bearing pods.

Antiquities Act (of 1906): Paleontological Resources

Provisions of the Antiquities Act provide for recovery of paleontological remains. With the discovery of mammoth remains in conjunction with National Ignition Facility construction in 1997, LLNL has remained vigilant for other fossil finds. No remains subject to the provisions of the Antiquities Act were identified in 2001.

Environmental Occurrences

Notification of environmental occurrences is required under a number of environmental laws and regulations as well as DOE Order 232.1, *Occurrence Reporting and Processing of Operations Information*. DOE Order 232.1 provides guidelines to contractor facilities regarding categorization and reporting of environmental occurrences to DOE and divides occurrences into two categories: unusual occurrences and off-normal occurrences. Operational emergencies are also reported under DOE Order 232.1; however, DOE Order 151.1, *Categorization and Classification of Operational Emergencies*, defines the criteria for categorization and classification of operational emergency events.

The Environmental Protection Department's (EPD) response to environmental occurrences is part of the larger LLNL on-site emergency response organization that also includes representatives from Hazards Control (including the LLNL Fire Department), Health Services, Plant Engineering, Public Affairs, Safeguards and Security, and Site 300. In 2001, seven environmental incidents, summarized in **Table 2-10**, were reportable under DOE Order 232.1 and were categorized as off-normal occurrences according to DOE Order 232.1.

Agencies notified of these incidents included DOE, Alameda County Department of Health Services, and San Francisco Bay Regional Water Quality Control Board.

Contributing Authors Acknowledgment

Many authors significantly contributed to this large and diverse chapter. We acknowledge here the work of Richard Blake, Shari Brigdon, John Buchanan, Winifred Burks-Houck, Tina Carlsen, Connie DeGrange, Karen Folks, Gretchen Gallegos, Keith Gilbert, Robert Harrach, Steve Harris, Bert Heffner, Rod Hollister, Bill Hoppes, Susi Jackson, Albert Lamarre, Saverio Mancieri, Sandra Mathews, Paul McGuff, Jennifer Nelson-Lee, Barbara Nisbet, Kathy Pandrea-Raine, Ring Peterson, Victoria Salvo, Bill Schwartz, Judy Steenhoven, Michael Taffet, Stan Terusaki, Jayne Tonowski, Michael van Hattem, Joseph Woods, Jim Woollett, Jr., and Kenneth Zahn.



Table 2-10. Environmental occurrences reported under the Occurrence Reporting (OR) System, 2001

Date ^(a)	Occurrence category	Description ^(b)
January 12	Off-Normal	<p>LLNL received an NOV from the LWRP on January 12, 2001, for exceeding Federal pretreatment categorical effluent limits for the discharge from the Building 321C water jet machine. Analytical results of samples collected on November 2, 2000, from the discharge of the Building 321C water jet machine indicated a chromium concentration of 8.2 mg/L and a nickel concentration of 3.6 mg/L. The chromium and nickel concentrations exceed the applicable Federal pretreatment categorical effluent limits of 1.71 mg/L for chromium and 2.38 mg/L for nickel. The LLNL organization responsible for the water jet operation took prompt action to correct the situation and prevent future occurrences. On February 1, 2001, the LWRP resampled the process and deemed the operation in compliance. Receiving an NOV meets the requirements of an Off-Normal occurrence. OR 2001-0002.</p>
February 22	Off-Normal	<p>On February 22 and 23, LLNL reported the release of methyl tertiary-butyl ether (MTBE) at Building 611. In November 2000, an inspector from the Alameda County Health Care Services noted a deficiency during the inspection of the Building 611 gasoline and diesel underground storage tanks. The deficiency noted the absence of gaskets and bolts from the underground tank system man way covers. In addition, the regulator requested that a sample be obtained from water observed in the tank system containment area directly beneath the man way covers. Analytical results from subsequent samples indicated the possible presence of MTBE in the water at 19.0 mg/L. The possible release of MTBE was reported to the Alameda County Department of Health Services and the San Francisco Bay Regional Water Quality Control Board on February 22 and February 23, 2001. Subsequently, it was determined that the MTBE contaminated water was contained within the containment structure surrounding the underground piping and man way covers. While no contaminated water was detected outside the secondary containment, the OR was initiated to address the non-routine notification of any outside agency. This was reported under the Off-Normal category. OR 2001-0007.</p>
May 16	Off-Normal	<p>Three potentially contaminated countertops were disposed of before being properly cleared for release. Three potentially contaminated stainless steel countertops from Building 227 were stored in the Building 227 Staging Area. The countertops were painted red to signify that they were potentially contaminated with a hazardous material and not yet cleared for disposal. According to the procedure, potentially contaminated items are painted red. Once the item has been evaluated and determined to be clear for disposal, it is painted green. During activities on the job site, several cleared countertops that were painted green were inadvertently stacked on top of the three red countertops. It is believed that the entire stack of countertops, including the three potentially contaminated countertops, was sent to the landfill. Upon review of the survey data and process knowledge, it was concluded that the items were suitable for free release to the public. This was reported under the Off-Normal category. OR 2001-0017.</p>
May 18	Off-Normal	<p>On May 17, 2001, LLNL received an SOV from the DTSC. While conducting an inspection of the Explosives Waste Storage Facility (EWSF) at Site 300, the DTSC inspector noticed that the lock rings on five 55-gallon drums containing solid hazardous waste were not tight. All five drums had the lids in place, the lock rings with bolts installed, and the waste inside the drums was contained in plastic bags; however, the bolts were determined to be not sufficiently tight and therefore the containers were not considered adequately closed. Although the discrepancy was immediately corrected during the inspection, the DTSC issued a formal violation for this discrepancy. Receiving an SOV meets the requirements of an Off-Normal occurrence. OR 2001-0018.</p>

Table 2-10. Environmental occurrences reported under the Occurrence Reporting (OR) System, 2001

Date ^(a)	Occurrence category	Description ^(b)
August 1	Off-Normal	LLNL received an NOV from the LWRP for exceeding the effluent discharge permit limit for lead. Analysis of the daily compliance sample representing May 11 identified lead present at 1.4 mg/L. The LLNL permit limit for lead is 0.20 mg/L. Receiving an NOV meets the requirement of an Off-Normal occurrence. OR 2001-0029.
August 15	Off-Normal	<p>LLNL received an addendum to an earlier SOV received from the DTSC for findings from the May 17 and May 18 inspection of Site 300. On May 17, the DTSC issued an SOV for failing to keep containers of hazardous waste adequately closed (OR 2001-0018). On August 15, LLNL received an addendum to the SOV, identifying two additional findings from the May 17 and May 18 inspection. The new findings included:</p> <ul style="list-style-type: none"> • Failing to conduct a detailed waste analysis of the spent parts washer waste for waste listed on manifest #99555391 • Failing to maintain and provide records, waste analysis, and waste determination for waste streams on manifest 99555390, line 11(c) and 99555391, line 11(a). <p>Receiving an SOV meets the requirements of an Off-Normal occurrence. OR 2001-0033.</p>
September 12	Off-Normal	<p>LLNL received an SOV from the DTSC for findings observed during the DTSC inspection of the Livermore site on June 20-22. During the DTSC inspection of the Livermore site, the DTSC observed and documented three findings:</p> <ul style="list-style-type: none"> • Storage of hazardous waste for greater than 90 days at a location that was not authorized for storage of hazardous waste by permit, interim status, or variance. (Corrected 4/3/01) • Failure to mark each lab-packed container with the earliest date of acceptance of any original hazardous waste container to be placed into the lab-pack. (Corrected 7/5/01) • Inaccurate storage date in the operating record. (Corrected 7/20/01) <p>Receiving an SOV meets the requirements of an Off-Normal Occurrence. OR 2001-0037</p>

a The date indicated is the date when the occurrence was categorized, not the date of its discovery.

b See [Acronyms and Abbreviations](#) for list of acronyms



ENVIRONMENTAL PROGRAM INFORMATION

Introduction

Lawrence Livermore National Laboratory is committed to operating in a manner that preserves the quality of the environment. The Environmental Protection Department (EPD) leads this effort in the areas of environmental compliance and accountability. This chapter begins with a brief description of LLNL's integrated Environment, Safety, and Health (ES&H) Management System, Work Smart Standards (WSS), and the missions and activities of EPD and its three divisions. Performance measures (PMs) used by the U.S. Department of Energy (DOE) to evaluate the Laboratory's environmental protection efforts are then summarized. The bulk of the chapter is devoted to an account of LLNL's activities and progress in waste minimization and pollution prevention in 2001. Following descriptions of current issues and actions in the environmental program arena, this chapter concludes with a brief discussion of spill response.

Integrated Environment, Safety, and Health Management System

In accordance with the requirements of the University of California's (UC's) Prime Contract W-7405-ENG-48, Clause 6.7, LLNL has implemented an Integrated Safety Management System (ISMS). The LLNL ISMS is designed to ensure the systematic integration of ES&H considerations into management and work practices so that missions are accomplished safely. "Safety," used in

this context, is synonymous with environment, safety, and health to encompass protection of the public, workers, and the environment (including pollution prevention and waste minimization). The core requirements of ISMS are based on the DOE's Seven Guiding Principles and Five Core Functions.

The Seven Guiding Principles can be summarized as: (1) line management is responsible for ensuring the protection of employees, the public, and the environment; (2) clear roles and responsibilities for ES&H are established and maintained; (3) personnel competence is commensurate with their responsibilities; (4) resources are effectively allocated to address ES&H, programmatic, and operational considerations with balanced priorities;





(5) safety standards and requirements are established that ensure adequate protection of the employees, the public, and the environment; (6) administrative and engineering controls to prevent and mitigate ES&H hazards are tailored to the work being performed; and (7) operations are authorized.

The Five Core Functions that describe how LLNL manages and performs work are summarized as:

(1) define the scope of work; (2) identify and analyze the hazards associated with the work; (3) develop and implement hazards controls; (4) perform work within the controls; and (5) provide feedback on the adequacy of the controls for continuous improvement.

The implementation of a management system based on these principles and functions results in accountability at all levels of the organization, project planning with protection in mind, and excellence in program execution. The ISMS Program at LLNL employs a process of assessing hazards and the environmental implications of work; designing and implementing standards-based methods intended to control risks; and complying with applicable ES&H requirements. This process is implemented using a graded approach, which increases the level of risk management as hazards increase. The complete description of LLNL's ISMS can be found in *Integrated Safety Management System Description* (Clough 2000). This description was most recently revised in September 2001, to incorporate references to the National Nuclear Security Administration and add clarity to the document.

DOE initiated a verification review of LLNL's implementation of ISMS on November 29, 1999, and the results of the verification were presented on December 9, 1999. DOE recommended approval of the LLNL ISMS description after the

completion of several action items. The Verification of the LLNL Institutional ISMS was successfully completed in September 2000.

Work Smart Standards

Work Smart Standards (WSS) are an integral part of an ISMS, whereby safety professionals identify ES&H hazards and establish standards of operation appropriate for a particular work environment.

The WSS process requires an understanding of the work, an analysis of the hazards associated with the work, and the selection of standards from which hazard controls are developed. This process empowers the Laboratory and the local DOE staff, through consensus, to focus on the work being performed and to select sitewide ES&H standards based on the actual work being conducted and its associated hazards and threats to the environment.

WSS are approved at the management level closest to and with the most expertise in the work. The LLNL Director and DOE/OAK Manager approved the initial complete set of sitewide standards on August 5, 1999, after they were confirmed by an independent panel of external experts in March 1999.

The WSS set was essentially considered part of the UC contract once it was signed by the LLNL Director and the DOE/OAK Manager. Reaching these agreements with DOE on new work-based standards aligns the Laboratory with industry practice, establishes common ES&H expectations for DOE and UC, and facilitates the tailoring of requirements to streamline and increase the effectiveness of management at the Laboratory. LLNL's existing ES&H methodologies and documentation have been modified to incorporate the newly identified set of standards and to reflect the requirements of ISMS. These standards are continually reviewed and revised through the change



control process as either new DOE Orders are issued or regulations are adopted. In addition, the Laboratory undertakes periodic review of all the requirements to assure that the WSS set is current and complete.

The WSS set currently identified to satisfy the ES&H needs of the LLNL work environment are in the UC contract, Appendix G and can be viewed at: <http://labs.ucop.edu/internet/wss/wss.html>. The DOE orders applicable to the environment that are included in the WSS are listed in Appendix B of this report.

Meeting new expectations for integrated ES&H management at the Laboratory will take several years, but the WSS approach, coupled with enhanced, integrated management, continues to promise further safety improvements and lower costs.

Environmental Protection Department

As the lead organization at LLNL for providing environmental expertise and guidance on operations at LLNL, EPD is responsible for environmental monitoring, environmental regulatory interpretation and implementation guidance, environmental restoration, environmental community relations, and hazardous waste management in support of the Laboratory's programs. EPD prepares and maintains environmental plans, reports, and permits; maintains the environmental portions of the *ES&H Manual*; informs management about pending changes in environmental regulations pertinent to LLNL; represents the Laboratory in day-to-day interactions with regulatory agencies and the public; and assesses the effectiveness of pollution control programs. These functions are organized into three divisions within

the department: Operations and Regulatory Affairs, Hazardous Waste Management, and Environmental Restoration.

EPD monitors air, sewerable water, groundwater, surface water, soil, sediments, vegetation, and foodstuff, as well as direct radiation; evaluates possible contaminant sources; and models the impact of LLNL operations on humans and the environment. In 2001, 30,736 samples were taken, and 242,418 analytes were tested. The type of samples collected at a specific location depends on the site and the potential pollutants to be monitored; see the specific chapters of this report for discussions of each environmental medium.

A principal part of EPD's mission is to work with LLNL programs to ensure that operations are conducted in a manner that limits environmental impacts and is in compliance with regulatory guidelines. EPD helps LLNL programs manage and minimize hazardous, radioactive, and mixed wastes; determines the concentrations of environmental contaminants remaining from past activities; cleans up environmental contamination to acceptable standards; responds to emergencies in order to minimize and assess any impact on the environment and the public; and provides training programs to improve the ability of LLNL employees to comply with environmental regulations.

LLNL programs are supported by the Hazards Control Department's five ES&H teams and by EPD's five environmental support teams (ESTs). The ESTs are integrated into the ES&H teams through environmental analysts, who also chair the ESTs. Each EST includes representatives from environmental specialties within the Operations and Regulatory Affairs Division (ORAD), the ES&H teams, and a field technician from the Hazardous Waste Management (HWM) Division. Some ESTs also include a representative from the Environmental Restoration Division (ERD) or the



organizations supported by the ESTs. These teams evaluate operations, determine potential environmental impacts, and provide guidance on environmental regulations and applicable DOE orders for existing and proposed projects. ESTs assist programs in planning, implementing, and operating projects and in understanding and meeting their environmental obligations. When permits are obtained from regulatory agencies, ESTs aid the programs in evaluating the permit conditions and implementing requirements.

Operations and Regulatory Affairs Division

ORAD currently consists of seven groups that specialize in environmental compliance and monitoring and provide Laboratory programs with a wide range of information, data, and guidance to make more informed environmental decisions.

ORAD prepares the environmental permit applications and related documents for submittal to federal, state, and local agencies; provides the liaison between LLNL and regulatory agencies conducting inspections; tracks chemical inventories; prepares National Environmental Policy Act (NEPA) documents and conducts related field studies; oversees wetland protection and floodplain management requirements; coordinates cultural and wildlife resource protection and management; facilitates and provides support for the pollution prevention and recycling programs; teaches environmental training courses; coordinates the tank environmental compliance program; conducts compliance and surveillance monitoring; provides environmental impact modeling and analysis, risk assessment, and reporting; and develops new methods and innovative applications of existing technologies to improve environmental practices and assist LLNL in achieving its mission.

ORAD also actively assists in responding to environmental emergencies such as spills. During normal working hours, an environmental analyst from the ORAD Environmental Operations Group (EOG) responds to environmental emergencies and notifies a specially trained Environmental Duty Officer. Environmental Duty Officers are on duty 24 hours a day, 7 days a week, and coordinate emergency response with LLNL's ES&H team and other first responders or environmental specialists.

Hazardous Waste Management Division

All hazardous, radioactive, medical, and mixed wastes generated at LLNL facilities are managed by the HWM Division in accordance with local, state and federal requirements. HWM processes, stores, packages, solidifies, treats, and prepares waste for shipment and disposal, recycling, or discharge to the sanitary sewer.

As part of its waste management activities, HWM tracks and documents the movement of hazardous, mixed, and radioactive wastes from waste accumulation areas (WAAs), which are located near the waste generator, to final disposition; develops and implements approved standard operating procedures; decontaminates LLNL equipment; ensures that containers for shipment of waste meet the specifications of the U.S. Department of Transportation (DOT) and other regulatory agencies; responds to emergencies; and participates in the cleanup of potential hazardous and radioactive spills at LLNL facilities. HWM prepares numerous reports, including the annual and biennial hazardous waste reports required by the state and federal environmental protection agencies (see [Appendix C](#)). HWM also prepares waste acceptance criteria documents, safety analysis reports, and various waste guidance and management plans.

HWM meets regulations requiring the treatment and disposal of LLNL's mixed waste in accordance with the requirements of the Federal Facility Compliance Act. The schedule for this treatment is negotiated with the State of California and involves developing new on-site treatment options as well as finding off-site alternatives.

HWM is responsible for implementing a program directed at eliminating the backlog of legacy waste (waste that is not at present certified for disposal). This effort includes a large characterization effort to identify all components of the waste and a certification effort that will provide appropriate documentation for the disposal site.

Environmental Restoration Division

ERD was established to evaluate and remediate soil and groundwater contaminated by past hazardous materials handling and disposal processes and from leaks and spills that have occurred at the Livermore site and Site 300, both prior to and during LLNL operations. ERD conducts field investigations at both the Livermore site and Site 300 to characterize the existence, extent, and impact of contamination. ERD evaluates and develops various remediation technologies, makes recommendations, and implements actions for site restoration. ERD is responsible for managing remedial activities, such as soil removal and groundwater extraction, and for assisting in closing inactive facilities in a manner designed to prevent environmental contamination.

As part of its responsibility for Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) compliance issues, ERD plans, directs, and conducts assessments to determine both the impact of past releases on the environment and the restoration activities needed to reduce contaminant concentrations to protect human health and the environment. ERD interacts

with the community on these issues through Environmental Community Relations. Public workshops are held each year and information is provided to the public as required in the ERD CERCLA Community Relations Plans.

To comply with CERCLA groundwater remedial actions at the Livermore site, ERD has to date designed, constructed, and operated 5 fixed groundwater treatment facilities and associated pipeline networks and wells, 20 portable groundwater treatment units, 2 catalytic dehalogenation units, and 3 soil vapor extraction facilities (see [Chapter 8](#)). In 2001, ERD operated 4 fixed, 19 portable, 2 catalytic reductive dehalogenation, and 2 soil vapor treatment units. ERD also installed an electroosmosis system to improve its ability to remove contaminants from fine grained sediments. At Site 300, ERD has designed, constructed, and operated 3 soil vapor extraction facilities and 11 groundwater extraction and treatment facilities. In addition, ERD has capped and closed 4 landfills and the High Explosives Rinse Water Lagoons and Burn Pits, excavated and closed numerous waste water disposal sumps, and removed contaminated waste and soil to prevent further impacts to groundwater at Site 300.

ERD is actively designing, testing, and applying innovative remediation and assessment technologies to contaminant problems at the Livermore site and Site 300. ERD provides the sampling and data management support for groundwater surveillance and compliance monitoring activities.

Environmental Training

The LLNL Environmental Protection Training Program (EPTP) provides Laboratory workers the appropriate training support to assure that they have the knowledge, skills, and abilities to competently, safely, and effectively carry out the job-related environmental protection responsibilities of



their work assignments. In 2001, EPTP provided nearly 9000 hours of environmental protection training to Laboratory workers involved in science related work at LLNL. EPTP also provided an additional 3000 hours of specialized training to LLNL environmental professionals involved with the management of waste and other environmental protection activities. The environmental training developed and delivered to Laboratory workers during 2001 addressed the requirements of the National Environmental Policy Act, the Resource Conservation and Recovery Act, the Superfund Amendment and Reauthorization Act, the Occupational Safety and Health Administration and other Federal and California State regulatory requirements. Training subjects included hazardous waste management; low-level waste generation and certification; transuranic waste generation and certification; spill prevention, control, and countermeasures; pollution prevention; and other similar environmental protection related topics.

The EPTP staff is supported in the development and delivery of training by environmental protection subject matter experts (SMEs) from the three EPD divisions. In close coordination, the divisions provide the assessment and interpretation of training to be given to Laboratory workers and to internal department environmental protection specialists. In addition, the divisions supply SMEs and personnel who are trained and qualified to be instructors for the EPTP.

The EPTP staff consists of training professionals and technical and administrative personnel familiar with the various environmental regulations and requirements and cognizant in Laboratory operations requiring environmental protection training.

Performance Measures Summary

Since 1992, UC's contract to manage and operate LLNL for DOE has contained performance objectives, criteria, and measures. Four of these performance measures (PMs) are used to evaluate LLNL's environmental protection activities, and four are used to evaluate LLNL's environmental restoration and waste management activities.

At the end of 2001, DOE gave LLNL an average score of excellent for its environmental performance and an average score of outstanding for its environmental restoration and waste management performance (DOE 2001). DOE scores for individual performance measures are shown in [Table 3-1](#).

DOE Pollution Prevention Goals

In a memo dated November 12, 1999, the Secretary of Energy issued a new and challenging set of pollution prevention and energy efficiency (P2/E2) goals for the DOE Complex in response to the President's Executive Orders for Greening the Federal Government. The DOE P2/E2 Leadership goals, presented in [Table 3-2](#), have expanded the scope of the P2 goals in place during the 1990s by including the following: building and facility energy efficiency; reduction of releases of toxic chemicals, ozone-depleting substances, and green-house gases; increased vehicle fleet efficiency and use of alternative fuels; and the required purchasing of environmentally preferable products and services. The new P2/E2 goals continue to use 1993 as a baseline for waste reduction goals and have interim measurement points in 2005 and 2010.

Table 3-1. UC Contract 48 environmental protection performance measures for environmental performance in FY2001

PM designator	Performance measure synopsis	Location in <i>Environmental Report</i>	Score
Performance Area: Environment, Safety, and Health			
1.2.b	Radiation dose to the public Public radiation doses to the maximally exposed individual from DOE operations will be measured or calculated and controlled to ensure that doses are kept as low as reasonably achievable (ALARA).	Chapter 13, Radiological Dose Assessment, section on Results of 2001 Radiological Dose Assessment Chapter 2, Compliance Summary, section on National Emission Standards for Hazardous Air Pollutants, Radionuclides	Outstanding
1.2.f	Waste reduction and recycling) The Laboratory continues to progress toward meeting the DOE pollution prevention goal for the year 2005.	Chapter 3, Environmental Program Information, section on Waste Minimization/Pollution Prevention	Excellent
1.2.g	Environmental violations The rate of validated environmental violations, determined from inspections and reporting requirements from regulatory agencies is kept low.	Chapter 2, Compliance Summary, Tables 2-5 and 2-10	Marginal
1.2.h	Environmental releases The Laboratory controls and reduces the number of occurrences of environmental releases and the number of releases that result in violations.	Chapter 2, Compliance Summary, Table 2-10	Excellent
Performance Area: Environmental Restoration and Waste Management			
1.1.a	Waste management productivity The Laboratory will collect data on the volume of waste received and volume of waste shipped	Chapter 3, section on Hazardous Waste Management Division	Outstanding
1.1.b	Waste Management Treatment and Disposal The Laboratory will reduce low-level and mixed waste inventories through treatment and disposal activities.	Chapter 3, section on Hazardous Waste Management Division	Outstanding
1.1.c	Legacy Waste Management The Laboratory will reduce the legacy waste low-level and mixed waste inventories through treatment and disposal activities.	Chapter 3, section on Hazardous Waste Management Division	Excellent
1.3.a	Environmental Restoration The performance indicator is the ratio of the total contaminant mass removed divided by total budget dollars to the baseline total contaminant mass removed divided by baseline total budget dollars.	Chapter 2, Compliance Summary, section on Comprehensive Environmental Response, Compensation and Liability Act Chapter 8 , Groundwater Investigation and Remediation	Outstanding



Table 3-2. Pollution prevention and energy efficiency leadership goals at Department of Energy facilities

Goal ^(a)	Detail
Reduce Waste and Recycling	Reduce waste from routine operations by 2005, using a 1993 baseline, for these waste types: Hazardous by 90% Low Level Radioactive by 80% Low Level-Mixed Radioactive by 80% Transuranic (TRU) by 80%
	Reduce releases of toxic chemicals subject to Toxic Chemical Release Inventory reporting by 90% by 2005, using a 1993 baseline.
	Reduce sanitary waste from routine operations by 75% by 2005 and 80% by 2010, using a 1993 baseline.
	Recycle 45% of sanitary wastes from all operations by 2005 and 50% by 2010.
	Reduce waste resulting from cleanup, stabilization, and decommissioning activities by 10% on an annual basis.
Buy Items with Recycled Content	Increase purchases of EPA-designated items with recycled content to 100%, except when not available competitively at a reasonable price or that do not meet performance standards.
Improve Energy Usage	Reduce energy consumption through life-cycle cost effective measures by: 40% by 2005 and 45% by 2010 per gross square foot for buildings, using a 1985 baseline 20% by 2005 and 30% by 2010 per gross square foot, or per other unit as applicable, for Laboratory and industrial facilities, using a 1990 baseline.
	Increase the purchase of electricity from clean energy sources: (a) Increase purchase of electricity from renewable energy sources by including provisions for such purchase as a component of our requests for bids in 100% of all future DOE competitive solicitations for electricity. (b) Increase the purchase of electricity from less greenhouse gas-intensive sources including, but not limited to, new advanced technology fossil energy systems, hydroelectric, and other highly efficient generating technologies.
Reduce Ozone Depleting Substances and Greenhouse Gases	Retrofit or replace 100% of chillers greater than 150 tons of cooling capacity and manufactured before 1984 that use class I refrigerants by 2005.
	Eliminate use of class I ozone depleting substances by 2010, to the extent economically practicable, and to the extent that safe alternative chemicals are available for DOE class I applications.
	Reduce greenhouse gas emissions attributed to facility energy use through life-cycle cost-effective measures by 25% by 2005 and 30% by 2010, using 1990 as a baseline.
Increase Vehicle Fleet Efficiency and Use of Alternative Fuels	Reduce our entire fleet's annual petroleum consumption by at least 20% by 2005 in comparison to 1999, including improving the fuel economy of new light duty vehicle acquisitions and by other means.
	Acquire each year at least 75% of light duty vehicles as alternative fuel vehicles, in accordance with the requirements of the Energy Policy Act of 1992.
	Increase usage rate of alternative fuel in departmental alternative fuel vehicles to 75% by 2005 and 90% by 2010 in areas where alternative fuel infrastructure is available.

a From DOE P2/E2 leadership goals, dated November 12, 1999



The DOE P2/E2 Leadership Goals are set to establish a Department-wide achievement standard. DOE field offices, such as the Oakland Field Office, have the responsibility to adapt, develop and incorporate these goals into annual performance agreements for each of their sites. For LLNL, DOE P2/E2 goals for routine hazardous, low-level radioactive and mixed waste are part of the UC Contract performance measures (designator 1.2.f). The LLNL performance measure for sanitary waste differs from the DOE P2/E2 goal, which states that 45% of sanitary wastes from all operations will be recycled by 2005 and 50% by 2010. LLNL performance measures apply only to routine waste. When the DOE P2/E2 goals were established, LLNL already recycled/diverted greater than 45% of routine wastes. Hence the LLNL performance measure goal was set at achieving a diversion of 66.7% of sanitary wastes by 2005.

Pollution Prevention Reporting

UC contract performance measure 1.2.f requires LLNL to provide an annual review of its waste generation. The review focuses on pollution prevention opportunities and proposes implementation projects.

During 2001, the LLNL P2 staff completed the *1999 Comprehensive Opportunity Assessment for Pollution Prevention, Energy Efficiency, and Water Conservation at Lawrence Livermore National Laboratory, Livermore Site*. The report was submitted to DOE Oakland Operations Office in January 2002. The report identified and cataloged opportunities for pollution prevention throughout the Livermore site using fiscal year 1999 data from routinely generated hazardous, mixed, and radioactive waste; nonhazardous solid waste; and industrial solid waste databases. The report recorded previously evaluated alternatives and current or planned programs for particular waste streams and potential projects in the energy efficiency and water conservation areas. It differed from the previous *1997*

Comprehensive Opportunity Assessment (Celeste 1998) report by reviewing only routinely generated wastes.

In February 2001, LLNL submitted the *LLNL Report on Pollution Prevention and Energy Efficiency Leadership Goals*. The report outlines how LLNL intends to accomplish the DOE P2/E2 goals identified by the Secretary of Energy. The P2/E2 report also outlined the resources needed to reach the goals. This report took the place of the required triennial P2 Plan.

In November 2001, LLNL submitted to the DOE Oakland Office the *Fiscal Year (FY) 2001 Annual Report on Waste Generation and Pollution Prevention Progress*. The report outlined waste generation data for FY 2001 and made a progress report for the ongoing pollution prevention activities on site.

Waste Minimization/Pollution Prevention

The P2 Program at LLNL strives to systematically reduce solid, hazardous, radioactive, and mixed-waste generation and eliminate or minimize pollutant releases to all environmental media from all aspects of the site's operations. These efforts help protect public health and the environment by reducing or eliminating waste management and compliance costs, improving resource usage, reducing inventories and releases of hazardous chemicals, and minimizing civil and criminal liabilities under environmental laws. In accordance with EPA guidelines and DOE policy, the P2 Program uses a hierarchical approach to waste reduction (i.e., source elimination or reduction, material substitution, reuse and recycling, and treatment and disposal) applied, where feasible, to all types of waste.

The P2 staff tracks waste generation using the HWM Division's Total Waste Management System (TWMS) database.



By reviewing this database, the P2 staff can monitor waste streams for pollution prevention purposes. With the purpose to track and report waste minimization/pollution prevention efforts, LLNL compares waste generation against the baseline year, 1993, waste generation quantities.

Table 3-3 presents the routine waste generation for 1993 baseline year and for 2001; it provides a calculation of percent reductions in routine waste generation. In 2001, LLNL revised the method by which it calculates waste generated for the purposes of tracking and reporting on pollution prevention efforts. The reported waste quantities for hazardous waste, low-level mixed waste, and low-level radioactive waste now include wastes that were shipped off site, those treated and sewerred on site as well as 50% of wastes that were recycled on site. Rather than counting 100% of waste that is recycled as waste generated, 50% of waste recycled on site is counted towards waste generated to encourage on-site recycling. HWM generated wastes are excluded now since they are generated as a result of waste management activities. Previously, reported waste quantities excluded waste treated and sewerred, and recycled, and it included wastes generated at HWM.

To incorporate the new waste generation calculations in the baseline year, the baseline quantities have been increased by the percent change observed in actual 2000 waste generation quantities. The baseline quantities were previously calculated by excluding the treated and sewerred and recycled wastes.

Nonhazardous Solid Waste Minimization

LLNL changed the method by which routine sanitary waste generation is calculated in FY 2001. The amount of sanitary waste generated now includes the wastes that are disposed at landfill and wastes that are diverted. In this category, LLNL has two goals; one is to reduce the routine sanitary waste generation, and the other is to increase the routine sanitary waste diversion.

LLNL's goal is to reduce the generation of routine sanitary waste by 75% of the 1993 baseline year and to do so by year 2005. LLNL generated 4666.9 metric tons of routine sanitary waste in FY 2001, a 21% reduction since 1993. In addition, LLNL generated 10,185.9 metric tons of nonroutine sanitary waste. Nonroutine sanitary wastes include wastes from construction, and decontamination and demolition activities.

Table 3-3. Routine waste reduction, FY 2001

Waste category	1993 (baseline)	FY 2001	Reduction 2001 vs. 1993 (%)
Low-level radioactive	346.0 m ³	267.1 m ³	23
Mixed	26.2 m ³	22.6 m ³	14
Hazardous	1054 MT ^(a)	373.0 MT	65
Sanitary	5873 MT	4666.9 MT	21

Note: In 2001 the units for reporting low-level radioactive and mixed waste became cubic meters and hazardous and sanitary waste became metric tons, consistent with DOE P2 reporting. These units will be used in future UC performance measure reporting.

a MT = metric tons

In FY 2001, the portion of sanitary waste sent to landfill was 4819.8 metric tons. The routine portion was 1825.2 metric tons and the nonroutine portion was 2994.6 metric tons. The breakdown for routine and nonroutine waste is shown in [Table 3-4](#).

Table 3-4. Total nonhazardous waste sent to landfills, FY 2001

Nonhazardous waste	2001 total (metric tons)
Routine	
Compacted	1630.2
Industrial (TWMS) ^(a)	195
Routine subtotal	1825.2
Nonroutine	
Construction demolition (noncompacted)	2911.2
Industrial (TWMS)	83.4
Nonroutine subtotal	2994.6
LLNL total	4819.8

^a TWMS = Total Waste Management System

Diverted Waste

According to its management contract with UC, LLNL's goal is to divert 66.7% of its annual routine nonhazardous waste generated. LLNL diverted 2848.0 metric tons of routine nonhazardous waste in 2001. This represents a diversion rate of 61% of routine nonhazardous waste in 2001. The total routine and nonroutine waste diverted from landfills in 2001 was 10,038.4 metric tons.

[Table 3-5](#) shows a breakdown of waste diversion categories for 2001, reflecting the variety of diversion programs in place at LLNL. Soil, a major contributor to diversion totals, is reused both on site and at the landfill for daily cover. Asphalt and concrete are reused as road base material at the landfill. No cost-effective on-site reuse strategy for wood waste (created by broken pallets, shipping crates, and demolition or construction scrap) is

available, so LLNL gathers this waste in a collection yard for recycling by a vendor at a cost lower than that of other disposal alternatives. Intact pallets and other reusable wood remain on site for internal reuse.

Table 3-5. Diverted waste summary, FY 2001

Waste description	Cumulative 2001 total (metric tons)
Asphalt/concrete	2,800.5
Batteries	18.9
Cardboard	130.0
Compost	466.3
Cooking grease/food	4.4
Diverted soil	4,332.6
Miscellaneous	57.3
Magazines, newspapers, and phone books	27.6
Metals	1,449.36
Paper	262.2
Tires and scrap	24.2
Toner cartridges	1.7
Wood	443.0
Beverage and food containers	20.3
LLNL diversion total	10,038.4

Composting of landscape clippings from the site's lawns, trees, shrubs, and annual plantings provides another waste diversion method. LLNL uses properly aged compost on site as a soil amendment. By generating its own soil builders, LLNL benefits twice: by eliminating an organic waste stream (with no tipping fees or hauling required) and by saving the purchase cost of new material. In one activity



that both reduces waste and helps conserve water, gardeners chip office Christmas trees at the end of the holiday season to create mulch that is used year-round, reducing the amount of dry-season irrigation necessary in tree wells.

Another well-developed and highly visible component of the LLNL recycling effort is the office paper collection and reclamation project. The Laboratory operates a full-site program, with more than 122 facility collection points. Unclassified paper, including newspapers and magazines, is transported to a contract firm, where it is shredded and recycled. Classified paper is preprocessed at the Livermore site using a hammer mill destruction process. These items would otherwise contribute to the solid waste stream.

LLNL continues to look for diversion opportunities. A beverage container recycling program initiated in late 1999 was increasingly successful in 2001. This program, which serves all three on-site cafeterias, collected 20.3 metric tons of aluminum, glass, and plastic containers and steel food cans, which were taken off site for recycling by a local vendor.

Source Reduction and Pollution Prevention

Efforts to identify and implement pollution prevention measures are carried out both by LLNL P2 staff and individuals within the different directorates. Some examples include the Defense Nuclear Technologies Program's Contained Firing Facility at Site 300 that moves explosive tests inside a facility where the debris is contained, the Laser Program's efforts to design the National Ignition Facility to have minimal environmental impact, Engineering's Metal Finishing Group's continuing efforts to reduce waste and substitute less

hazardous chemicals in many of its processes, and the Education Program's efforts to enhance environmental education.

During 2001 a number of directorates were recognized for implementing pollution prevention measures within their operations through nominations for DOE Oakland Operations Office P2 Awards. These measures are summarized in [Table 3-6](#).

Current Return-on-Investment Projects

The DOE funds P2 projects through the High-Return-on-Investment (ROI) P2 Program. LLNL prepared and received funding for five high ROI P2 project proposals in 2001. High ROI projects that received funding during this time period are listed in [Table 3-7](#).

Review of New Processes or Experiments

Many organizations at LLNL use a "front-end" review process that applies to new programs, projects, or experiments that could have a significant impact on the environment. In this review, hazardous materials projected to be used are identified and wastes expected to be generated are estimated. The possibilities for chemical substitution, process changes, and recycling are then addressed. Researchers and project managers are encouraged to implement reasonable P2 opportunities that have been identified.

Design for Environment

Design for environment is a concept that involves developing an understanding of potential environmental impacts over the lifetime of a project, with the goal of minimizing or mitigating those potential impacts through modifications to the project at the design stage.

Table 3-6. P2 Award Nominations

LLNL organization	Nomination title/description
Business Services Department—Fleet Management	Implementation of Pollution Prevention Practices at LLNL's Fleet Maintenance Facility
Chemistry & Materials Science Operations	Donation of Excess Laboratory Glassware to Local High Schools
Chemistry & Materials Science Operations	<i>Take-back/buy-back of AVLIS chemicals, materials and equipment</i> —This nomination recognized efforts made to identify parties to either take-back, buy-back, or reuse excess chemicals, materials and equipment, preventing the need for their disposal.
DNT	<i>Contained Firing Facility</i> —This facility supports P2 by reducing the quantities of wastes generated during explosive tests.
DNT	<i>Site 300 Firing Tables</i> —This project substituted reusable steel firing tables instead of wood to minimize waste.
DNT	<i>Tritium recovery and reuse</i> —LLNL's Tritium Facility is recovering tritium from field devices. In addition to providing tritium for reuse by the DOE complex, the U.S. government benefits by realizing a waste avoidance of approximately 7 tons of radioactive waste.
EPD-ERD	<i>Specific Depth Ground Water Sampling</i> —Achieves waste minimization through improved groundwater sampling techniques
EPD-ERD	<i>Application of Passive Above Ground Iron Filings Ground Water Treatment System</i> —Achieves significant reduction in the volume of waste generated at ground water treatment facilities treatment
EPD-ERD	<i>Removing Nitrate and Perchlorate from Ground Water Using a Containerized Wetland System</i> —Reduces in the volume of treatment waste generated by a groundwater treatment system
NIF	<i>Incorporation of P2/E2 in Aqueous Parts Cleaning of Optics Hardware</i> —This nomination recognized the efforts of the teams responsible for the design and implementation of a large aqueous parts cleaner in the NIF Optics Assembly Building

Table 3-7. High return-on-investment projects, 2001

Operation	Project
Water Recovery/Drain Down System (FY2001)	This project funded the purchase and conversion of a water-tank trailer to facilitate removal, storage and replacement of chiller water during maintenance operations
Installation of Powder Coating Facilities to replace VOC-containing spray paints at Building 418 (FY2001)	This project funded the installation of powder coating equipment/facilities to replace spray painting operations which involve the use of VOC-containing paints at Building 418.
Aqueous Parts Washer at Building 611 (FY2001)	This project funded the installation of an aqueous spray cabinet washer in the Business Services Automotive Shop at Building 611. This Cabinet Washer will replace some varieties of solvent based cleaning and reduce human exposure and atmospheric release of associated VOCs.
Vehicle Car Wash Recycling System (FY2001)	This project will facilitate the recycling / reuse of vehicle car wash water and will yield savings in water and cleaning chemical consumption.
Photovoltaic Demonstration Project (FY2001)	This project will include the purchase and installation of several configurations of photovoltaic panels, power collection wiring, electric power inverter and grid connection in the vicinity of the LLNL Visitor's Center

In 1997, the Pollution Prevention Team and National Ignition Facility (NIF) project management completed a design-for-environment evaluation of the opportunities within the NIF project. Based on this evaluation, the Laboratory implemented recycling programs during NIF construction, prepared a Pollution Prevention Plan for NIF, and implemented aqueous cleaning concepts in the design for parts and optics cleaning.



The *NIF Pollution Prevention and Waste Minimization Plan* (Cantwell and Celeste 1998), which was completed in 1998, included pollution prevention opportunity assessments (PPOAs) on the predicted waste streams identified in the preliminary environmental impact statement. In 2000, a follow up document was completed, the *NIF Pollution Prevention and Waste Minimization 2000 Supplement*, which updated the PPOAs as needed, accounting for two years of design progress and process development. This work continues with the aim of developing and implementing waste minimization options before NIF becomes operational.

Implementing P2 Employee Training and Awareness Programs

General P2 awareness for LLNL employees is promoted through new employee training and orientation, posters, articles in *Newsline* (LLNL's weekly newspaper), and administrative briefings and memos. P2 information directed at technical employees is found in Document 30.1 of the *ES&H Manual* and is covered in the EPD training course *Hazardous Waste Generation and Certification*. This information is also disseminated to employees at conferences and workshops, and by making formal presentations to groups such as the ES&H Working Group's Environmental Subcommittee.

ChemTrack

ChemTrack, a computerized chemical inventory and material safety data sheet (MSDS) management system, is designed to ensure that LLNL complies with the Superfund Amendment and Reauthorization Act (SARA) Title III and California Business Plan reporting requirements. In addition, it serves to enhance the overall management of hazardous materials through tracking of specific high-hazard chemicals and other regulated

substances, facilitating chemical sharing, improving emergency response capabilities, and assisting in the preliminary hazard analyses for LLNL facilities. ChemTrack currently contains records of approximately 166,000 chemical containers ranging from 210-L (55-gal) drums to gram-quantity vials.

Response to Spills and Other Environmental Emergencies

All spills and leaks (releases) at LLNL that are potentially hazardous to the environment are investigated and evaluated. The release response process includes identifying the release, shutting off the source (if it is safe to do so), eliminating ignition sources, contacting appropriate emergency personnel, cordoning off the area containing the released material, absorbing and neutralizing the released material, assisting in cleanup, determining if a release must be reported to regulatory agencies, and verifying that cleanup (including decontaminating and replenishing spill equipment) is complete. Environmental analysts provide guidance to the programs on preventing spill recurrence.

To maximize efficient and effective emergency environmental response, EPD established a 7-day-a-week, 24-hour-a-day, on-call rotational position entitled the Environmental Duty Officer (EDO). Specialized EDO training includes simulated incidents to provide the response personnel with the experience of working together to mitigate an environmental emergency, determine any reporting requirements to regulatory agencies and DOE, and resolve environmental and regulatory issues within the LLNL emergency response organization. The on-duty EDO can be reached by pager or cellular phone at any time.

During normal work hours, Laboratory employees report all environmental incidents to the Environmental Operations Group (EOG) environmental analyst assigned to support their program area. The



EOG environmental analyst then notifies the on-duty EDO of the incident, and together they determine applicable reporting requirements to local, state, and federal regulatory agencies and to DOE. The EDO and the EOG environmental analyst also notify and consult with program management and have 7-day-a-week, 24-hour-a-day access to the office of Laboratory Counsel for questions concerning regulatory reporting requirements.

During off hours, Laboratory employees report all environmental incidents to the Fire Dispatcher, who, in turn, notifies the EDO and the Fire Department, if required. The EDO then calls out additional EPD support to the incident scene as necessary, and follows the same procedures as outlined above for normal work hours.

LLNL's Other Environmental Programs

Integral to LLNL's environmental efforts is the ongoing research and development activities of the Energy and Environment Directorate. This directorate conducts multidisciplinary research to understand the processes by which human activities impact the environment, to assess and mitigate environmental and human risk from natural and man-made hazards and to develop and demonstrate new tools and technologies for environmental restoration. This work primarily involves state-of-the-art groundwater modeling and advanced hydrogeologic tracer studies; in situ environmental remediation using natural and engineered processes; pathway, dosimetry, and risk analysis of radioactive and toxic substances; atmospheric dispersion modeling and dynamics; subsurface imaging and characterization; and seismic processes.

LLNL has implemented a specialized Space Action Team (SAT) for the decommissioning and demolishing of facilities. The SAT has implemented a systematic approach that evaluates all ES&H aspects in order to assure releases, waste generation and personnel exposures are minimized, while regulatory compliance and opportunities for recycling are maximized.

Contributing Authors Acknowledgment

Major contributors to this diverse chapter were Mohammad Abri, Mo Bissani, Winifred A. Burks-Houck, Bruce Campbell, Charlene Grandfield, Steve Harris, C. Susi Jackson, Saverio Mancieri, Barbara Nisbet, Ellen Raber, David Rice, George Sanford, Kris Surano, Joseph Woods, and Kenneth Zahn.



Paula J. Tate

AIR EFFLUENT MONITORING

Introduction

Lawrence Livermore National Laboratory performs continuous air effluent sampling of atmospheric discharge points at several facilities. LLNL assesses air effluent emissions from facility operations to evaluate compliance with local, state, and federal regulations and to ensure that human health and the environment are protected from hazardous and radioactive air emissions.

Air Quality Laws

LLNL complies with local, state, and federal environmental air quality laws and Department of Energy (DOE) regulations. Applicable sections of DOE Orders 5400.1, General Environmental Protection Program, and 5400.5, Radiation Protection of the Public and the Environment, define standards for controlling exposures to the public from operations at DOE facilities. Subpart H of the National Emissions Standards for Hazardous Air Pollutants (NESHAPs), 40 Code of Federal Regulations (CFR) 61, requires the continuous monitoring of certain discharge points and the estimation of dose to the public resulting from operations at DOE facilities. Guidance on air effluent sampling is provided in the *Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance* (U.S. DOE 1991), 40 CFR 60, and NESHAPs-cited American National Standards Institute (ANSI) standards. The Environmental Protection Agency (EPA) Region IX

has oversight responsibility for LLNL compliance with regulations regarding radiological air emissions.

Enforcement authority of the Clean Air Act regulations for nonradiological air emissions has been delegated to the local air districts: the Bay Area Air Quality Management District (BAAQMD) for the Livermore site and the San Joaquin Valley Unified Air Pollution Control District (SJVUAPCD) for Site 300.





Applicable regulations and permitting requirements are contained in the BAAQMD Regulations 1-12 for the Livermore site and the SJVUAPCD Regulations Rules 1010-9120 for Site 300.

Monitored Emissions

LLNL uses a variety of radioisotopes—including uranium, transuranics, biomedical tracers, tritium, and mixed-fission products—for research purposes. The major radionuclide released to the atmosphere from the Livermore site is tritium. In addition to effluent sampling for tritium, a number of facilities at the Livermore site have air effluent samplers to detect the release of uranium and transuranic aerosols. The air effluent sampling systems described in this chapter apply to stationary and point source discharges. LLNL also monitors diffuse, or nonpoint, sources to fulfill NESHAPs requirements. Sampling methods to evaluate LLNL diffuse sources are described in [Chapter 5](#) of the Data Supplement. Summary data from these diffuse sources can be found in [Chapter 5](#) of this volume.

Assessment of air effluent emissions and resulting dose to the public is performed by monitoring emissions and/or evaluating potential emissions. Currently, the air effluent sampling program measures only radiological emissions. LLNL has operations with nonradiological discharges; however, permits for these operations are obtained through local agencies, BAAQMD and SJVUAPCD, and monitoring of the effluent is not required.

The California Air Toxics “Hot Spots” legislation requires facilities to prepare an air toxics emissions inventory and risk assessment, which LLNL has completed. Based on the assessment, BAAQMD and SJVUAPCD have ranked LLNL as a low-risk facility for nonradiological air emissions.

Historically, monitoring of radionuclide air effluents at LLNL has been implemented according to the DOE as low as reasonably achievable (ALARA) policy. This policy is meant to ensure that DOE facilities are capable of monitoring routine and nonroutine radiological releases so that the dose to members of the public can be assessed, and so that doses are ALARA.

In addition, the NESHAPs 40 CFR 61, Subpart H, regulations require that facility radiological air effluents must be continuously monitored if the potential off-site dose equivalent is greater than $1 \mu\text{Sv}/\text{y}$ ($0.1 \text{ mrem}/\text{y}$), as calculated using the EPA-mandated air dispersion dose model and assuming that there are no emission control devices. The results from monitoring the air discharge points provide the actual emission source information for modeling, which is used to ensure that the NESHAPs standard, $100 \mu\text{Sv}/\text{y}$ ($10 \text{ mrem}/\text{y}$) total site effective dose equivalent, is not exceeded. Discharges from non-monitored operations with the potential to release radionuclides are also evaluated according to NESHAPs regulations.

To determine radiological NESHAPs compliance, corresponding doses are added to those obtained by modeling monitored emissions.

Operation of Monitoring Systems

Air effluent monitoring of atmospheric discharge points is used to determine the actual radionuclide releases from individual facilities and processes during routine and nonroutine operations, to confirm the operation of facility emission control systems, and to corroborate and aid in the resolution of ambient air measurement results for the site. (The relationship can work the other way as well—air surveillance measurements can corroborate effluent monitoring.) Measurements made by the air surveillance samplers located on and off site are reported in [Chapter 5](#).



Methods

Air effluent monitoring involves the extraction of a measured volume of air from the exhaust of a facility or process and subsequent collection of particles by filters or of vapors by a collection medium. After collection, the various radionuclides

in the sample are measured by appropriate analytical methods.

In 2001, LLNL operated 77 sampling systems for radioactivity from air exhausts at 7 facilities at the Livermore site (see **Figure 4-1**). These systems are listed in **Table 4-1** along with the analytes of



Figure 4-1. Facilities at the Livermore site with air monitoring systems for effluent gas streams during all or part of 2001

**Table 4-1. Air effluent sampling locations and sampling systems**

Building	Facility	Analytes	Sampler type	Number of samplers
175	MARS	Gross α , β on particles	Filter	6
177	Extractor Test Facility	Gross α , β on particles	Filter	1
235	Chemistry and Materials Science	Gross α , β on particles	Filter	1
251	Heavy elements	Gross α , β on particles	Filter	32
331	Tritium	Tritium	Stack ionization chamber ^(a)	4
		Gaseous tritium and tritiated water vapor	Molecular sieves	4
332	Plutonium	Gross α , β on particles	Stack CAM ^(a,b)	12
		Gross α , β on particles	Filter	16
491	Laser isotope separation	Gross α , β on particles	Filter	1

a Alarmed systems

b CAM = Eberline continuous air monitors

interest, the type of sampler, and the number of samplers. LLNL reassesses the need for continuous monitoring on an annual basis and more often if warranted by new operations or changes in operations. From NESHAPs assessments of operations during 2001, one additional discharge point, Building 235, was found to require continuous sampling.

In the past, sampling operations performed in Buildings 175, 177, 490, and 491 have supported research and development for the separation of uranium isotopes under the Advanced Vapor Laser Isotope Separation (AVLIS) Program. In 1999, the AVLIS Program was shut down, and samplers on a Building 490 exhaust system were deactivated because the operation of the ventilation system was stopped. Air effluent sampling systems at Buildings 175, 177, and 491 continue to operate as part of the maintenance and surveillance shutdown plan for AVLIS facilities.

Building 177 is currently undergoing decontamination activities that are scheduled to be completed in early 2002. At that time, the sampling system will be deactivated.

Sampling for particles containing radioactivity was conducted in six of the facilities and sampling for tritium was conducted in the Tritium Facility (Building 331). All sampling systems operated continuously. Samples were collected weekly or biweekly, depending on the facility. Most air samples for particulate emissions were extracted downstream of high-efficiency particulate air (HEPA) filters and before the emissions were discharged to the atmosphere. Particles in the extracted air were collected on sample filters and analyzed for gross alpha and beta activity. Tritium was collected using molecular sieves.



In addition to sample collection for environmental reporting, some facilities used real-time alarm monitors (listed in [Table 4-1](#)) at discharge points to provide faster notification in the event of a release of radioactivity.

Analytical results from the continuous samplers are reported as a measured concentration per volume of air or as less than the minimum detection concentration (MDC) when no activity is detected. In all cases, the MDC is more than adequate for demonstrating compliance with the pertinent regulatory requirements for radionuclides that are present or may be present in the sampled air. Further details of LLNL air effluent sampling systems are included in Chapter 4 of the *Environmental Monitoring Plan* (Tate et al. 1999).

Measured Radioactive Air Emissions

This section discusses the radiological air emissions from facilities that have continuously monitored discharge points.

Livermore Site

In 2001, a total of 0.74 TBq (20 Ci) of tritium was released from the Tritium Facility (Building 331). Of this, approximately 0.68 TBq (18.3 Ci) were released as tritiated water vapor (HTO). The remaining tritium released, 0.064 TBq (1.7 Ci), was elemental tritium gas (HT). Weekly HTO emissions from the facility ranged from 0 Bq/m³ (0 Ci/m³) to 4.8×10^3 Bq/m³ (1.3×10^{-7} Ci/m³), while HT emissions ranged from 0 Bq/m³ (0 Ci/m³) to 2.3×10^3 Bq/m³ (6.3×10^{-8} Ci/m³). The highest single weekly stack emission from the facility was 0.025 TBq (0.67 Ci), of which 0.024 TBq (0.64 Ci) was HTO.

Emissions from Building 331 for 2001 continued to remain considerably lower than those during the 1980s and were half that of the year 2000 emissions. [Figure 4-2](#) illustrates the HTO and HT emissions from the facility since 1981.

Most sample results from the continuously sampled discharge points that have the potential for releasing particulate radionuclides were below the MDC of the analysis. Sometimes as few as 1 to 4 samples (out of 25 to 50 samples per year) exhibited concentrations greater than the MDC. Generally, these few samples were only marginally above the MDC. In addition, because of the way some exhaust systems were configured, the monitoring systems sometimes sampled air from the ambient atmosphere as well as HEPA-filtered air from facility operations, which means that background atmospheric radioactivity was also collected. When gross alpha is detected, a check is performed to determine if the blowers were operational at the time of the detection. If the blowers were operational, the sample result is considered a valid detection, otherwise the result is considered to be background atmospheric radioactivity.

LLNL uses zero values for these results based on knowledge of the facility, the use of HEPA filters in all significant release pathways, and alpha-spectroscopy-based isotopic analyses of selected air sampling filters. These analyses demonstrate the presence of naturally occurring radionuclides, such as radon daughters like polonium. Even if LLNL used the MDC values to calculate the emission estimates for these facilities (which would be an extremely conservative approach), the total dose to a member of the public attributable to LLNL activities would not be significantly affected. None of the facilities monitored for gross alpha and beta had emissions in 2001.

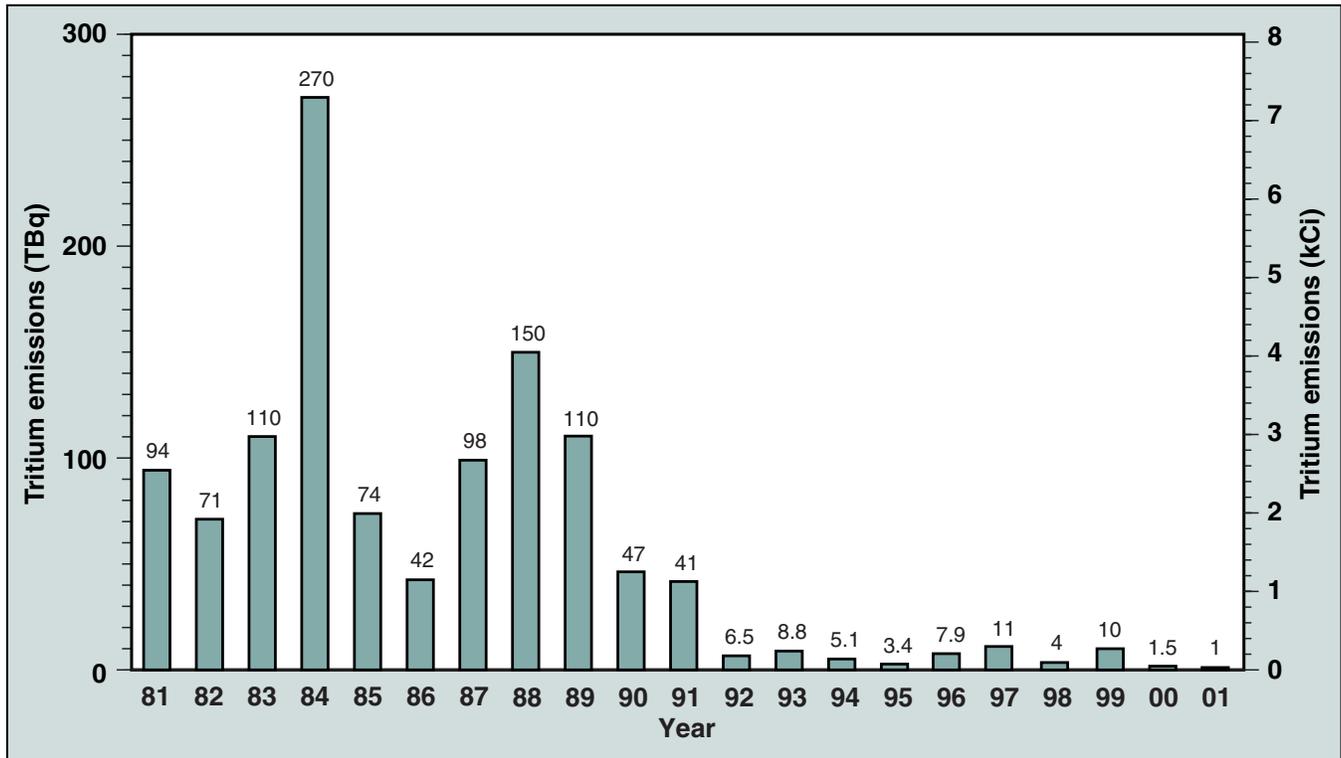


Figure 4-2. Tritium Facility combined HTO and HT emissions from 1981 through 2001

Radioactive effluent concentrations from individual discharge points at all monitored facilities are reported in [Chapter 4](#) of the Data Supplement.

Site 300

Currently, there is no requirement for air effluent monitoring of facilities at Site 300. However, Building 801 will have an effluent sampling system installed in early 2002. Air surveillance monitoring is performed for Site 300, and results are reported in [Chapter 5](#).

All Potential Sources of Radioactive Air Emissions

This section discusses the evaluation of all potential sources of radionuclide emissions to air at the Livermore site and Site 300. LLNL evaluates all discharge points with the potential to release radionuclides to the air according to 40 CFR 61, Subpart H, of the NESHAPs regulations. LLNL uses radionuclide usage inventories and/or monitoring data, along with EPA-accepted release factors for operations and EPA-suggested reduction factors for emission control devices, to estimate the potential release for each individual discharge point. Potential emissions are calculated using radionuclide usage inventories as distinguished from emissions-based air effluent sampling. LLNL conducts this evaluation annually to assess

both the potential dose to the public from all LLNL operations and the need for continuous sampling of individual discharge points.

For 2001, LLNL evaluated potential emissions of radionuclides from approximately 25 facilities and/or diffuse sources to determine their contribution of dose to a member of the public. Potential emissions were estimated based on radionuclide usage inventories specific to individual discharge points, physical state of the materials involved in the processes, and reductions caused by emission control systems. The effective dose equivalent (EDE) to a member of the public from specific operations at the Livermore site and Site 300 were published in *LLNL NESHAPs 2001 Annual Report* (Harrach et al. 2002) and are summarized in Chapter 13 of this report.

The radionuclide isotope responsible for the majority of the 2001 EDE was tritium. Emissions from the Tritium Facility, in the form of HTO, accounted for 25% of the potential EDE to the maximally exposed member of the public from the Livermore site. A brief discussion of the relative dose impacts from HTO and HT is given in *LLNL NESHAPs 2001 Annual Report*.

When determining if continuous sampling is needed at a discharge point, LLNL evaluates operations to determine if the potential dose to the maximally exposed member of the public will exceed 0.1 mrem for the calendar year. This evaluation is similar to the evaluation of EDE previously described except no credit is allowed for emission control systems (according to the regulations).

Nonradioactive Air Emissions

The Livermore site currently emits approximately 90 kg/day of criteria air pollutants (e.g., nitrogen oxides, sulfur oxides, particulate matter [PM-10], carbon monoxide, and lead, as defined by the

Clean Air Act). The largest sources of criteria pollutants from the Livermore site are surface-coating operations, internal combustion engines, solvent operations, and, when grouped together, boilers (oil and natural gas fired). **Table 4-2** lists the estimated Livermore site 2001 total airborne releases for criteria pollutants.

Table 4-2. Nonradioactive air emissions, Livermore site and Site 300, 2001

Pollutant	Estimated releases (kg/day)	
	Livermore site	Site 300
Organics/volatile organics	18.9	0.1
Nitrogen oxides	51.7	0.9
Carbon monoxide	13.6	1.1
Particulates (PM-10)	5.5	0.3
Sulfur oxides	0.6	0.1

When comparing the estimated releases from exempt and permitted sources of air pollutants at the Livermore site with daily releases of air pollutants for the entire Bay Area, LLNL emissions are very low. For example, the total emissions of nitrogen oxides released in the Bay Area for 2001 were approximately 7.7×10^4 kg/day, compared with an estimate for LLNL releases of 52 kg/day for the Livermore site (0.07% of total Bay Area emissions from stationary sources). The BAAQMD estimate for reactive organic emissions was 1.3×10^5 kg/day for 2001, versus the Livermore site's estimated releases of 19 kg/day (0.01% of total Bay Area emissions from stationary sources) in 2001.

Certain operations at Site 300 require permits from SJVUAPCD. The total estimated air emissions during 2001 from operations (permitted and exempt air sources) at Site 300 are given in **Table 4-2**. The largest sources of criteria pollutants at Site 300 include internal combustion engines,



boilers, a gasoline-dispensing operation, open burning, paint spray booths, drying ovens, and soil vapor extraction operations.

Environmental Impact

Measured radiological air emissions from the Livermore site operations for 2001 are well below levels that would cause concern for public health, according to existing regulatory standards for radioactive dose. The dose to the hypothetical maximally exposed member of the public caused by the measured air emissions reported here (that is, caused by emissions from monitored stacks and modeling HT emissions as HTO as required by EPA) is 0.043 $\mu\text{Sv}/\text{y}$ (0.0043 mrem/y).

Evaluating the emissions with NEWTRIT, a model that expressly treats the HT emissions and incorporates the dose from organically bound tritium (see [Chapter 13](#)), the dose to the hypothetical maximally exposed member of the public is 0.031 $\mu\text{Sv}/\text{y}$ (0.0031 mrem/y).

In either case, the dose is far below the NESHAPs standard of 100 $\mu\text{Sv}/\text{y}$ (10 mrem/y), and the doses are below those from naturally occurring radiation. Thus, the estimated radiological dose caused by measured air emissions from LLNL operations is minimal. See [Table 13-2](#) in [Chapter 13](#) for a summary of doses.

Nonradioactive air effluents, which are also very small compared with emissions in surrounding areas, are well below standards and are not a threat to the environment or public health.

Contributing Authors Acknowledgment

The author acknowledges Barbara Nisbet as a contributor to the “[Nonradioactive Air Emissions](#)” section of this chapter.

Paris E. Althouse
S. Ring Peterson
Paula J. Tate

AIR SURVEILLANCE MONITORING

Introduction

Lawrence Livermore National Laboratory performs ambient air monitoring to evaluate its compliance with local, state, and federal laws and regulations and to ensure that human health and the environment are protected from hazardous and radioactive air emissions. Federal environmental air quality laws and U.S. Department of Energy (DOE) regulations include Title 40 of the Code of Federal Regulations (CFR) Part 61, the National Emissions Standards for Hazardous Air Pollutants (NESHAPs) section of the Clean Air Act, and applicable portions of DOE Orders 5400.1 and 5400.5. The *Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance* (U.S. DOE 1991) provides the guidance for implementing DOE Orders 5400.1 and 5400.5. In general, the airborne substances for which LLNL monitors are at levels far below regulatory standards.

LLNL monitors ambient air to determine if airborne radionuclides or hazardous materials are being released by Laboratory operations, what the concentrations are, and what the trends are in the LLNL environs. In the air monitoring program, LLNL collects particles on filters and

chemically traps vapors on a collection medium. Concentrations of various airborne radionuclides (including particles and tritiated water vapor) and beryllium are measured at the Livermore site, Site 300, and at off-site locations throughout the Livermore Valley and in the City of Tracy. In addition, some point sources and diffuse, or nonpoint sources, are monitored to fulfill NESHAPs requirements (Harrach et al. 2002).





Methods

Monitoring networks are established for surveillance of air particulates and tritium in the environs of LLNL and Site 300, as well as in the surrounding Livermore Valley and in the City of Tracy. The sampling locations for each monitoring network are listed in [Table 5-1](#) and shown on [Figure 5-1](#), [Figure 5-2](#), and [Figure 5-3](#). All monitoring networks use continuously operating samplers. The air particulate sampling network uses glass-fiber, cellulose, and membrane filters, while the collection medium for tritium is silica gel.

Particulate filters are changed each week at all locations, and tritium samples are changed every two weeks. Duplicate quality control samplers operate in parallel with the permanent sampler at a given site, and these samples are analyzed to confirm results.

Air Particulate Sampling Locations

All air samplers are positioned to provide reasonable probability that any significant concentration of radioactive or beryllium effluents from LLNL operations will be detected.

The Livermore site radiological air particulate sampling network (see [Figure 5-1](#)) consists of seven samplers at the perimeter with one (CRED) serving as the sitewide maximally exposed individual (SW-MEI) for NESHAPs reporting purposes. CRED is also located in the southeast quadrant in an area of known plutonium contamination attributed to historic operations, which included the operation of solar evaporators for plutonium-containing liquid waste.

The Livermore Valley network (see [Figure 5-2](#)) consists of air particulate samplers located in all directions from the Livermore site. For the purposes of data analysis, four samplers (FCC,

FIRE, HOSP, and CHUR) located in the least prevalent wind directions are considered to be upwind or representative of background locations. An additional upwind sampler is located in another area of special interest, the Livermore Water Reclamation Plant (LWRP), because of plutonium releases in 1967 and earlier to the sanitary sewer system with subsequent soil contamination and potential resuspension (see the “[Livermore Valley Surface Soil Results](#)” section of Chapter 10 for a discussion of this). Four samplers (PATT, ZON7, TANK, and AMON) are located in the most prevalent downwind directions that are considered most likely to be affected by Laboratory operations.

Livermore site beryllium monitoring continued in 2001 at all perimeter locations (except CRED). To satisfy beryllium reporting requirements and determine the effects of the Laboratory’s beryllium operations, LLNL conducted a technical assessment of the beryllium monitoring locations at Site 300 in 1997. Although there is no requirement to sample for beryllium at Site 300, LLNL has decided, as a best management practice, to continue beryllium monitoring at three locations on site (801E, EOBS, GOLF) and at one location in the City of Tracy (TFIR) (see [Figure 5-3](#)).

The Site 300 air particulate monitoring network includes eight sampling units placed around the site and near firing tables and one in downtown Tracy (see [Figure 5-3](#)). Due to the remoteness of Site 300 and the difficulties with weekly access, monitoring sites were chosen based on safety, power, and access considerations. COHO serves as the SW-MEI for NESHAPs reporting purposes.

Two sampling systems were added in the Livermore Valley in July 1997 as part of the new low-volume radiological air particulate sampling network. The samplers are situated at FCC and HOSP and are generally upwind of the Livermore site. The results are used to establish background levels of gross

Table 5-1. Sampling locations and type and frequency of analyses for ambient air

Livermore site						
	Weekly gross alpha & beta (low volume)	Weekly gross alpha & beta (high volume)	Monthly $^{239+240}\text{Pu}$	Monthly Gamma & $^{235, 238}\text{U}^{(a)}$	Monthly Beryllium	Biweekly Tritium
Network	Air particulate					Air vapor
Collection Media	Membrane	Glass fiber			Cellulose	Silica gel
SALV		X	X	X	X	X
MESQ		X	X	X	X	X
CAFE		X	X	X	X	X
MET		X	X	X	X	X
VIS		X	X	X	X	X
COW		X	X	X	X	X
CRED		X	X			
DWTF						X ^(b)
B292						X
B331						X
B514						X
B624						X
POOL						X
VET						X
ZON7		X	X			X
PATT		X	X			X ^(c)
CHUR		X	X			
AMON		X	X			X
FCC	X	X	X			
HOSP	X	X	X			X
LWRP		X	X			
FIRE		X	X			X
TANK		X	X			
Site 300						
		Weekly gross alpha & beta (high volume)	Monthly $^{235, 238}\text{U}$	Monthly Gamma & $^{239+240}\text{Pu}^{(a)}$	Monthly Beryllium	Biweekly Tritium
Network	Air particulate					Air vapor
Collection Media	Glass fiber			Cellulose	Silica gel	
EOBS		X	X	X	X	
ECP		X	X	X		
WCP		X	X	X		
GOLF		X	X	X	X	
NPS		X	X	X		
WOBS		X	X	X	X	
801E		X	X	X		
COHO		X	X			X
TFIR		X	X		X	

a Perimeter composites samples include portions of weekly filters from the specified locations.

b New monitoring station started October 2001.

c PATT replaced XRDS (for tritium only). Monitoring began February 2001.

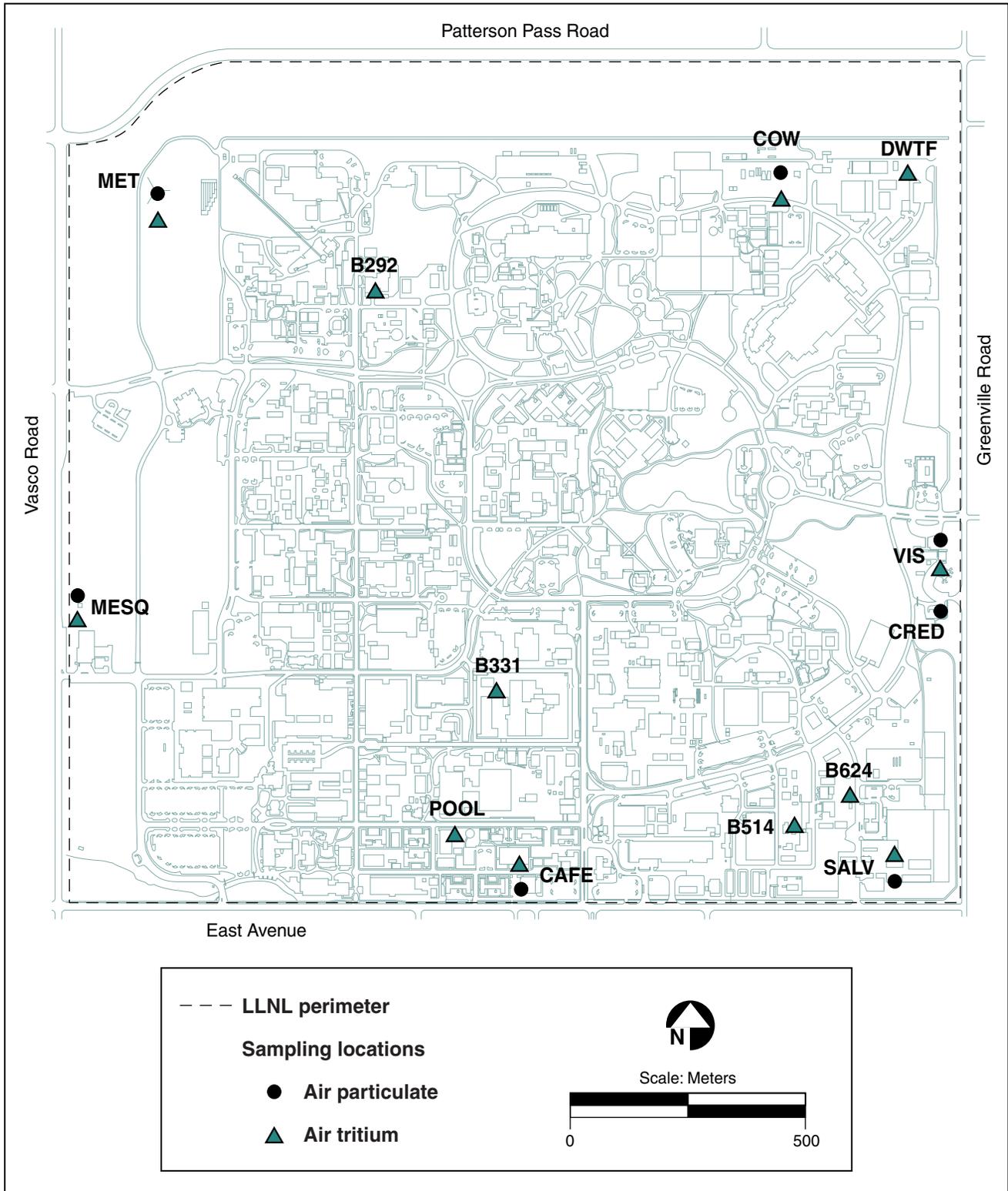


Figure 5-1. Air particulate and tritium sampling locations on the Livermore site, 2001

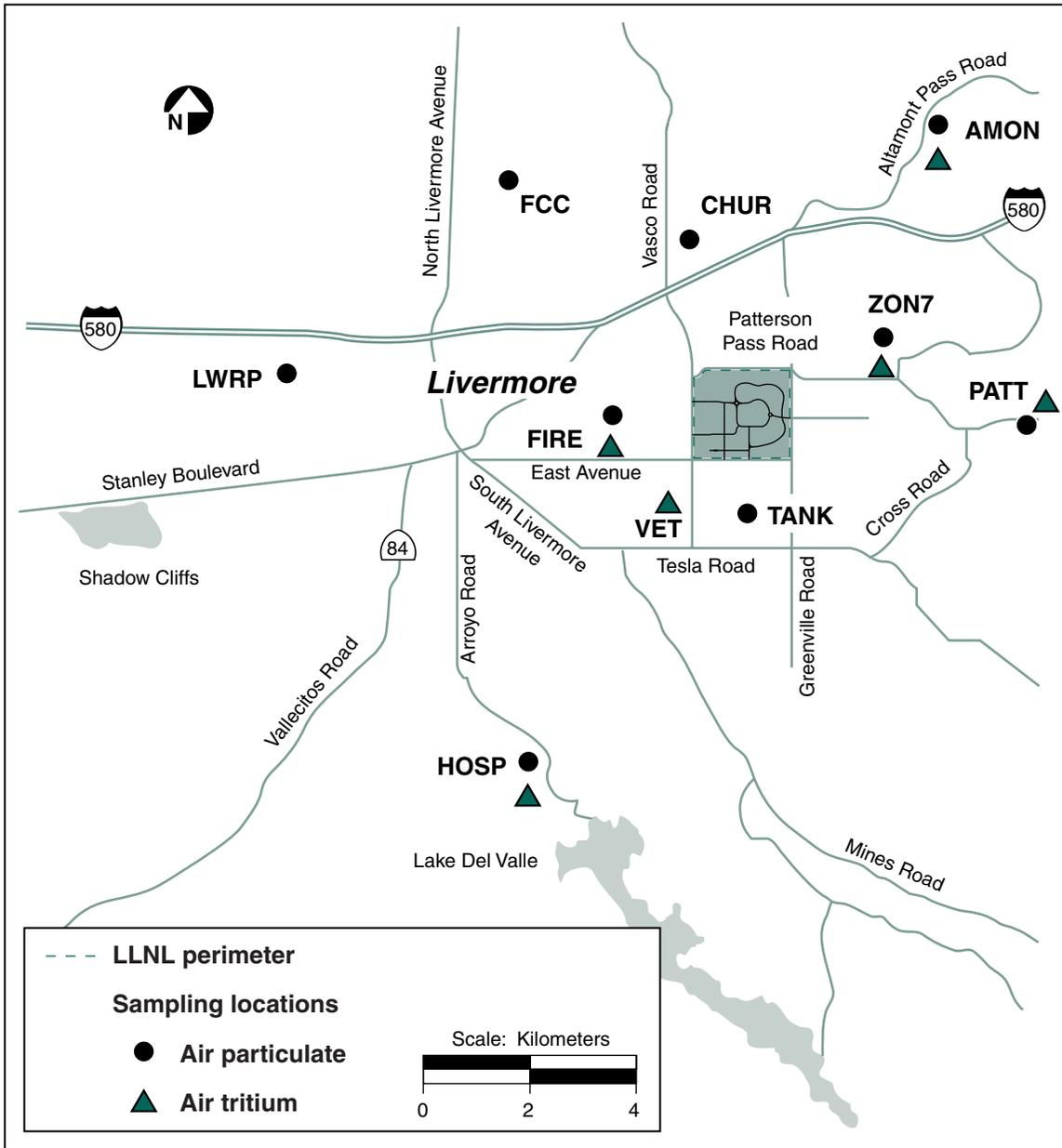


Figure 5-2. Air particulate and tritium sampling locations in the Livermore Valley, 2001

alpha and beta activity for direct comparison to emissions from the air effluent samplers (see Chapter 4). The low-volume sampling systems are very similar to the air-effluent samplers used in facilities, including sampling system design, sampler operation, sampler flow rate, filter media, sample tracking, sample analysis, and processing of results.

Air Tritium Sampling Locations

LLNL also maintains 12 continuously operating airborne tritium samplers on the Livermore site (see Figure 5-1), 6 samplers in the Livermore Valley (see Figure 5-2), and 1 sampler at Site 300 (see

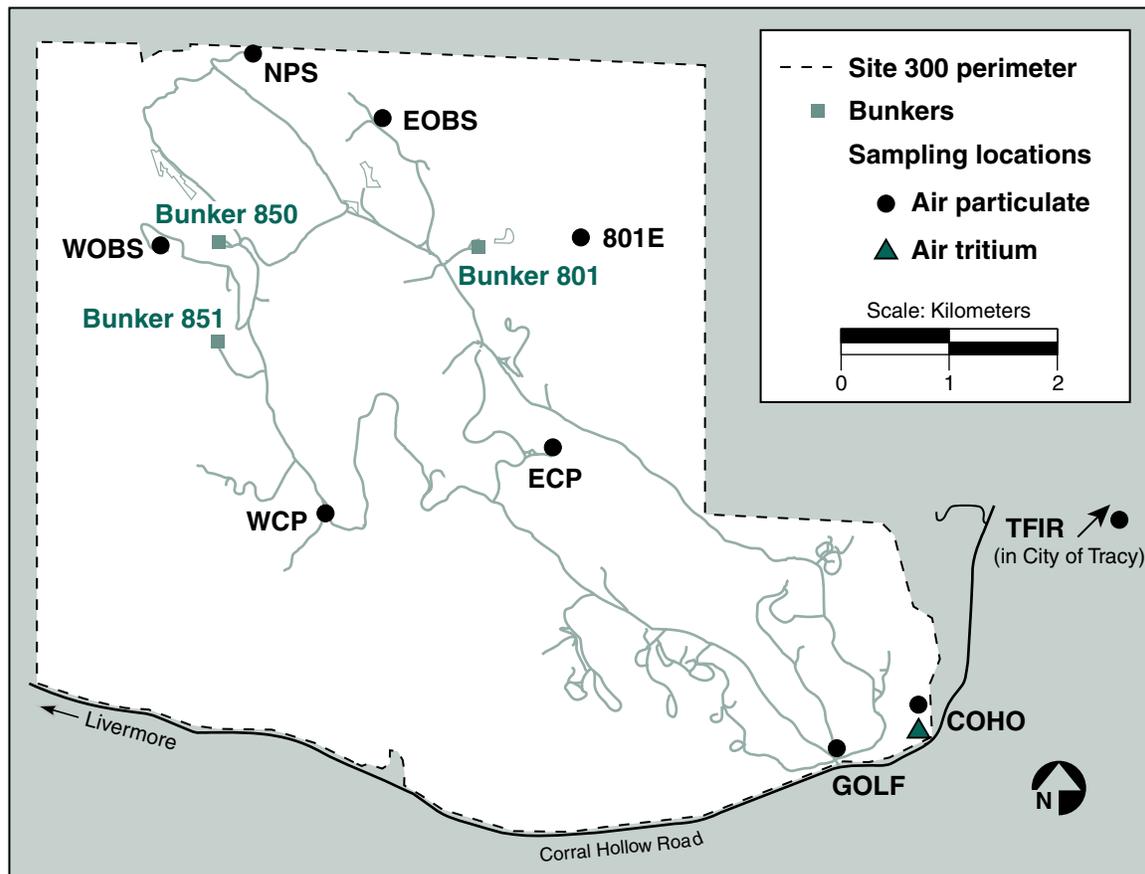


Figure 5-3. Air particulate and tritium sampling locations at Site 300 and off-site, 2001

Figure 5-3) to assess current activities that influence environmental impacts. Four of the Livermore site locations (B331, B292, B514, and B624) monitor diffuse tritium emissions.

Radiological Analysis

As outlined in *Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance* (U.S. DOE 1991), gross alpha, gross beta and gamma emitters on air filters are used as trend indicators; specific radionuclide analysis is done for plutonium and uranium. Radiological analytical results are reported as a measured activity per volume of air. Regardless of whether any activity is considered to have been detected, the result of the analysis is reported.

Particle size distribution on air samples is not determined because the estimated effective dose equivalent to the maximally exposed individual (from the total particulate) is well below the 0.01-mSv (1-mrem) allowable limit as discussed in the above-mentioned environmental regulatory guide.

Gross alpha and gross beta activities are determined by gas flow proportional counting; plutonium and uranium isotopes by alpha spectrometry; gamma emitters by gamma spectroscopy; and tritium by liquid scintillation.

In 2001, a correction factor was applied to tritium concentrations to account for dilution of the collected tritium from air moisture by a heretofore

unknown quantity of water in supposedly dry silica gel. On average, the corrected concentrations are 1.6 times higher than uncorrected concentrations. Further details of the monitoring and analytical methods for ambient air are provided in [Chapter 5](#) of the Data Supplement.

For air, Derived Concentration Guides (DCGs) specify the concentrations of radionuclides that can be inhaled continuously 365 days a year without exceeding the DOE primary radiation protection standard for the public, which is 1 mSv/y (100 mrem/y) effective dose equivalent (DOE Order 5400.5). ([Chapter 13](#) provides an explanation of this and other units of dose.) Each table in this chapter presents the DCG and the percent of the DCG for the given isotope. In all air samples, the maximum concentration for any sample is less than 0.2% of the DCG.

Results

This section discusses the air monitoring results from all air surveillance locations at the Livermore site, Site 300, and all off-site surveillance locations.

In April 1997, the radiological air particulate sampling filter media were changed from cellulose to glass fiber; however, blank glass-fiber filters contain nontrivial amounts of some naturally occurring radiological isotopes (Althouse 1998) including uranium-235, uranium-238, potassium-40, radium-226, radium-228, and thorium-228. In fact, the amounts of these naturally occurring isotopes contained in these filters is often greater than the amounts of the isotopes being filtered from the air.

LLNL adjusts the gross measured concentrations of these isotopes according to U.S. Environmental Protection Agency (EPA) procedures (Eadie and Bernhardt 1976). LLNL staff subtracts the appropriate blank filter content from the gross analytical

result to obtain a corrected net result. This subtraction of the background filter content results in highly variable uranium-235 to uranium-238 ratios. Historically, these ratios have been used to determine the presence of naturally occurring uranium; however, this variability makes the ratio results useless. Therefore, the ratios are not reported in 2001. Changes in filter media and analytical methodology were implemented in 2002. These changes should once again enable the use of the uranium ratios for identification of natural uranium.

Livermore Site

Airborne Radioactivity

[Figure 5-4](#) shows the two-year history of monthly gross alpha and gross beta median activities for the LLNL perimeter, Livermore Valley, and Site 300 sampling locations. Detailed location results for the high volume network for gross alpha and gross beta concentrations are summarized in the Data Supplement [Tables 5-1](#), [5-2](#), and [5-3](#). The median concentrations, interquartile ranges (IQR), and maximum concentration for each location are provided in addition to the monthly median for each area of interest.

The typical gross alpha activity (annual median value) for the LLNL perimeter is 4.6×10^{-5} Bq/m³ (1.2×10^{-15} Ci/m³); for the upwind Livermore Valley stations, the value is 5.2×10^{-5} Bq/m³ (1.4×10^{-15} Ci/m³), while the downwind Livermore valley stations increase only slightly at 5.6×10^{-5} Bq/m³ (1.5×10^{-15} Ci/m³). The maximum values for all gross alpha and gross beta data occurred in January.

The January high values are a continuation of an increase in the latter part of 2000 and coincide with the lack of rain into the beginning of the year. Both the gross alpha and gross beta data decrease significantly in February with the increase in rainfall. The

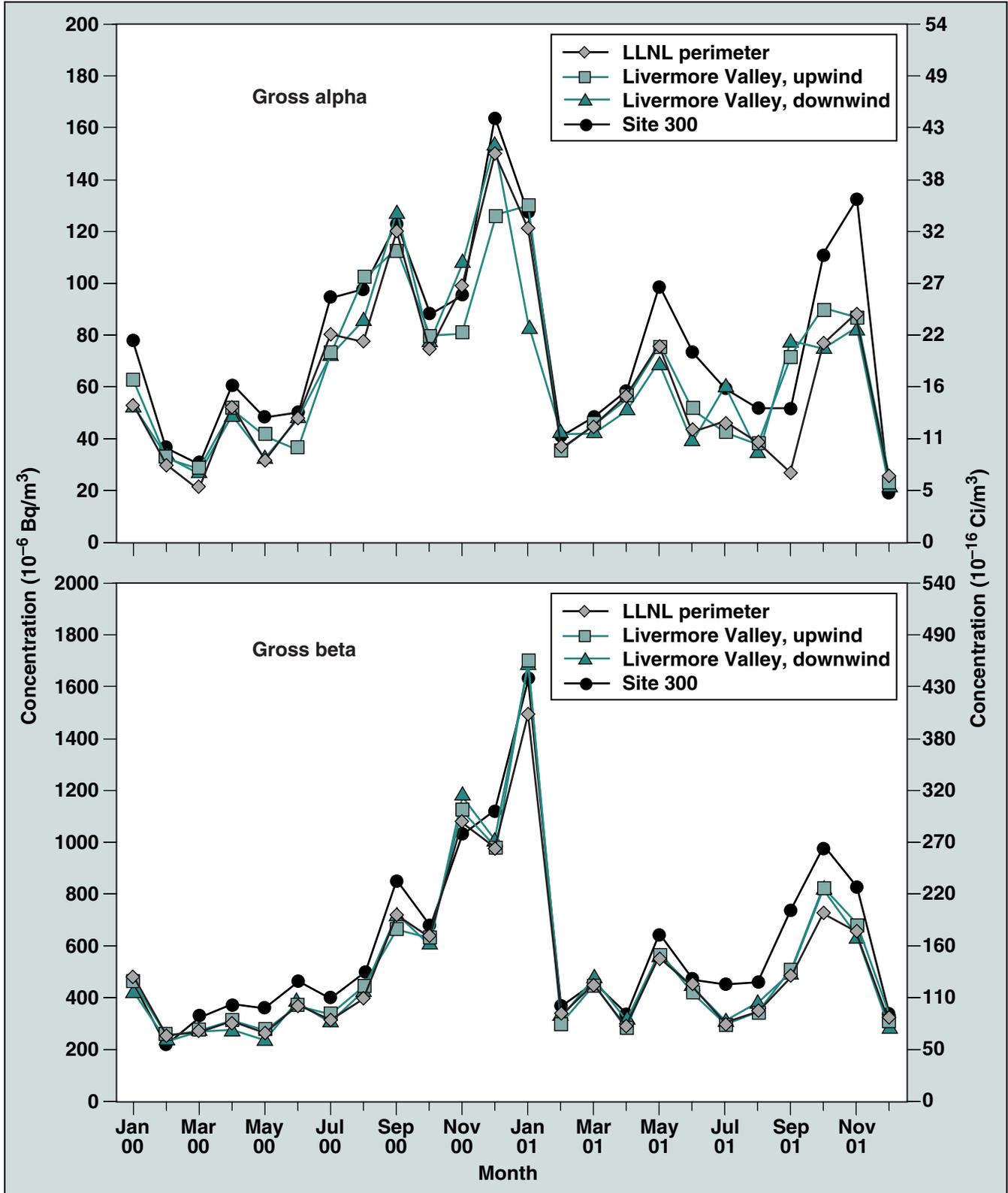


Figure 5-4. Two-year history of the median gross alpha and gross beta activities for all particulate samples grouped by area, 2000-2001



gross beta activity ranged from the lowest annual median value recorded at an upwind Livermore Valley station (FCC) at 4.1×10^{-4} Bq/m³ (1.1×10^{-14} Ci/m³) to the highest value of 5.0×10^{-4} Bq/m³ (1.3×10^{-14} Ci/m³) at a downwind Livermore station (AMON). The LLNL median perimeter value was between the upwind and downwind valley values.

The primary sources of the alpha and beta activities are the naturally occurring radioisotopes of uranium and thorium, and any residual fallout from atmospheric weapons testing and the 1986 Chernobyl reactor accident. These data follow a similar pattern to the low-volume gross alpha and gross beta data.

Composite samples for the Livermore site and Site 300 are analyzed for over 40 gamma-emitting radionuclide concentrations in air. Of those isotopes, only beryllium-7, a naturally occurring product primarily formed as a result of cosmic ray interactions, was consistently detected. Cesium-137 was detected in the June sample with a concentration of 1.0×10^{-6} Bq/m³ (2.7×10^{-17} Ci/m³) (less than 0.00001% of the DCG). The primary source of cesium-137 is long-term global fallout and fallout resuspension. The beryllium-7 data are shown in **Table 5-2**. All other gamma results were less than the detection limit. By analyzing air samples for gamma-emitting radionuclides, LLNL verifies that there is no evidence of release of the small inventories of mixed fission products and radiochemical tracers used at LLNL and also obtains baseline data on global fallout. Air filter results indicate there were no significant gamma emitting isotopes detected as a result of LLNL activities.

Table 5-4 in the Data Supplement shows the concentrations of airborne plutonium-239+240 on air filters from the LLNL perimeter locations. Of the over 80 samples analyzed for plutonium along

Table 5-2. Beryllium-7 activity in air particulate samples for the Livermore site and Site 300 composites, 2001

Month	LLNL Composite ^(a) (10 ⁻³ Bq/m ³)	Site 300 Composite ^(b) (10 ⁻³ Bq/m ³)
Jan	0.641 ± 0.0293	1.04 ± 0.113
Feb	1.28 ± 0.0445	0.693 ± 0.0286
Mar	1.46 ± 0.0476	0.575 ± 0.0266
Apr	0.852 ± 0.0941	0.979 ± 0.0363
May	0.957 ± 0.0328	1.29 ± 0.0375
Jun	1.45 ± 0.159	2.26 ± 0.274
Jul	0.681 ± 0.0790	1.33 ± 0.148
Aug	0.436 ± 0.0624	0.886 ± 0.106
Sep	1.46 ± 0.166	2.25 ± 0.245
Oct	1.49 ± 0.164	1.47 ± 0.156
Nov	0.914 ± 0.100	1.06 ± 0.121
Dec	0.530 ± 0.0579	0.491 ± 0.0554
Median	0.936	1.05
IQR^(c)	0.782	0.527
Maximum	1.49	2.26
Percent of DCG	6.24×10^{-5}	7.00×10^{-5}
DCG (Bq/m³)	1500	

a Livermore composite consists of samples from SALV, MESQ, CAFE, MET, VIS, and COW. See **Figure 5-2**.

b Site 300 composite consists of samples from 801E, EOBS, ECP, GOLF, NPS, WCP, and WOBS. See **Figure 5-3**.

c IQR= Interquartile range

the perimeter in 2001, only 3 samples (one at each of these locations: CRED, MET, and VIS) detected plutonium. Of these samples, the highest value was detected during October at MET, located on the west perimeter of LLNL. This value of 9.5×10^{-7} Bq/m³ (2.6×10^{-17} Ci/m³) is still only 0.13% of the DCG (7.4×10^{-4} Bq/m³). The sample for the following month for MET was well within the historical range for this location. The annual median plutonium activity for this location and all perimeter locations was 4.7×10^{-9} Bq/m³ (1.3×10^{-19} Ci/m³) or 0.0006% of the DCG.



Table 5-5 in the Data Supplement shows the monthly plutonium-239+240 data for the Livermore Valley samples. Over 100 samples were analyzed for plutonium from off-site locations. Two downwind samples and six upwind samples detected plutonium. The highest downwind detection of 7.3×10^{-7} Bq/m³ was from the October sample located at TANK, representing 0.10% of the DCG. The highest upwind detection was also collected during October from the FIRE location and registered 1.2×10^{-7} Bq/m³ or 0.02% of the DGC.

The maximum plutonium values in Tables 5-4 and 5-5 of the Data Supplement were further investigated. Since the analytical process involves total consumption of the air filter, reanalysis is not possible. To investigate high composite values on our filters, weekly gross alpha and gross beta (GAB) data for the same period are checked. These GAB data for the high plutonium composite showed no significant increase. In addition, all data for plutonium in the following month returned to typical historical values.

Figure 5-5 shows the monthly median plutonium-239+240 results for the Livermore locations. While fewer air samples positively detected plutonium in 2001 compared to 2000, their annual median values were similar. The highest values for all areas of interest occurred during October, which is typical for particulate data with low activity and usually the result of resuspended mass particle buildup. LLNL is investigating the effect of particle loading and its effect on detected activities.

Figure 5-6 shows the historical annual median concentrations of plutonium-239+240 for locations SALV (on site) and FCC (off site) from 1982 to 2001. The graph also plots the current achievable detection limit. Data below the detection limit is an estimated activity value, meaning the value is somewhere between the reported estimated value and

zero. Location FCC represents an upwind background location, and SALV represents a perimeter location. The annual median concentration for FCC (9.6×10^{-9} Bq/m³) is the highest annual median value from an off-site location in the Livermore Valley and represents 0.001% of the DCG.

Figure 5-6 uses a log scale, and for the years when a negative median concentration was calculated, the lowest positive value was plotted. The higher values in the past at SALV may be attributed to historical activities at LLNL. The general downward trend at both locations is likely the result of decreasing residual global fallout. The apparent increase in the annual median at both locations in 2000 and 2001 is most likely the result of the change in the analytical laboratory. (Changes in the analytical laboratories often result in changes to the minimum detection limit.)

As the result of a network assessment and reduced operations involving uranium, Livermore perimeter site-specific uranium analysis was eliminated because there are no significant sources of uranium on site. Instead, a composite from six perimeter locations (CAFE, COW, MESQ, MET, SALV, and VIS) is created to determine uranium activities at LLNL while specific locations at Site 300 receive uranium analysis. The Livermore composite and Site 300 data are shown in Table 5-3. Only one sample for the Livermore composite had positive results for both uranium-235 and uranium-238 and this sample had uncertainties.

Site 300 data are discussed in the “Site 300” section of this chapter.

The low-volume radiological air sampling locations FCC and HOSP have annual medians for gross alpha and gross beta activity of 3.6×10^{-5} Bq/m³ (9.7×10^{-16} Ci/m³) and 5.4×10^{-4} Bq/m³ (1.5×10^{-14} Ci/m³), respectively. (See Data Supplement Table 5-6 for monthly median data.)

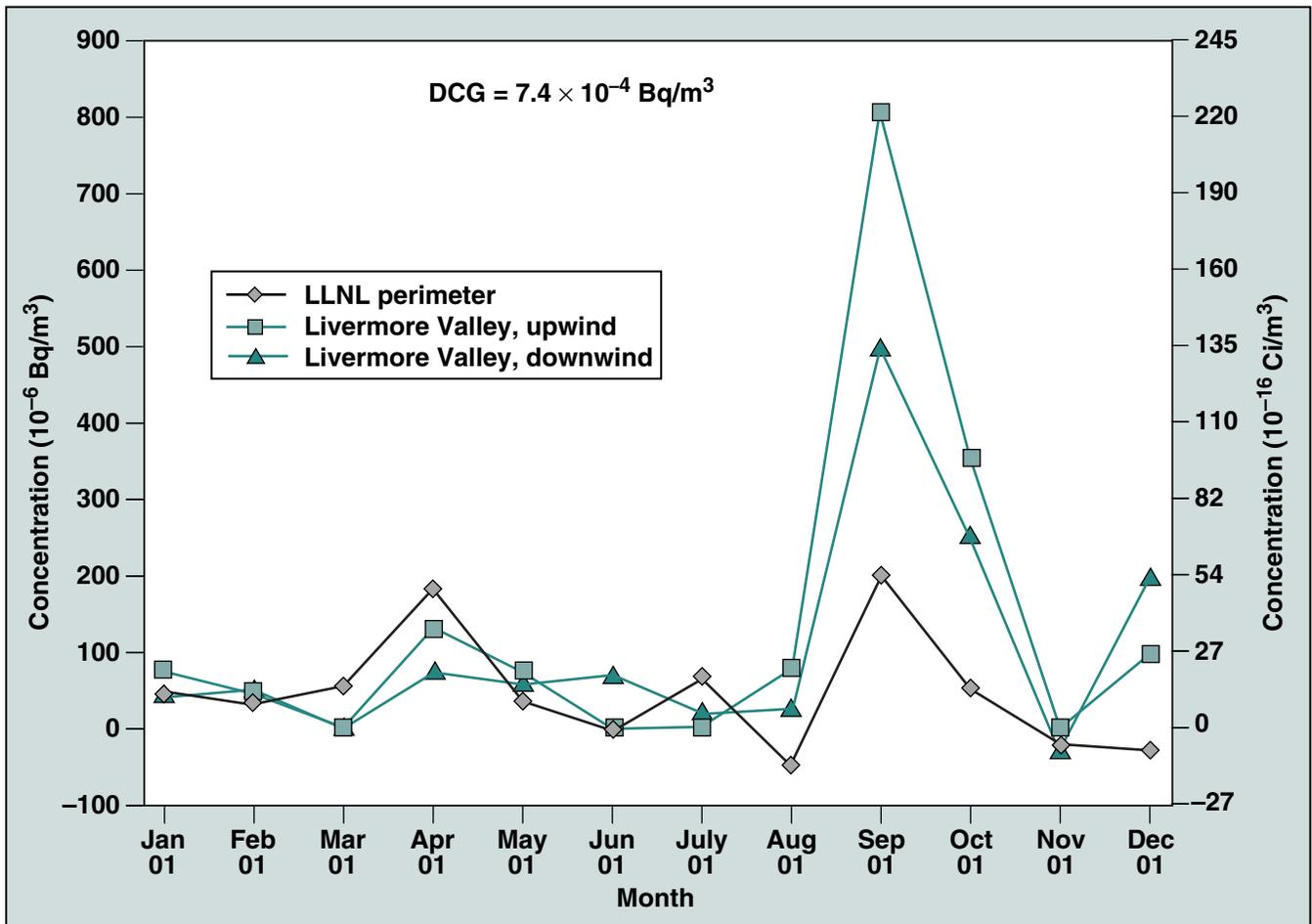


Figure 5-5. Monthly median concentrations of plutonium-239+240 in air particulate samples, 2001

These gross alpha values are similar to those reported from the high-volume sampling systems at the same locations.

Tritium data presented in Table 5-4 summarize the biweekly tritium data presented in Tables 5-7, 5-8, 5-9 and 5-14 of the Data Supplement. Locations are grouped by expected concentrations of tritium. The highest concentrations of tritium are from samplers on the Livermore site near locations of diffuse tritium (B292, B331, B514, and B624). The sources of tritium in these locations are mostly stored containers of tritium waste or tritiated contaminated equipment, but B292 is near a pine tree acting as a diffuse source of tritium because its

roots are growing in water contaminated with tritium from an underground retention tank that leaked (see Chapter 11). Median concentrations for 2001 from all the diffuse-source samplers are lower than those from 2000 when uncorrected data are compared. Corrected concentrations of tritium that account for dilution by bound water in silica gel were only calculated for 2001. Because the corrected concentrations are about 1.6 times higher than uncorrected concentrations, a comparison of trends can only be made between uncorrected data from 2000 and uncorrected data from 2001.

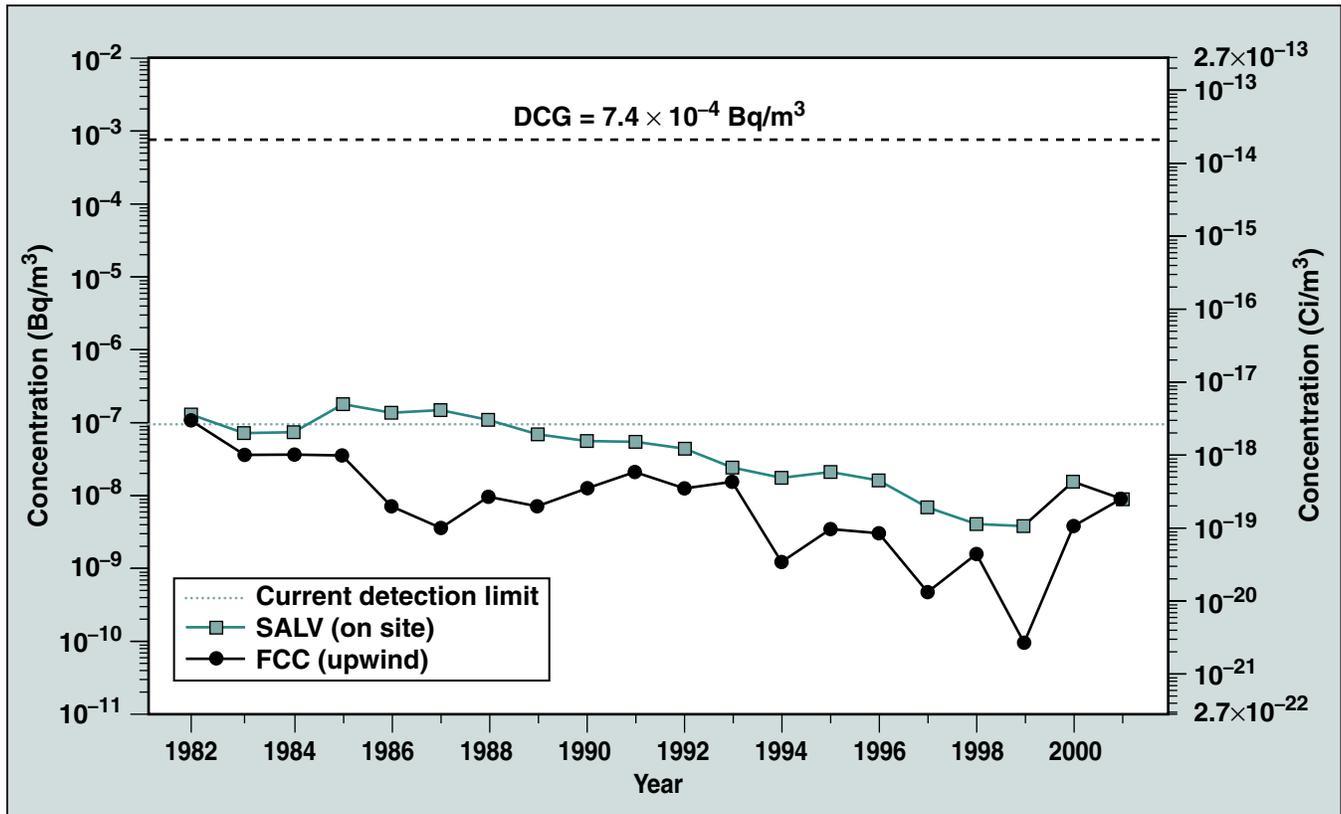


Figure 5-6. Calculated annual median concentrations of plutonium-239+240 for SALV and FCC with current detection limit and DCG identified, 2001

Samplers on the perimeter of the Livermore site exhibit the next highest air tritium concentrations, which are much lower than those at the locations of the diffuse sources. Of the perimeter locations, POOL exhibits the highest concentrations (Table 5-7, Data Supplement), and yet the POOL results are statistically different at the 5% significance level (Games-Howell 1976) from those of the sampler at B292, which has the lowest concentrations of the diffuse-source samplers. Median concentrations for 2001 for all the perimeter locations are uniformly less than those for 2000 when uncorrected results are compared. This corresponds to lower emissions from the Tritium Facility as well as from all the diffuse sources.

Perimeter concentrations for 2001 (even when data from POOL are omitted) are statistically higher than concentrations of tritium in air from the Livermore Valley. Sampling locations in the Livermore Valley demonstrate that LLNL tritium has an insignificant impact past the perimeter fence. Seventy-six percent of the Valley samples were below the limits of detection. The uncorrected median concentrations for the Valley locations for 2001 are uniformly lower than those for 2000 except for HOSP. Because all median concentrations from the Valley samplers are less than detection limits for 2001 and 2000, with the exception of ZON7, meaningful comparison of results cannot be made. When HOSP and Site 300 concentrations for 2001 are compared, there is no statistical

Table 5-3. Summary of uranium mass concentration in air samples, 2001

Location ^(a)	Uranium-235 ($10^{-7} \mu\text{g}/\text{m}^3$) ^(b)				Uranium-238 ($10^{-5} \mu\text{g}/\text{m}^3$) ^(c)			
	Median	IQR ^(d)	Maximum	Percent of DCG ^(e)	Median	IQR ^(d)	Maximum	Percent of DCG ^(e)
801E	4.06	6.84	58.2	0.000864	3.51	7.31	70.3	0.0117
COHO	3.90	4.75	25.0	0.000830	2.74	2.44	8.18	0.00913
ECP	2.96	12.0	36.5	0.000630	2.60	6.05	6.86	0.00865
EOBS	4.71	9.21	46.0	0.00100	1.30	7.27	68.9	0.00433
GOLF	-0.355	8.62	16.5	0.00351	1.84	1.64	8.61	0.00612
NPS	5.14	17.3	47.7	0.00109	0.891	3.78	66.5	0.00297
TFIR	4.86	9.05	21.1	0.00103	5.08	6.43	14.1	0.0169
WCP	-0.170	4.88	26.8	0.00570	3.44	1.14	47.7	0.0115
WOBS	0.230	5.78	22.9	0.0000490	2.93	3.76	32.9	0.00977
Livermore composite	-6.81	5.16	8.90	0.00189	-5.39	6.15	0.100	0.000390

Note: The negative values occur when the instrument or filter background median is greater than sample activity. See [Chapter 14](#).

- a See [Figure 5-3](#) for sampling locations at Site 300. Livermore composite consists of samples from CAFE, COW, MESQ, MET, SALV, and VIS ([Figure 5.1](#)).
- b Uranium-235 activities in Bq/m^3 can be determined by dividing the mass in $\mu\text{g}/\text{m}^3$ by 12.5.
- c Uranium-238 activities in Bq/m^3 can be determined by dividing the mass in $\mu\text{g}/\text{m}^3$ by 80.3.
- d IQR = Interquartile range
- e Derived Concentration Guides (DCG) for activity in air are $0.3 \mu\text{g}/\text{m}^3$ for uranium-238 and $0.047 \mu\text{g}/\text{m}^3$ for uranium-235. Percent DCG was calculated from median value, unless median value was negative; in such cases percent DCG was calculated from the maximum value.

Table 5-4. Tritium in air samples, 2001

Sampling locations ^(a)	Detection frequency ^(b)	Median	Interquartile range (mBq/m^3)	Maximum (mBq/m^3)	Percent of DCG ^(c)	Median Dose ^(d) (nSv)
Diffuse on-site sources	96/101	270	1300	4600	7.3×10^{-3}	57
Livermore perimeter	130/172	35	44	170	9.4×10^{-4}	7.3
Livermore Valley	34/142	8.0	17	52	2.2×10^{-4}	1.7
Site 300	2/25	-2.5	13	17	$1.35 \times 10^{-5(e)}$	0.10 ^(e)

- a See [Figures 5-1](#), [5-2](#), and [5-3](#) for sample locations.
- b Detection frequency is shown as the number of samples with results above the detection limit relative to the total number of samples.
- c DCG = Derived Concentration Guide of $3.7 \times 10^6 \text{ mBq}/\text{m}^3$ for tritium in air. Percent is calculated from the median concentration.
- d Dose is calculated for inhalation (see [Appendix A](#)).
- e Percent DCG and dose were derived from the lowest positive air concentration, because the median was negative.



difference between them. Both locations may be considered background locations unaffected by local sources of atmospheric tritium.

Beryllium in Air

The median concentrations of airborne beryllium for the Livermore site perimeter sampling locations are plotted in [Figure 5-7](#). (See Data Supplement [Table 5-10](#) for monthly data.) The highest value of 31.5 pg/m^3 was found in the August composite at location CAFE. The median concentration for this location is 16.7 pg/m^3 , 0.17% of the

monthly ambient concentration limit (ACL) of $10,000 \text{ pg/m}^3$ established by the Bay Area Air Quality Management District (BAAQMD) and the EPA. The median for all Livermore perimeter samples for 2001 was 11.6 pg/m^3 (0.12% of the ACL).

[Figure 5-8](#) is a plot of the median beryllium concentration at the Livermore site perimeter from 1975 through 2001. The decrease in median concentration in 1993 and the slight increase in 1999 were the result of a change in the analytical

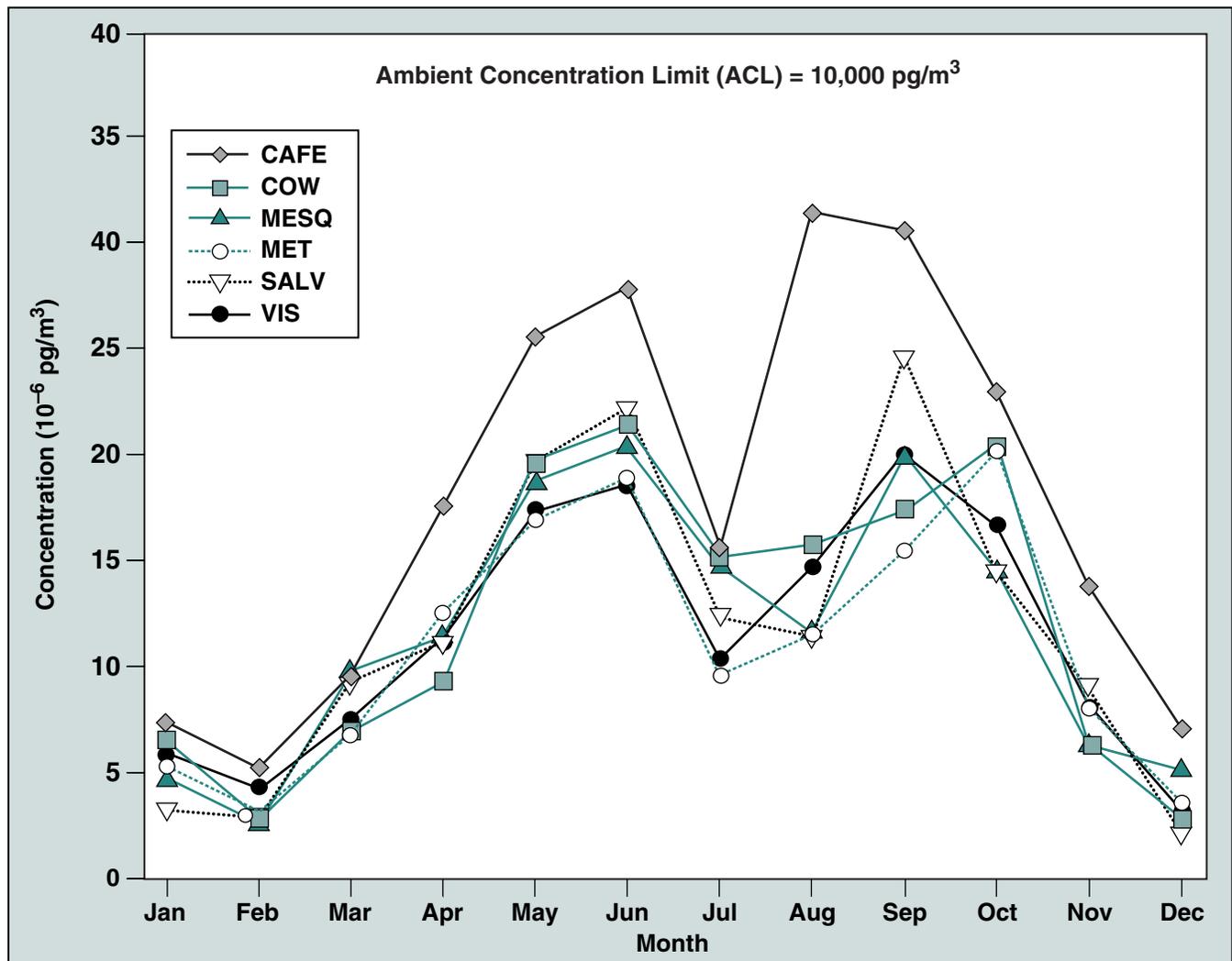


Figure 5-7. Monthly median concentration of beryllium in air particulate samples

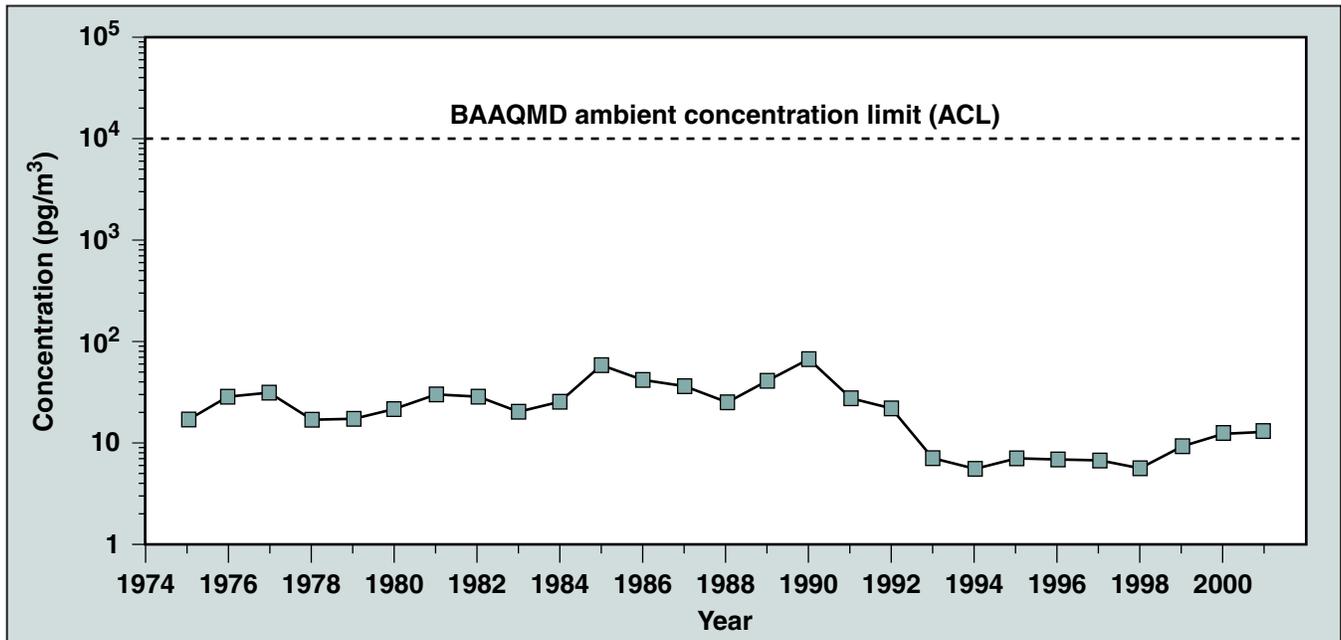


Figure 5-8. Median concentration of beryllium in air particulate samples taken at the Livermore site perimeter, 1975–2001

laboratory used to perform this analysis. (Changes in the analytical laboratories often result in changes to the minimum detection limit.) The overall median concentration from 1975 through 2001 was calculated to be 0.18% of the ACL.

Site 300

Airborne Radioactivity

Table 5-11 in the Data Supplement shows the monthly gross alpha and gross beta median, IQR, and maximum for sampling locations at Site 300, as well as the monthly median for all Site 300 locations. The monthly median gross alpha and gross beta concentrations are plotted in Figure 5-4 along with the Livermore areas of interest.

The Site 300 gross alpha and gross beta results show a similar pattern to those found at the Livermore site. Generally, Site 300 has the highest median values for both gross alpha and gross beta.

This is attributed to the abundance of uncovered soils found at the site. Site 300 has fewer structures and buildings and less pavement, compared to Livermore locations, thereby enabling greater mass loading of resuspended particles on air filters. The median gross alpha activity is 6.3×10^{-5} Bq/m³ (1.7×10^{-15} Ci/m³). The median gross beta activity is 5.1×10^{-4} Bq/m³ (1.4×10^{-14} Ci/m³). These values are similar to those obtained from monitoring data during the past several years.

The primary sources of observed gross alpha and gross beta activity are naturally occurring radioisotopes of uranium and thorium, their decay products, and any residual fallout from atmospheric weapons testing and the 1986 Chernobyl reactor accident.

Monthly Site 300 composite samples are scanned for over 40 gamma emitting nuclides, and like the Livermore perimeter samples, only beryllium-7 was



consistently detected. **Table 5-2** lists the annual median activity, IQR, maximum, the percent of the DCG, as well as the DCG, for beryllium-7 from Site 300.

The monthly median value for beryllium-7 from Site 300 composites was 1.0×10^{-3} Bq/m³. Sodium-22 was detected in 2 samples (January and November) with the highest value of 6.3×10^{-7} Bq/m³ (less than 0.000002% of the DCG). The May composite had a positive detection of radium-228 (4.1×10^{-6} Bq/m³) which was 0.01% of the DCG. No other gamma isotopes were detected in the Site 300 composite samples. Of the nuclides detected, all are naturally occurring.

A composite of all Site 300 onsite locations is analyzed for plutonium-239+240 (see Data Supplement **Table 5-12** for monthly data). The highest concentration of plutonium-239+240 was recorded in the March composite at a level of 9.8×10^{-9} Bq/m³ (5.1×10^{-19} Ci/m³). This value was a calculated value with an uncertainty of 100% and not considered a detection (see **Chapter 14** for further details on detection criteria).

As the result of a network assessment, and because Site 300 has uranium sources (from explosive testing and resuspension of this residue in these soils), the uranium analysis was expanded to all Site 300 locations (including TFIR). **Table 5-3** shows the median concentration of uranium-235 and uranium-238 for the air samples from the Site 300 network. (See Data Supplement **Table 5-13** for monthly data.) The highest concentrations registered 58×10^{-7} µg/m³ for uranium-235 and 70×10^{-5} µg/m³ for uranium-238. These were observed in July at location 801E and represent less than 0.02% of the

DCG for both isotopes. High values were also reported during July at EOBS and NPS. All three locations are positioned north to northeast from Bunker 850 where depleted uranium was used in a test shot in late July.

Table 5-4 shows the median concentration of tritium in air that was observed at the sampling location at Site 300 (see Data Supplement **Table 5-14** for biweekly data). Site 300 concentrations are mostly below the detection limit and most likely represent background levels of tritium unaffected by local sources of tritium. Site 300 air tritium concentrations are no different statistically than those from the Livermore Valley location, HOSP.

Beryllium in Air

The monthly median beryllium concentrations are shown in **Figure 5-7** with the Livermore perimeter locations. (See Data Supplement **Table 5-15** for monthly data.) The highest beryllium concentration of 33.1 pg/m³ occurred in October at location 801E. The annual median concentration for this location is 15.8 pg/m³ or 0.16% of the federal and state ambient concentration limit, which is 10,000 pg/m³. The highest monthly beryllium median was reported at TFIR at 21.4 pg/m³. This is typical and believed to be the result of the location of the sampler which is situated in downtown Tracy and, therefore, accumulates more industrial and urban air pollutants than the other Site 300 locations.

Environmental Impact

The environmental impacts from both radioactive and nonradioactive effluents are described in this section.



Radioactive Materials

LLNL operations involving radioactive materials had little impact on radionuclide concentrations in ambient air during 2001. Radionuclide concentrations in air at the Livermore site and in the Livermore Valley were well below the levels that would cause concern for the environment or public health according to existing regulatory standards.

The diffuse tritium sources at B292, B331, B514, and B624 had a small, localized effect with minimal impact, if any, on the public. Any potential dose received by a member of the public from the diffuse sources is included in doses calculated for tritium concentrations at the Livermore site perimeter (see Table 5-8, Data Supplement). Tritium concentrations at the Livermore site perimeter, as well as off-site, were uniformly lower in 2001 than in 2000 when uncorrected data are compared. A maximum dose of 35 nSv/y to a member of the public at the Livermore site perimeter can be estimated based on the extraordinarily conservative assumption that the maximum biweekly corrected concentration (170 mBq/m^3) is maintained for an entire year and that a member of the public breathes that concentration for the entire year. This improbable inhalation dose to the public is just 0.035% of NESHAPs standard of 0.1 mSv/y arising as a result of releases of radionuclides to air from DOE facilities.

Even though the July samples detected uranium activity that was likely produced from a test shot, the concentrations of radionuclides measured around Site 300 and in the City of Tracy were well below the levels that would cause concern for the environment or public health according to existing regulatory standards.

Nonradioactive Materials

The concentrations of beryllium at both sites can be attributed to resuspension of surface soil containing naturally occurring beryllium. Local soils contain approximately 1 ppm of beryllium, and the air of the Livermore area and the Central Valley typically contains 10 to $100 \text{ }\mu\text{g/m}^3$ of particulates. Using a value of $50 \text{ }\mu\text{g/m}^3$ for an average dust load and 1 ppm for beryllium content of dust, a conservative airborne beryllium concentration of 50 pg/m^3 can be predicted. The overall annual medians for the Livermore site and Site 300 are 11.6 pg/m^3 and 11.7 pg/m^3 , respectively. These data are lower than predicted, well below standards, and do not indicate the presence of a threat to the environment or public health.



SEWERABLE WATER MONITORING

*Henry E. Jones
Michael A. Revelli
Robert A. Williams*

*Allen R. Grayson
Shari L. Brigdon
Lily Sanchez*

Introduction

In 2001, the Livermore site discharged an average of 0.88 million liters (ML) per day of wastewater to the City of Livermore sewer system, an amount that constituted 4.0% of the total flow to the system. This volume includes wastewater generated by Sandia National Laboratories/California, which is discharged to the LLNL collection system and combines with LLNL sewage before it is released at a single point to the municipal collection system (**Figure 6-1**).

In 2001, Sandia/California generated approximately 12% of the total effluent discharged from the Livermore site. LLNL's wastewater contains sanitary sewage and industrial wastewater and is discharged in accordance with permit requirements and the City of Livermore Municipal Code, as discussed below in the "**Pretreatment Discharges**" and "**Categorical Discharges**" sections.

The effluent is treated at the Livermore Water Reclamation Plant (LWRP), which is part of the Livermore-Amador Valley Wastewater Management Agency. The treated sanitary wastewater is transported out of the valley through a pipeline and discharged into San Francisco Bay. A small portion (~20%) of this treated wastewater is used for fire suppression and summer irrigation of the municipal golf course adjacent to the LWRP.

LLNL receives water from two suppliers. LLNL's primary water source is the Hetch-Hetchy Aqueduct. Secondary or emergency water deliveries are taken from the Alameda County Flood Control and Water Conservation District Zone 7. This water is a mixture of groundwater and water from the South Bay Aqueduct of the State Water Project. Water quality parameters for the two sources are obtained from the suppliers and are used to evaluate compliance with the discharge permit conditions that limit changes in water quality between receipt and discharge.



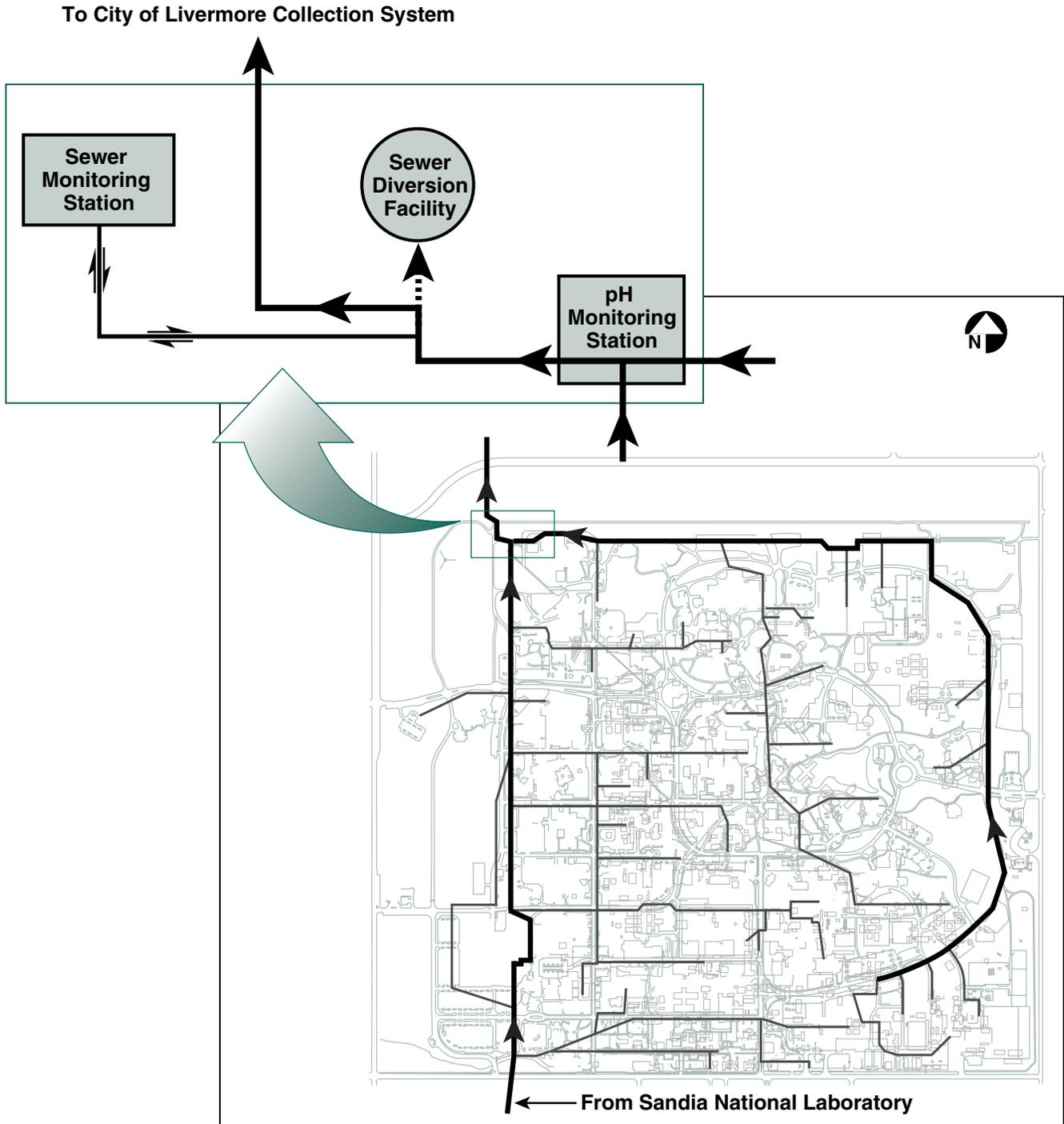


Figure 6-1. LLNL sanitary sewer system, monitoring stations, and diversion facility



Preventive Measures

Administrative and engineering controls at the Livermore site are designed to prevent potentially contaminated wastewater from being discharged directly to the sanitary sewer. Waste generators receive training on proper waste handling. LLNL Environmental Protection Department (EPD) personnel review facility procedures and inspect processes to ensure appropriate discharges. Retention tanks collect wastewater from processes that might release contaminants in quantities sufficient to violate permit conditions or disrupt operations at the LWRP. Wastewater that cannot be discharged into one or more of the surface water collection units at LLNL's Experimental Test Site (Site 300) is transported to LLNL's Livermore site and managed under Livermore site retention tank administrative controls. Groundwater (generated from startup operations associated with new, portable groundwater treatment units, tests of experimental treatment units, and maintenance of existing treatment facilities) is analyzed for pollutants of concern and must meet permitted criteria, or LWRP approval must be obtained before it can be discharged to the sanitary sewer. Finally, to verify the success of training and control equipment, wastewater is sampled and analyzed not only at the significant points of generation, as defined by type and quantity of contaminant generated, but also at the point of discharge to the municipal sewer system.

For facilities with installed retention tank systems, collected wastewater is discharged to the sanitary sewer only if analytical laboratory results show that pollutant levels are within allowable limits (Grandfield 1989). LLNL has developed internal guidelines to ensure that sewer effluent for the entire site complies with LLNL's wastewater discharge permit. The process of wastewater generation and discharge frequency from retention tanks varies over time, depending upon the process.

During 2001, there were approximately 33 waste retention tank systems in use at the Livermore site, with an average of 13 wastewater retention tanks discharged each month, averaging a volume of 8660 L per tank.

Processes that discharge to the sanitary sewer are subject to the general pretreatment self-monitoring program specified in the Wastewater Discharge Permit issued by the LWRP and, as such, are managed by LLNL using guidelines as applied at the point of discharge into the LLNL sewer.

If pollutant levels exceed concentrations that would result in a violation of LLNL's LWRP permit, the wastewater is either treated to reduce pollutants to levels that preclude a permit violation, or it is shipped to an off-site treatment or disposal facility. Liquids containing radioactivity are handled on site and may be treated using processes that reduce the activity to levels well below those required by DOE Order 5400.5, or they are shipped to an off-site treatment or disposal facility.

For the year as a whole, the monitoring data reflect the success of LLNL's discharge control program in preventing any adverse impact on the operations of Livermore's treatment plant and are consistent with past values.

Monitoring

Monitoring at the Sewer Monitoring Station

LLNL's sanitary sewer discharge permit requires continuous monitoring of the effluent flow rate and pH. Samplers collect flow-proportional composite samples and instantaneous grab samples that are analyzed for metals, radioactivity, toxic chemicals, and water-quality parameters. In addition, as a best management practice, the outflow to the municipal collection system is sampled continuously and analyzed in real time for conditions that might upset the LWRP treatment



process or otherwise impact the public welfare. The effluent is continuously analyzed for pH, regulated metals, and radioactivity. If concentrations above warning levels are detected, an alarm is registered at the LLNL Fire Dispatcher's Station, which is attended 24 hours a day, and the site effluent is diverted to the Sewer Diversion Facility (SDF). The monitoring system provides a continuous check on sewage control, and the LWRP is notified of contaminant alarms. Trained staff respond to all alarms to evaluate the cause and take appropriate action.

Monitoring at the Upstream pH Monitoring Station

In addition to the continuous monitoring at the Sewer Monitoring Station (SMS), LLNL monitors pH at the upstream pH Monitoring Station (pHMS) (see [Figure 6-1](#) for a system diagram). The pHMS continuously monitors pH between 7 a.m. and 7 p.m. during the workweek and diverts pH discharges outside the permitted 5-to-10 range to the SDF. The pHMS duplicates the pH monitoring and diversion capabilities of the SMS, but because it is located upstream of the SDF it is able to initiate diversion earlier. Earlier detection allows LLNL to divert all of the unpermitted site effluent detected by the pHMS.

Diversion System

LLNL operates and maintains a diversion system that activates automatically when either the SMS continuous monitoring system or the pHMS sounds an alarm. For SMS-activated alarms, the SDF ensures that all but the first few minutes of the potentially affected wastewater flow is retained at LLNL, thereby protecting the LWRP and minimizing any required cleanup. When the SDF is activated by the pHMS for pH excursions, even the first few minutes of affected wastewater flow are retained. Up to 775,000 L of potentially contaminated sewage can be held pending analysis to

determine the appropriate handling method. The diverted effluent may be returned to the sanitary sewer (if it meets LLNL's wastewater discharge permit limits), shipped for off-site disposal, or treated at LLNL's Hazardous Waste Management (HWM) Facility. All the diverted sewage in 2001 was returned to the sanitary sewer.

Pretreatment Discharges

The general pretreatment regulations establish both general and specific standards for the discharge of prohibited substances that apply to all industrial users (40 CFR 403.5). These regulations apply even if LLNL is subject to other federal, state, or local pretreatment standards. The pretreatment standards contain prohibitions intended to protect the LWRP and its operations from interference with its treatment processes or pass-through that would cause the LWRP to violate its own effluent limitations. The LWRP, under the authorization of the San Francisco Bay Regional Water Quality Control Board (SFBRWQCB), requires self-monitored pretreatment programs at both the Livermore site and Site 300. The sampling and monitoring of nondomestic, industrial sources covered by pretreatment standards defined in 40 CFR 403 are required in the 2001-2002 Wastewater Discharge Permit No. 1250 issued for the discharge of wastewater from LLNL into the City of Livermore sewer system.

Permit 1250 lists all the self-monitoring parameters that are applied at the SMS before wastewater enters the municipal collection system at LLNL's effluent outfall (see [Figure 6-1](#)). Parameters with numerical limits are listed in [Table 6-1](#). The additional discharge limits shown in [Table 6-1](#) are discussed in the "Categorical Discharges" and "Discharges of Treated Groundwater" sections. Other required parameters such as flow rate, biological oxygen demand, total dissolved solids,

Table 6-1. Permit discharge limits for nonradioactive pollutants in LLNL wastewaters

Parameter	Permit discharge limits			
	Permit 1250			Permit 1510G
	Outfall ^(a)	Metal finishing ^(b)	Electric component ^(b)	Treated groundwater
Metals (mg/L)				
Arsenic	0.06	— ^(c)	0.83	0.06
Cadmium	0.14	0.07	— ^(c)	0.14
Chromium (total)	0.62	1.71	— ^(c)	0.62
Copper	1.0	2.07	— ^(c)	1.00
Lead	0.20	0.43	— ^(c)	0.20
Mercury	0.01	— ^(c)	— ^(c)	0.01
Nickel	0.61	2.38	— ^(c)	0.61
Silver	0.20	0.24	— ^(c)	0.20
Zinc	3.0	1.48	— ^(c)	3.00
Organics (mg/L)				
TTO ^(d)	1.00	2.13	1.37	1.00
Other (mg/L)				
Cyanide ^(e)	0.04	0.65	— ^(c)	0.04 ^(f)
Oil and grease	100	— ^(c)	— ^(c)	— ^(g)
pH (pH units)	5–10	— ^(c)	— ^(c)	5–10

- a These standards apply at the SMS (the point of discharge to the municipal sewer). All other standards in this table apply at the point of discharge into LLNL's sanitary sewer system.
- b Values shown for these categorical standards were specified by EPA. By regulation, the EPA or City of Livermore limit is used, whichever is lower. The internal limits in **Table 6-1** are applied by LLNL where no other standard is specified.
- c There is no specific categorical limit for this parameter; therefore, the **Table 6-1** internal discharge limits apply.
- d Total toxic organics (TTO) is defined by the Livermore Municipal Code as the sum total of all detectable organic compounds that are on EPA's current priority pollutant list and that are present in concentrations of 0.01 mg/L or greater. Analysis using EPA Methods 624 and 625 satisfies this requirement. A listing of the specific compounds included may be found in the [Data Supplement, Chapter 6](#).
- e Limits apply to cyanide discharges other than cyanide salts. Cyanide salts are classified by the State of California as "extremely hazardous waste" and cannot be discharged to the sewer.
- f Although Permit 1510G lists a discharge limit for cyanide, sample collection is not required by the self-monitoring program.
- g Permit 1510G does not list a discharge limit for oil and grease.



total suspended solids, and tributyltin are also monitored at the SMS but have no specific numerical limits.

In 2001, LLNL only received one Notice of Violation (NOV) from the LWRP for exceeding permit limits in 2001. (LLNL received one NOV from the LWRP in early 2001 for a discharge of chromium and nickel in 2000 that exceeded permit limits.) The only effluent discharge limit for wastewater that was exceeded was the discharge limit for lead.

Categorical Discharges

The Environmental Protection Agency (EPA) publishes categorical standards as regulations separate from the general pretreatment regulations and developed for broad categories of specific industrial processes determined to be the most significant contributors to point-source water pollution. These standards contain specific numerical limits for the discharge of industry-specific pollutants from individual processes. The number of processes at LLNL using these pollutants is subject to change as programmatic requirements dictate. During 2001, the LWRP identified 14 specific LLNL wastewater-generating processes that fall under the definition of two categorical standards: Electrical and Electronic Components (40 CFR 469), and Metal Finishing (40 CFR 433). The discharge limits for these standards are shown in [Table 6-1](#). Under the terms in Permit 1250, only those processes that discharge to the sanitary sewer require sampling, inspection, and reporting. Three of the 14 identified processes meet these criteria. In 2001, LLNL analyzed samples for all regulated parameters from these three processes and demonstrated compliance with all Federal Categorical Discharge limits.

The first of the three categorical processes that discharge directly into the sanitary sewer system is an abrasive jet machine (or water-jet) that is

regulated under the Metal-Finishing Point Source Category; the filtered water from this process is discharged to the sanitary sewer. In January 2001, LLNL received a Notice of Violation from the LWRP for discharges from this process on November 2, 2000. The LWRP conducted a corrective action review and determined that no fines or penalties were required. This event was fully described in Table 2-7 in the *LLNL Environmental Report 2000*.

The other two discharging categorical processes are both regulated under the Federal Electrical and Electronic Component Point Source Category. One is a series of processes clustered within a single building that houses research-scale microfabrication laboratories used for developing prototype semiconductor devices. These laboratories discharge into a building wastewater retention system, and because they are housed within the same building with no diluting flow, they share a single point of compliance. The other categorical process is a small gallium arsenide cutting operation; this process discharges directly to the sanitary sewer.

The nondischarging processes, all regulated under the Metal-Finishing Point Source Category (40 CFR 433), were printed circuit board manufacturing, electrolysis plating, chemical etching, electroplating, anodizing, coating, electrical discharge machining, and abrasive jet machining (water-jet). The wastewater from these processes was contained for removal and off-site shipment by LLNL's HWM Division.

Discharges of Treated Groundwater

LLNL's groundwater discharge permit (1510G 2001) allows treated groundwater from site-wide cleanup activities under the Comprehensive Environmental Response, Compensation and Liability



Act (CERCLA) of 1980 to be discharged to the City of Livermore sanitary sewer in compliance with [Table 6-1](#) effluent limitations taken from the Livermore Municipal Code.

During 2001, the volume of groundwater discharged to the sanitary sewer was approximately 30,945 L. Two groundwater discharges occurred during 2001. The first was related to well purging and maintenance of an existing treatment facility (TFD); the second contained groundwater from the lower zone, discharged directly to the sanitary sewer during an off-site pump test (well W-1701). Both events were separately sampled and discharged to the sewer in 2001, all in compliance with self-monitoring permit provisions and discharge limits of Permit 1510G. Monitoring data are presented in the Data Supplement, [Chapter 6](#).

Radioactive Pollutants in Sewage Monitoring Results

LLNL determines the total radioactivity released from tritium, alpha emitters, and beta emitters based either on the measured radioactivity in the effluent or on the limit of sensitivity, whichever is higher (see [Table 6-2](#)). The 2001 combined releases of alpha and beta sources was 0.32 GBq (0.0086 Ci). The combined total is based on the alpha and beta results shown in [Table 6-2](#). The tritium total was 4.9 GBq (0.13 Ci), and the annual mean concentration of tritium in LLNL sanitary sewer effluent was 0.014 Bq/mL (0.38 pCi/mL).

Summary results for tritium measured in the sanitary sewer effluent from LLNL and LWRP are presented in [Table 6-3](#).

The monthly tritium numbers are based on the flow-weighted average of the individual daily sample results for a given month. The total annual result is based on the multiplication of each daily

Table 6-2. Estimated total radioactivity in LLNL sanitary sewer effluent, 2001

Radioactive emitter	Estimate based on effluent activity (GBq) ^(a)	Limit of sensitivity (GBq)
Tritium	4.9	3.3
Alpha sources	0.061	0.034
Beta sources	0.262	0.040

^a 37 GBq = 3.7×10^{10} Bq = 1 Ci

sample result or the limit of sensitivity, whichever is greater, by the total flow volume over which the sample was collected, and summing up over all samples. (All other total annual results presented in this chapter for radioactive emitters are also calculated conservatively; the limit of sensitivity or minimum detectable concentration is used to determine the total annual activity when the limit of sensitivity is greater than the sample result.) Also included in the table are fractions of LWRP, Department of Energy (DOE), and 10 CFR 20 limits, which are discussed in the “[Environmental Impact](#)” section of this chapter.

The historical trend in the monthly average concentration of tritium is shown in [Figure 6-2](#). Also included in the figure are the limit of sensitivity (LOS) values for the tritium analysis and the DOE tritium limit (370 Bq/mL), which are discussed in the “[Environmental Impact](#)” section. The trend indicates a well-controlled tritium discharge, orders of magnitude below the DOE tritium limit. (Note that for 2000–2001 data, only results above the LOS are plotted.)

The concentrations of plutonium-239 and cesium-137 measured in the sanitary sewer effluent from LLNL and LWRP are presented in [Table 6-4](#). The plutonium and cesium numbers are the direct results of analyses of monthly composite samples of LLNL and LWRP effluent, and quarterly composites of LWRP sludge. At the


Table 6-3. Tritium in sanitary sewer effluents, LLNL and LWRP, 2001

Monitoring results			
	LLNL		LWRP
	Daily	Monthly average	Weekly
Maximum (Bq/mL)	0.370 ± 0.012 ^(a)	0.047 ^(b)	0.0097 ^(c)
Median (Bq/mL)	0.002	0.002	-0.0006
IQR ^(d) (Bq/mL)	0.005	0.001	0.004
LLNL annual total (GBq)	4.9		
Discharge limits for LLNL effluent			
	Discharge limit	Monitoring results as percentage of limit	
		Maximum	Median
LWRP permit daily (Bq/mL)	12	3.08	0.014
DOE 5400.5 monthly (DCG) ^(e) (Bq/mL)	370	0.013 ^(f)	0.0005 ^(f)
10 CFR 20 annual total (GBq)	185	2.6	

a This daily result is for a March sample; the detection limit for the analysis was 0.01 Bq/mL. See the Data Supplement, [Chapter 6](#), for all daily results.

b This is the monthly average for March. All monthly averages above limit of sensitivity (LOS) are plotted in [Figure 6-2](#).

c This is a weekly result for a June sample. The result was not above the detection limit (0.010 Bq/mL) for the analysis. None of the LWRP weekly monitoring results were greater than the detection limits for the analyses; a detection limit is the smallest concentration of radioactive material that can be detected with a large degree of confidence. (See [Chapter 14](#).) The detection limits ranged from 0.008 to 0.012 Bq/mL. See the Data Supplement, [Chapter 6](#), for all weekly results.

d IQR = Interquartile range.

e DCG = Derived Concentration Guide

f Monitoring results as a percentage of limit are calculated using LLNL monthly average results and the DOE annualized discharge limit.

bottom of the table, the total annual activity released is given by radioisotope. Also included in the table are fractions of DOE limits, discussed in the “[Environmental Impact](#)” section.

[Figure 6-3](#) shows the average monthly plutonium and cesium concentrations in sewage since 1992. For 2001, the annual mean concentration of cesium-137 was 3.2×10^{-6} Bq/mL (8.7×10^{-5} pCi/mL); the annual mean concentration of plutonium-239 was 3.5×10^{-7} Bq/mL (9.5×10^{-6} pCi/mL).

Environmental Impact

During 2001, no inadvertent discharges exceeded any discharge limits for release of radioactive materials to the sanitary sewer system.

In 1999, the Work Smart Standards (WSS) developed for LLNL became effective. Included in the WSS are the standards selected for sanitary sewer discharges. For radioactive material releases, complementary (rather than redundant) sections

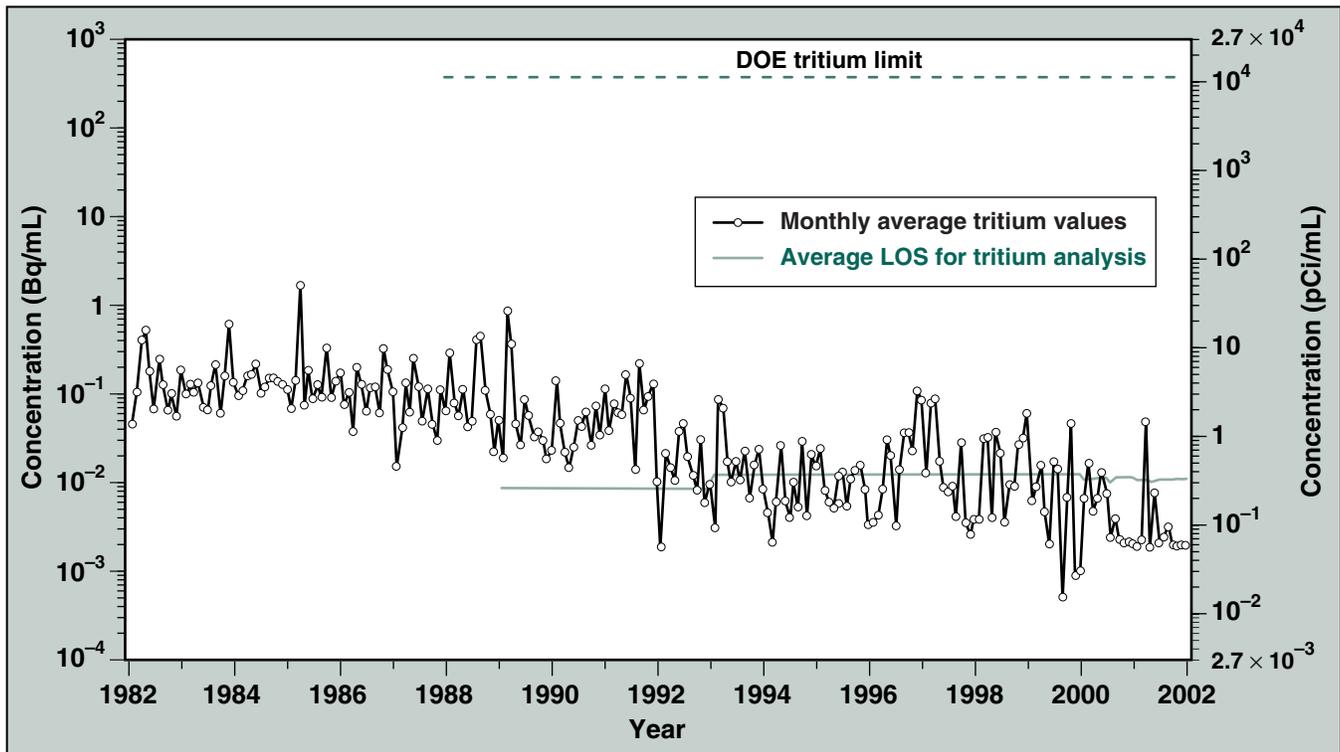


Figure 6-2. Historical trend in tritium concentration in LLNL sewage

from DOE Order 5400.5 and Title 10 of the Code of Federal Regulations, Part 20, are both part of the standards.

From DOE Order 5400.5, the WSS for sanitary sewer discharges include the criteria DOE established for the application of best available technology to protect public health and minimize degradation of the environment. These criteria (the Derived Concentration Guides, or DCGs) limit the concentration of each radionuclide discharged to publicly owned treatment works. If a measurement of the monthly average concentration of a radioisotope exceeds its specific concentration limit, LLNL is required to improve discharge control measures until concentrations are again below the DOE

limits. [Table 6-3](#) and [Table 6-4](#) include the DCGs for the specific radioisotopes of most interest at LLNL.

The median monthly average concentration of tritium in LLNL sanitary sewer effluent was 0.0005% of the DOE DCG, and the maximum monthly average concentration of tritium was 0.013% of the DCG (see [Table 6-3](#)).

The annual average concentration of cesium-137 was 0.00057% of the DOE DCG; and the annual average plutonium-239 concentration was 0.000095% of the DOE DCG. These results are shown at the bottom of [Table 6-4](#).



Table 6-4. Cesium and plutonium in sanitary sewer effluents, LLNL and LWRP, 2001

Month	^{137}Cs ($\mu\text{Bq/mL}$)				^{239}Pu (nBq/mL)				^{239}Pu (mBq/dry g)	
	LLNL		LWRP		LLNL		LWRP		LWRP sludge ^(a)	
	Radio-activity	MDC	Radio-activity	MDC	Radio-activity	MDC	Radio-activity	MDC	Radio-activity	MDC
Jan	-0.81 ± 2.8	2.48	-0.818 ± 2.52	2.22	95.1 ± 23.2	9.58	5 ± 5.62	7.03		
Feb	8.03 ± 1.84	2.65	-0.559 ± 2.86	2.49	1890 ± 125	9.62	1.67 ± 5.4	8.84		
Mar	3.34 ± 2.65	2.5	-0.866 ± 2.42	2.08	381 ± 54	12.3	1.62 ± 4.37	8.18	0.183 ± 0.016	0.002
Apr	0.318 ± 2.63	2.36	1.13 ± 2.62	2.42	195 ± 33.4	6.81	8.62 ± 7.73	8.88		
May	1.27 ± 0.577	1.38	-0.67 ± 2.61	2.26	492 ± 54.4	9.77	-0.981 ± 7.59	11.8		
Jun	1.55 ± 2.82	2.62	0.803 ± 2.52	2.29	319 ± 29.5	7.33	-3.69 ± 10.6	13.4	0.525 ± 0.051	0.007
Jul	-0.0219 ± 2.8	2.48	0.0829 ± 2.32	2.06	105 ± 23	11.1	-0.836 ± 4.22	9.73		
Aug	-1.67 ± 2.65	2.21	0.0266 ± 2.56	2.28	171 ± 35.3	17.9	-3.1 ± 3.53	10.8		
Sep	1.62 ± 3.85	3.48	1.19 ± 3.65	3.29	174 ± 31.5	12.6	0.186 ± 6.22	13	0.243 ± 0.028	0.007
Oct	3.64 ± 3.85	3.57	-0.64 ± 3.3	2.88	136 ± 26	11.4	2.35 ± 5	8.84		
Nov	-0.84 ± 3.81	3.32	1.6 ± 3.59	3.25	92.5 ± 27	11.8	0.847 ± 3.92	7.44		
Dec	1.7 ± 3.77	3.45	0.777 ± 3.54	3.17	185 ± 35.1	9.92	2.15 ± 2.98	4.22	0.296 ± 0.037	0.009
Median	1.4		0.1		353		-1.23		0.27	
IQR ^(b)	2.33		1.53		206		3.07		0.13	
	$\mu\text{Ci/mL}^{(c)}$								$\mu\text{Ci/dry g}^{(c)}$	
Median	3.8×10^{-5}		1.5×10^{-6}		4.8×10^{-6}		-3.3×10^{-8}		0.0073	
IQR ^(b)	6.3×10^{-5}		4.1×10^{-5}		5.6×10^{-6}		8.3×10^{-8}		0.0034	
	Annual LLNL total discharges by radioisotope									
	^{137}Cs				^{239}Pu					
Bq/y	1.0×10^6				1.1×10^5					
Ci/y	2.8×10^{-5}				3.0×10^{-6}					
	Fraction of limit^(d)									
DOE 5400.5 DCG ^(e)	5.7×10^{-6}				9.5×10^{-7}					

Note: Results in this table are reported as radioactivity (the measured concentration and a $\pm 2\sigma$ counting uncertainty) along with the detection limit or minimum detectable concentration (MDC). A measure concentration exhibiting a 2σ counting uncertainty greater than or equal to 100% is considered to be a nondetection. See Chapter 14.

a Sludge from LWRP digesters is dried before analysis. The resulting data indicate the plutonium concentration of the sludge prepared by LWRP workers for disposal at the Vasco Road Landfill in Alameda County.

b IQR= Interquartile range

c $1 \text{ Ci} = 3.7 \times 10^{10} \text{ Bq}$

d Fraction of limit calculations are based on the annual total discharge for a given isotope and the corresponding concentration-based limit (0.56 and 0.37 Bq/mL for cesium-137 and plutonium-239, respectively) multiplied by the annual volume of Livermore site effluent.

e DCG = Derived Concentration Guide

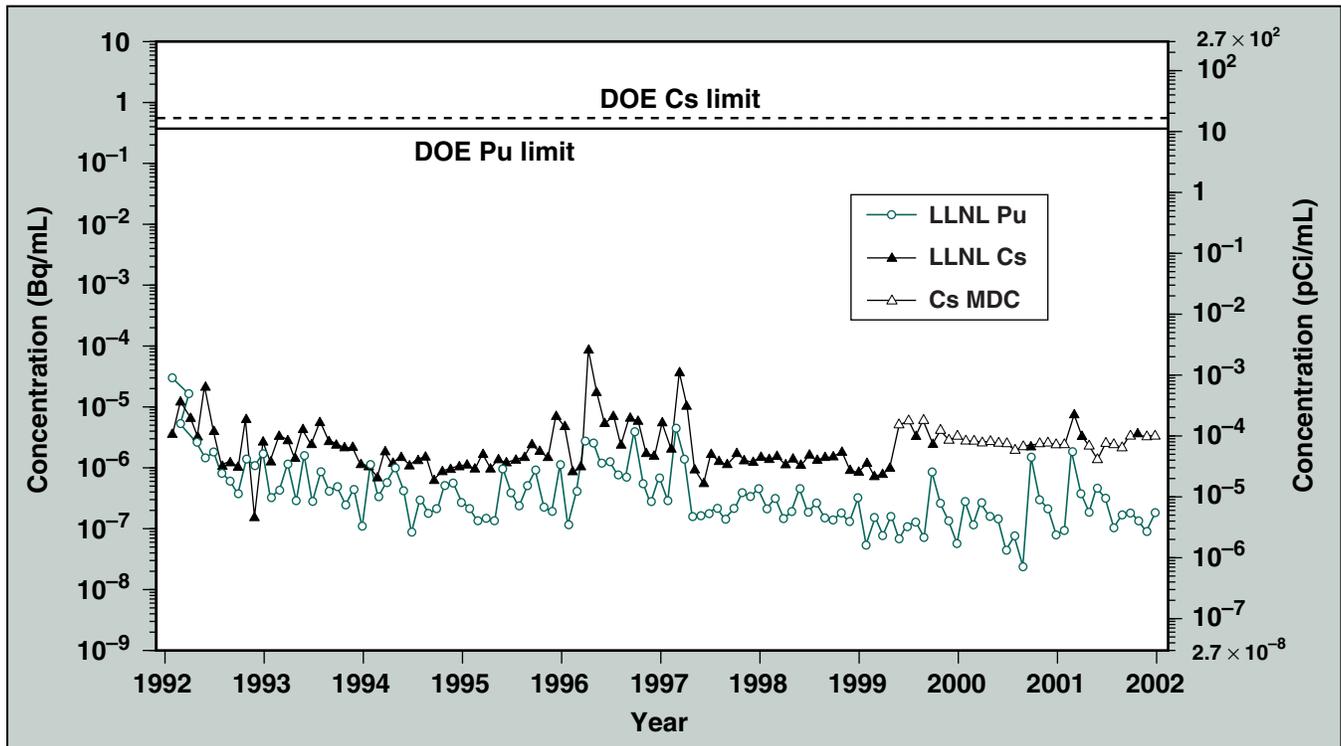


Figure 6-3. Historical trends in average monthly plutonium and cesium concentrations in LLNL sewage

From 10 CFR 20, the numerical discharge limits for sanitary sewer discharges in the WSS include the annual discharge limits for radioactivity: 185 GBq (5 Ci) of tritium, 37 GBq (1 Ci) of carbon-14, and 37 GBq (1 Ci) of all other radionuclides combined.

The 10 CFR 20 limit on total tritium activity dischargeable during a single year (185 GBq) overrides the DOE Order 5400.5 concentration-based limit for tritium for facilities such as LLNL that generate wastewater in large volumes. In 2001, the total LLNL tritium release was 2.6% of the 10 CFR 20 limit. Total LLNL releases (see [Table 6-2](#)), in the form of alpha and beta emitters (excluding tritium), were 0.87% of the corresponding 10 CFR 20 limit.

In addition to the DOE average concentration discharge limit for tritium and the 10 CFR 20 annual total discharge limit for tritium, the LWRP established in 1999 an effluent concentration discharge limit for LLNL daily releases of tritium. This limit is more stringent than the DOE discharge limit: it is a factor of 30 smaller and applies to a daily rather than an annualized concentration. The maximum daily concentration for tritium in 2001 was 3.08% of the permit discharge limit. [Table 6-3](#) shows this result and the daily effluent discharge limit for tritium. Both maximum daily and maximum monthly values are for the month of March. The values are higher than the 2000 values. Tritium releases that were well below DOE limits and approved by EPD and LWRP in the month of March account for these higher values.



LLNL also compares annual discharges with historical values to evaluate the effectiveness of ongoing discharge control programs. **Table 6-5** summarizes the radioactivity in liquid effluent released over the past 10 years. During 2001, a total of 4.9 GBq (0.13 Ci) of tritium was discharged to the sanitary sewer, an amount that is well within environmental protection standards and is comparable to the amounts reported since 1991. Moreover, the total tritium released by LLNL in 2001 continues the 1992 to 2000 trend of significantly smaller releases than those in the years prior to 1992.

Table 6-5. Radioactive liquid effluent releases from the Livermore site, 1992–2001

Year	Liquid effluent (GBq)	
	³ H	²³⁹ Pu
1992	8	1.9×10^{-3}
1993	13	2.6×10^{-4}
1994	6.9	1.9×10^{-4}
1995	6.0	1.2×10^{-4}
1996	12 ^(a)	4.2×10^{-4}
1997	9.1	2.1×10^{-4}
1998	10	7.7×10^{-5}
1999	7.1	6.8×10^{-5}
2000	5.0	9.6×10^{-5}
2001	4.9	1.1×10^{-4}

^a In 1995, Sandia/California ceased all tritium facility operations. Therefore, the annual tritium totals beginning with the 1996 value do not include contributions from Sandia/California.

Figure 6-3 summarizes the plutonium-239 monitoring data over the past 10 years. The historical levels observed since 1992 average 1 µBq/mL (3×10^{-5} pCi/mL). These historical levels generally are three-millionths (0.000003) of the DOE DCG for plutonium-239. The greatest part of the pluto-

nium discharged in LLNL effluent is ultimately concentrated in LWRP sludge. The median plutonium concentration observed in 2001 sludge (**Table 6-4**), 0.27 mBq/dry g, is approximately 350 times lower than the EPA preliminary remediation goal for residential soil (93 mBq/dry g) and is nearly 1400 times lower than the remediation goal for industrial or commercial soil (370 mBq/dry g).

As first discussed in the *Environmental Report 1991* (Gallegos et al. 1992), plutonium and cesium concentrations were slightly elevated during 1991 and 1992 over the lowest values seen historically. As was established in 1991, the overall upward trend was related to sewer cleaning with new, more-effective equipment. The concentrations in 1996 and the first quarter of 1997 were also slightly higher than the lowest values seen historically, although slightly lower than those of 1990 through 1992. In fact, the cyclic nature of the data in **Figure 6-3** suggests a potential frequency relationship in LLNL sewer lines for radionuclide buildup and subsequent liberation by line cleaning. The higher plutonium and cesium concentrations are all well below applicable DOE DCGs. In general, the plutonium and cesium concentrations for 2001 are comparable to the lowest values seen historically, and are well below the applicable DOE DCGs. (Note that because MDC values for cesium analysis increased in May 1999, most analytical results are below their respective MDCs; see **Table 6-4**.)

Nonradioactive Pollutants in Sewage

Monitoring Results

Table 6-6 presents monthly average concentrations for all regulated metals in LLNL's sanitary sewer effluent for 2001. The averages were obtained by a flow-proportional weighting of the analytical results for the weekly composite samples collected each month. Each result was weighted by

Table 6-6. Average monthly results for regulated metals in LLNL sanitary sewer effluent (mg/L), 2001

Month	Ag	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Jan	<0.010	0.0034	<0.0050	0.019	0.083	0.00020	0.0097	0.0063	0.18
Feb	<0.010	0.0052	<0.0050	0.014	0.12	0.00024	0.0069	0.0083	0.29
Mar	0.010	0.0031	<0.0050	0.020	0.13	0.00024	0.0074	0.019	0.36
Apr	0.016	0.0038	<0.0050	0.018	0.15	0.00031	0.0082	0.026	0.44
May	0.010	0.0051	<0.0050	0.031	0.23	0.00041	0.0069	0.051	0.54
Jun	0.010	0.0047	<0.0050	0.028	0.27	0.00048	0.0095	0.026	0.47
Jul	<0.010	0.0039	<0.0050	0.025	0.30	0.00041	0.0075	0.034	0.43
Aug	<0.010	0.0056	<0.0050	0.020	0.25	0.00031	0.0087	0.041	0.36
Sep	<0.010	0.0036	<0.0050	0.021	0.26	0.00042	0.0082	0.021	0.34
Oct	0.017	0.0030	<0.0050	0.014	0.14	0.00029	0.0066	0.012	0.25
Nov	<0.010	0.0030	<0.0050	0.011	0.15	0.00022	0.0053	0.014	0.28
Dec	<0.010	0.0045	<0.0050	0.014	0.14	0.00027	0.0069	0.015	0.33
Median	<0.010	0.0038	<0.0050	0.019	0.15	0.00030	0.0075	0.020	0.35
IQR ^(a)	— ^(b)	0.0014	— ^(b)	0.0081	0.11	0.00017	0.0014	0.015	0.15
EPL ^(c)	0.2	0.06	0.14	0.62	1	0.01	0.61	0.2	3.0
Median fraction of EPL	<0.05	0.06	<0.04	0.03	0.15	0.03	0.01	0.10	0.12

Note: Monthly values are presented with less-than signs when all weekly composite sample results for the month are below the detectable concentration.

a IQR = Interquartile range

b Because of the large number of nondetects, the interquartile range cannot be calculated for these metals. See [Chapter 14](#).

c Effluent pollutant limit (LLNL Wastewater Discharge Permit 2000–2001 and 2001–2002)

the total flow volume for the period during which the sample was collected. The results are generally typical of the values seen from 1994 to 2000; however, the median concentration values in 2001 are either less than, or equal to, the corresponding 2000 values for the nine regulated metals.

As discussed in the “[Environmental Impact](#)” section, no median concentration showed an increase above last year’s value. [Figure 6-4](#) presents historical trends for the monthly 24-hour composite sample results from 1994 through 2001 for eight of the nine regulated metals; cadmium is not presented because this metal is typically not detected. Although well below their respective

effluent pollutant limits (EPLs), both arsenic and lead show an occasional elevated concentration in 2001, and copper continues to show average concentrations above those observed in the mid-1990s. The other metals have no discernible trends in their concentrations.

The concentrations measured in the routine analysis of LLNL sewage samples collected once a week (seven-day composite sample) and once a month (24-hour composite samples) are presented for eight of nine regulated metals as a percentage of the corresponding EPL in [Figure 6-5](#); cadmium results are not presented because the metal was not detected, above the practical quantitation limit

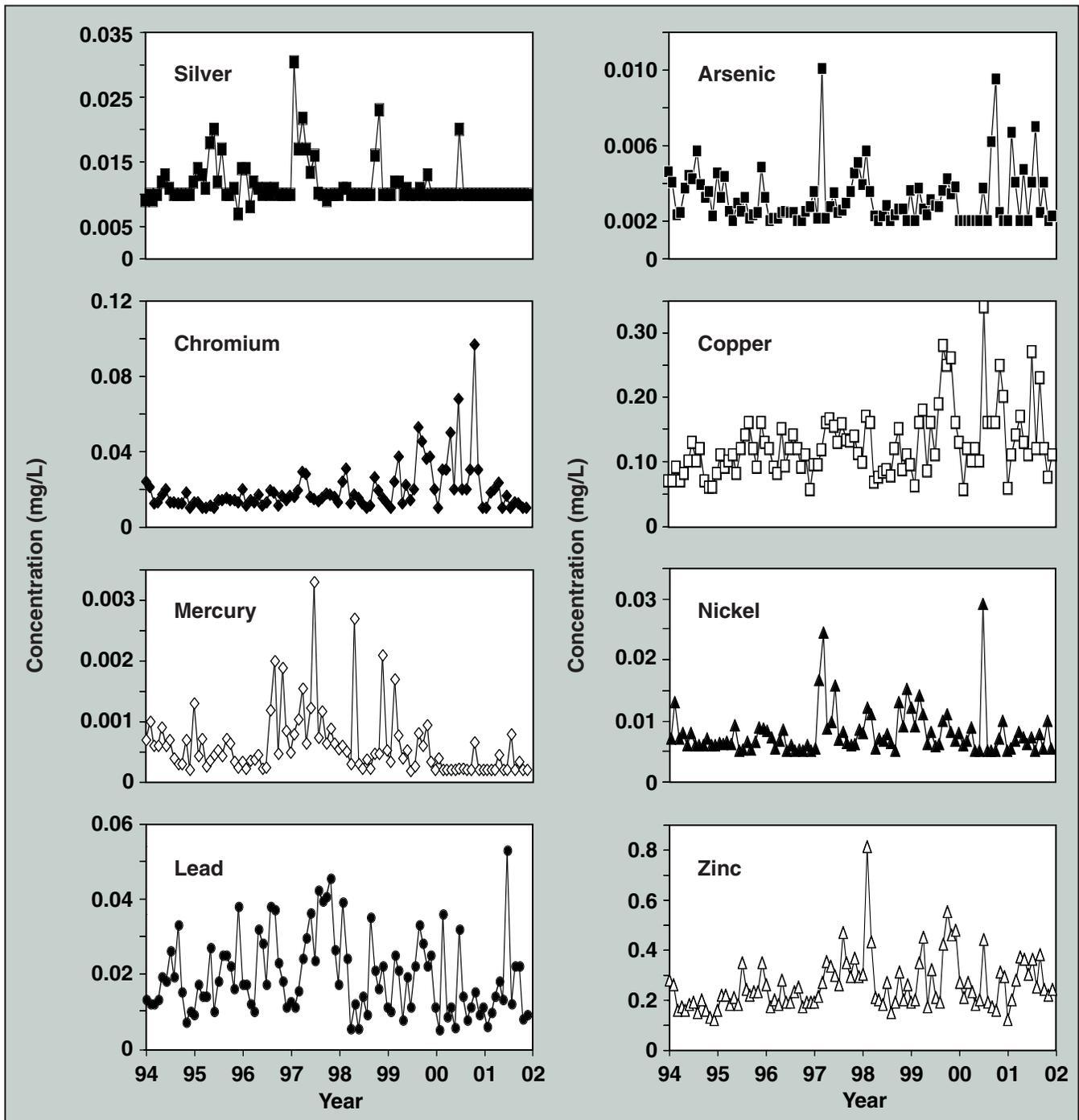


Figure 6-4. Monthly 24-hour composite sample concentrations for eight of the nine regulated metals in LLNL sanitary sewer effluent showing trends from 1994 to 2001

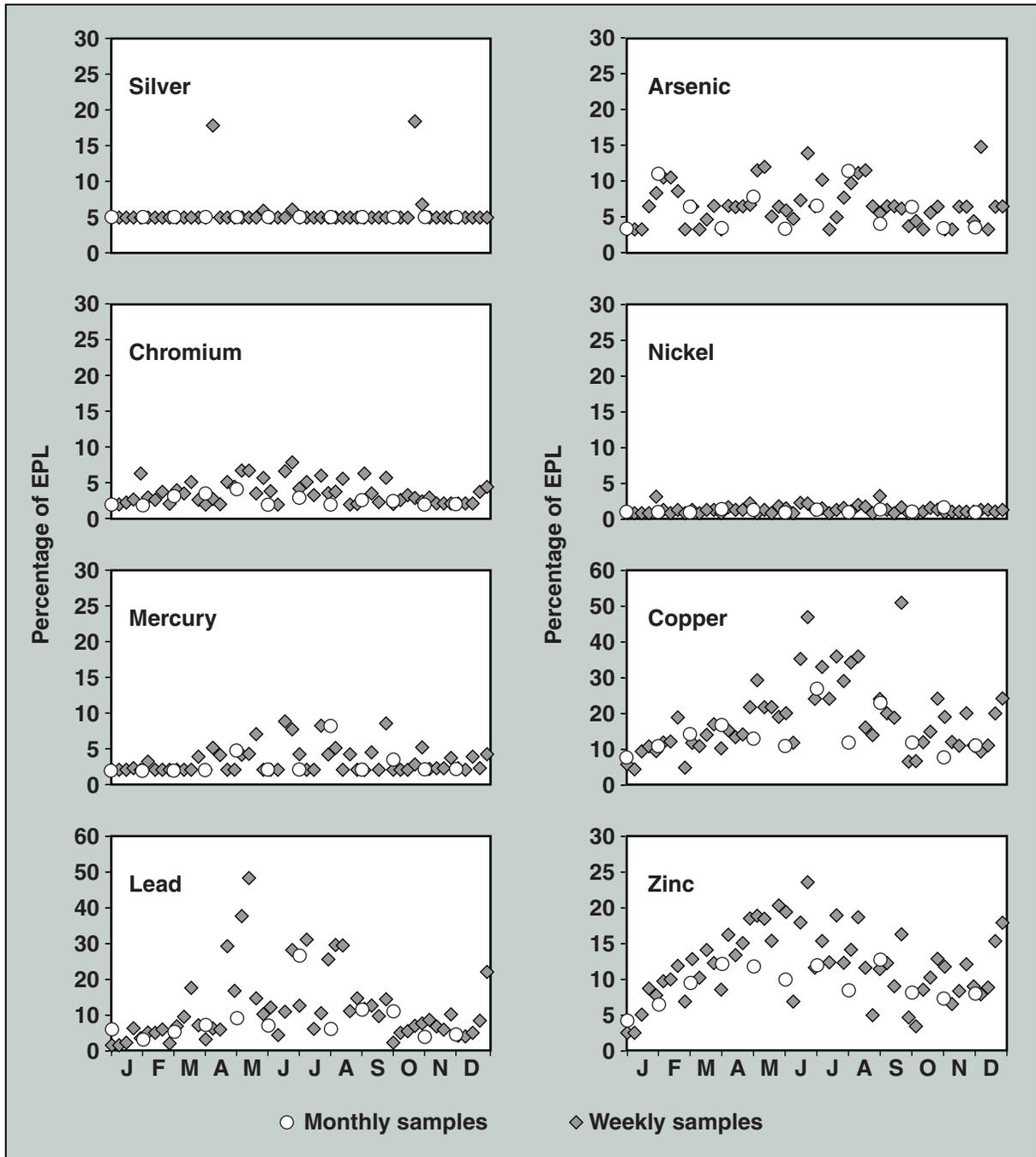


Figure 6-5. Results as percentages of effluent pollutant limits (EPLs) for eight of the nine regulated metals in LLNL sewage, 2001



(PQL) of 0.005 mg/L, in any of the weekly or monthly samples. The EPL is equal to the maximum pollutant concentration allowed per 24-hour composite sample, as specified by the LLNL wastewater discharge permit. When a weekly sample concentration is at or above 50% of its EPL, all daily (24-hour composite) samples collected in the SMS corresponding to the weekly sample period must be analyzed to determine if any of their concentrations are above the EPL.

Figure 6-5 shows no monthly sample metal concentration above 50% of its EPL; the highest monthly concentration reported was 27% of the respective EPL for both the July copper and July lead values. As discussed further in the “**Environmental Impact**” section, **Figure 6-5** also shows three weekly samples (one lead and two copper) at or near the specified action level.

Detections of anions, metals, and organic compounds and summary data concerning other physical and chemical characteristics of the sanitary sewer effluent are provided in **Table 6-7**. (All analytical results are provided in the Data Supplement, **Table 6-7**.) Although monthly (24-hour) composite samples were analyzed for carbonate alkalinity (as CaCO_3), hydroxide alkalinity (as CaCO_3), nitrate (as N), nitrate (as NO_3), beryllium, and selenium, these analytes were not detected in any sample acquired during 2001, and so are not presented in **Table 6-7**. Similarly, analytes not detected in any of the 2001 monthly grab samples are not shown in **Table 6-7**. These monthly monitoring results for physical and chemical characteristics of the LLNL sanitary sewer effluent are typical of those seen in previous years. See the “**Environmental Impact**” section for further discussion.

Environmental Impact

Table 6-6 presents monthly average concentrations and summary statistics for all regulated metals

monitored in LLNL’s sanitary sewer effluent. At the bottom of the table, the annual median concentration for each metal is shown and compared with the discharge limit. In 2001, the monthly average median concentration values have decreased from the corresponding 2000 values for seven of the nine regulated metals (As, Cr, Cu, Hg, Ni, Pb, and Zn). The two regulated metals not routinely detected in LLNL effluent, silver and cadmium, had median concentration values that remained unchanged at the PQL. These results are consistent with the weekly composite median values shown in Data Supplement **Table 6-5**. Monthly average median concentrations were less than one-tenth of the discharge limits for all but copper, lead, and zinc, which were at 15%, 10%, and 12%, respectively.

Although median values of metal concentrations have decreased, or remained at the PQL in the case of silver and cadmium, and all the monthly (24-hour) composite sample results for 2001 were less than 50% of the corresponding discharge limits, three weekly samples were identified for additional analyses based on metal concentrations at or near the action limit. These investigations examined a weekly sample in May (for lead at 49% of the EPL) and weekly samples in June and September (for copper at 47% and 51% of the EPL, respectively). The daily samples that correspond to the appropriate 7-day composite sampling periods were submitted to an off-site contract analytical laboratory for analysis. Lead concentrations in daily samples from the week of May 10–16 were reported as: 0.008 mg/L, 0.16 mg/L, 1.4 mg/L, 0.03 mg/L, 0.01 mg/L, 0.061 mg/L, and 0.021 mg/L, respectively. These results show an exceedance (1.4 mg/L) of the 0.2 mg/L permitted discharge limit for lead in the May 12, 2001, sample (representing effluent collected during the prior 24-hour period). In July 2001, the LWRP issued an NOV as a result of this exceedance of the EPL for lead. No corrective action was suggested or required, because LLNL had returned

Table 6-7. Monthly monitoring results for physical and chemical characteristics of the LLNL sanitary sewer effluent, 2001^(a)

	Detection frequency ^(b)	Minimum	Maximum	Median	IQR ^(c)
24-hour composite sample parameter (mg/L)					
Alkalinity					
Bicarbonate alkalinity (as CaCO ₃)	12/12	173	245	231	20
Total alkalinity (as CaCO ₃)	12/12	173	245	231	20
Anions					
Bromide	10/12	<0.1	1.1	0.4	0.45
Chloride	12/12	27	104	46	9
Fluoride	10/12	<0.050	0.92	0.125	0.11
Nitrate plus Nitrite (as N)	2/12	<0.1	1	1	— ^(d)
Nitrite (as N)	7/12	<0.02	0.23	0.02	0.006
Nitrite (as NO ₂)	7/12	<0.065	0.76	0.066	0.021
Orthophosphate	12/12	14.7	25	20	1.9
Sulfate	12/12	8.4	27	11.5	1.8
Nutrients					
Ammonia nitrogen (as N)	12/12	36	59	48	6
Total Kjeldahl nitrogen	12/12	35	94	70	8
Total phosphorus (as P)	12/12	6.2	13	10.5	2.6
Oxygen demand					
Biochemical oxygen demand	12/12	100	810	333	180
Chemical oxygen demand	12/12	145	1780	602	516
Solids					
Settleable solids	12/12	4	90	40	28
Total dissolved solids	12/12	165	413	256	28
Total suspended solids	12/12	88	650	385	255
Volatile solids	12/12	140	913	480	208
Total metals					
Calcium	12/12	9.3	20	15.5	3.3
Magnesium	12/12	1.7	5.1	3.05	0.65
Potassium	12/12	15	24	22	2.3
Sodium	12/12	23	73	37	4
Total organic carbon					
	12/12	38	73	57	11
Tributyltin (ng/L) ^(f)	2/2	14	19	16.5	— ^(d)



Table 6-7. Monthly monitoring results for physical and chemical characteristics of the LLNL sanitary sewer effluent, 2001^(a) (continued)

	Detection frequency ^(b)	Minimum	Maximum	Median	IQR ^(c)
Grab sample parameter					
Semivolatile organic compounds ($\mu\text{g/L}$)					
Benzoic acid	4/12	<10	72	15	— ^(d)
Benzyl alcohol	10/12	<2	71	7.4	8.2
Bis(2-ethylhexyl)phthalate ^(e)	10/12	<5	94	11.5	6.0
Diethylphthalate ^(e)	12/12	2.7	31	9.5	5.5
m- and p- Cresol	9/12	<2	35	9.2	13.2
Phenol ^(e)	4/12	<2	17	2	— ^(d)
Pyrene ^(e)	1/12	<2	3	2	— ^(d)
Total cyanide (mg/L)^(f)	0/2 ^(g)	<0.02	<0.02	<0.02	— ^(d)
Oil and grease (mg/L)^(f)	2/2	18	20	19	— ^(d)
Volatile organic compounds ($\mu\text{g/L}$)					
1,2-Dichloroethene ^(e)	1/12	<0.50	0.6	0.5	— ^(d)
1,4-Dichlorobenzene ^(e)	4/12	<0.50	3.4	0.5	— ^(d)
Acetone	12/12	98	480	225	175
Benzene ^(e)	1/12	<0.50	1.3	0.5	— ^(d)
Bromodichloromethane ^(e)	2/12	<0.50	3.5	0.5	— ^(d)
Bromoform ^(e)	2/12	<0.50	3.4	0.5	— ^(d)
Chloroform ^(e)	12/12	7	20	9.2	3.2
Dibromochloromethane ^(e)	1/12	<0.50	4.4	0.5	— ^(d)
Freon 113	1/12	<0.50	1.2	0.5	— ^(d)
Methylene chloride ^(e)	1/12	<1	1.6	1	— ^(d)
Napthalene ^(e)	1/12	<0.50	0.79	0.5	— ^(d)
Styrene	2/12	<0.50	9.3	0.5	— ^(d)
Toluene ^(e)	7/12	<0.50	1.4	0.58	0.31

a The monthly sample results plotted in Figure 6-5 and nondetected values reported in the Data Supplement, Chapter 6, are not reported in this table.

b The number of times an analyte was positively identified, followed by the number of samples that were analyzed (generally 12, one sample for each month of the year).

c IQR = Interquartile range

d When the detection frequency is less than or equal to 50%, there is no range, or there are fewer than four results for a sample parameter, then the interquartile range is omitted.

e Priority toxic pollutant parameter used in assessing compliance with the total toxic organic (TTO) permit limit of 1 mg/L (1000 $\mu\text{g/L}$) issued by the Livermore Water Reclamation Plant.

f Sampling for this parameter is required on a semiannual rather than a monthly basis.

g Although cyanide was not detected in either of the semiannual samples, the results are reported in this table to demonstrate compliance with the cyanide permit limit of 0.04 mg/L.



to compliance the following day and sufficient measures had been taken to investigate this inadvertent discharge. The results of similar analyses showed no copper concentration greater than 0.29 mg/L (29% of the EPL) in the June or September daily samples. Although each of these incidents was reported to the LWRP, none represented a threat to the integrity of the LWRP operations.

Table 6-7 presents summary results and statistics for monthly monitoring of physical and chemical characteristics of LLNL's sanitary sewer effluent. The results are generally similar to typical values seen in previous years for the two regulated parameters (cyanide and total toxic organics [TTO]) and all other nonregulated parameters. Cyanide was not detected in either of the required semiannual samples and the monthly TTO values ranged from less than 0.010 mg/L to 0.045 mg/L (median was 0.028 mg/L), well below the TTO permit limit of 1.0 mg/L. In addition to the organic compounds regulated under the TTO standard, six non-regulated organics were also detected in LLNL's sanitary sewer effluent: three volatile organic compounds (acetone, Freon 113, and styrene) and three semivolatile organic compounds (benzoic acid, benzyl alcohol, and 3- & 4-methylphenol).

In 2001, the SMS continuous monitoring system detected three inadvertent discharges outside the permitted pH range of 5 to 10. Two of the discharges were below pH 5 and one was above pH 10; all three discharges were captured in the SDF. For comparison, 2, 4, and 2 diversions occurred in 2000, 1999, and 1998, respectively.

Monitoring results for 2001 reflect an outstanding year for LLNL's sewerable water discharge control program and Livermore site personnel. As discussed above, LLNL's continuous monitoring system detected and diverted three inadvertent pH discharges. The one permit exceedance resulted from an elevated lead concentration in the May 12, 2001 daily effluent sample. Overall, LLNL achieved greater than 99% compliance with the provisions of its wastewater discharge permit.



SURFACE WATER MONITORING

Chris G. Campbell Richard A. Brown
Rebecca Ward Lily Sanchez
Sandra Mathews Michael A. Revelli

Overview

In accordance with federal, state, and internal requirements, Lawrence Livermore National Laboratory monitors and protects surface water quality at and around the facility. This includes the Livermore site, surrounding regions of the Livermore Valley and Altamont Hills, and Site 300. Specifically in the Livermore vicinity, LLNL monitors reservoirs and ponds, the Livermore site swimming pool, the Drainage Retention Basin (DRB), rainfall, tap water, storm water runoff, and receiving waters. At Site 300 and its vicinity, surface water monitoring encompasses rainfall, cooling tower discharges, drinking water system discharges, storm water runoff, and receiving waters.

Given the diverse activities and environmental conditions at and around the LLNL sites, water samples are analyzed for several water quality parameters including radionuclides, high explosives, residual chlorine, total organic carbon, total organic halides, total suspended solids, conductivity, pH, chemical oxygen demand, total dissolved solids, oil and grease, metals, minerals, anions, temperature, nutrients, and a wide range of organic compounds. In addition, bioassays are performed annually on water entering and leaving the Livermore site via the Arroyo Las Positas, discharges from the DRB, and water contained in the DRB.

The following sections will describe in detail the surface water monitoring programs performed at and around LLNL.

Storm Water

This section provides a general introduction to the storm water program at LLNL, including information on permits, constituent comparison criteria, and building inspections, as well as sampling





methods and results. The goals of the storm water runoff monitoring program are to demonstrate compliance with permit requirements, aid in implementing the Storm Water Pollution Prevention Plans (SWPPPs) (Eccher et al. 1994a, b), assess the risk of storm water contamination from various potential sources, and evaluate the effectiveness of best management practices (BMPs) for preventing storm water contamination.

General Information

Permits

To assess compliance with permit requirements, LLNL monitors storm water at the Livermore site in accordance with Waste Discharge Requirements (WDR 95-174), National Pollutant Discharge Elimination System permit (NPDES Permit No. CA0030023), issued in 1995 by the San Francisco Bay Regional Water Quality Control Board (SFBRWQCB 1995). LLNL monitors storm water discharges at Site 300 in accordance with the State-wide General NPDES Permit for Storm Water Discharges Associated with Industrial Activity (WDR 97-03-DWQ, NPDES Permit No. CAS000001, SWRCB).

In addition, Site 300 storm water monitoring meets the requirements of the *Post-Closure Plan for the Pit 6 Landfill Operable Unit* (Ferry et al. 1998). These permits include specific monitoring and reporting requirements. In addition to the storm water quality constituents required by the permits, LLNL monitors other constituents to provide a more complete water quality profile. The current list of analyses conducted on storm water samples is given in [Table 7-1](#).

Storm water monitoring follows the requirements in the *Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance* (U.S. DOE 1991) and meets the applicable requirements of DOE Order 5400.1,

General Environmental Protection Program, and DOE Order 5400.5, *Radiation Protection of the Public and the Environment*.

NPDES permits for storm water require that LLNL sample effluent two times per year. In addition, LLNL is required to visually inspect the storm drainage system monthly during the wet season (defined as October of one year through April or May of the following year, depending on the permit), whenever significant storms occur, and twice during the dry season to identify any dry weather flows. Influent sampling is also required at the Livermore site. LLNL monitors up to two more storm events each year at the Livermore site (a total of four sampling events) in support of DOE Orders 5400.1 and 5400.5. In addition, annual facility inspections are required to ensure that the best management practices are adequate and implemented.

LLNL also meets the storm water compliance monitoring requirements of the Statewide General NPDES Permit for Storm Water Discharges Associated with Construction Activity (Order 99-08- DWQ, NPDES Permit No. CAS000002) as modified by Resolution 2001-046 for construction projects that disturb two hectares of land or more (SWRCB 1999, 2001).

Constituent Criteria

Currently, there are no numeric criteria that limit concentrations of specific constituents in LLNL's storm water effluent. The Environmental Protection Agency (EPA) established parameter benchmark values but stressed that these concentrations were not intended to be interpreted as effluent limits (U.S. EPA 2000). Rather, the values are levels that the EPA has used to determine if storm water discharged from any given facility merits further monitoring. Although these criteria are not directly applicable, they are used as comparison criteria to help evaluate LLNL's storm water management

Table 7-1. Analyses conducted on storm water samples, 2001

Livermore site	Site 300
Chemical oxygen demand	Chemical oxygen demand
Dissolved oxygen	Cyanide
Oil and grease	Oil and grease
pH	pH
Specific conductance	Specific conductance
Total dissolved solids	Total dissolved solids
Total suspended solids	Total suspended solids
Anions	Ammonia
General minerals	Potassium
Metals	Metals
Polychlorinated biphenyls (PCBs)	Polychlorinated biphenyls (PCBs) and dioxins
Total organic carbon	Total organic carbon
Fish bioassay (fathead minnow)	Organic compounds
Diuron	Pesticides
Glyphosphate	Explosives (HE)
Herbicides	Total organic halides
Gross alpha and gross beta activity	Gross alpha and gross beta activity
Tritium	Tritium
Plutonium	Uranium

program. To further evaluate the storm water management program, LLNL established or calculated site-specific threshold comparison criteria for a select group of parameters. A value exceeds the threshold if it is greater than the 95% confidence limit computed for the historical mean value for a specific parameter (**Table 7-2**). The threshold comparison criteria are used to identify out-of-the-ordinary data that merit further investigation to determine if concentrations of that parameter are increasing in the storm water runoff.

For a better understanding of how LLNL storm water data relate to other target values, water samples are also compared with criteria listed in the *Water Quality Control Plan, San Francisco Bay Basin* (SFBRWQCB 1995), *The Water Quality Control Plan (Basin Plan) for the California Regional Water Quality Control Board, Central*

Valley Region, Sacramento and San Joaquin River Basins (Longley et al. 1994), EPA maximum contaminant levels (MCLs), and ambient water quality criteria (AWQC). The greatest importance is placed on the site-specific comparison criteria calculated from historical concentrations in storm runoff.

In addition to chemical monitoring, LLNL is required by NPDES permit WDR 95-174 to conduct acute and chronic fish toxicity testing in Arroyo Las Positas (Livermore site) once per wet season. Currently, LLNL is not required to test for fish toxicity at Site 300.

Inspections

Each directorate at LLNL conducts an annual inspection of its facilities to verify implementation of the SWPPPs and to ensure that measures to



Table 7-2. Threshold comparison criteria for selected water quality parameters. The sources of values above these are examined to determine if any action is necessary.

Parameter	Livermore site	Site 300
Total suspended solids (TSS)	750 mg/L ^(a)	1700 mg/L ^(a)
Chemical oxygen demand (COD)	200 mg/L ^(a)	200 mg/L ^(a)
pH	<6.0, >8.5 ^(a)	<6.0, >9.0 ^(b)
Nitrate (as NO ₃)	10 mg/L ^(a)	not monitored
Orthophosphate	2.5 mg/L ^(a)	not monitored
Mercury	above RL ^(c)	above RL ^(c)
Beryllium	0.0016 mg/L ^(a)	0.0016 mg/L ^(a)
Chromium(VI)	0.015 mg/L ^(a)	not monitored
Copper	0.026 mg/L ^(d)	not monitored
Lead	0.015 mg/L ^(e)	0.015 mg/L ^(e)
Zinc	0.35 mg/L ^(a)	not monitored
Diuron	0.014 mg/L ^(a)	not monitored
Oil and grease	9 mg/L ^(a)	9 mg/L ^(a)
Tritium	36 Bq/L ^(a)	3.17 Bq/L ^(a)
Gross alpha	0.34 Bq/L ^(a)	0.90 Bq/L ^(a)
Gross beta	0.48 Bq/L ^(a)	1.73 Bq/L ^(a)

a Site-specific value calculated from historical data and studies. These values are lower than the EPA benchmarks except for zinc, TSS, and COD.

b EPA benchmark

c RL = reporting limit = 0.0002 mg/L

d Ambient water quality criteria (AWQC)

e EPA primary maximum contaminant level (PMCL)

reduce pollutant loadings to storm water runoff are adequate. The Laboratory's associate directors certified in 2001 that their facilities complied with the provisions of WDR 95-174, WDR 97-03-DWQ, and the SWPPPs. LLNL submits annual storm water monitoring reports to the SFBRWQCB and to the CVRWQCB with the results of sampling, observations, and inspections (Campbell 2001a, b).

For each construction project permitted by Order 99-08-DWQ, the construction staff conducts visual observations of construction sites before, during, and after storms to assess the effectiveness of implemented BMPs. Annual compliance certifications summarize these inspections.

As in past years, the SFBRWQCB requested submission of compliance status reports for the Livermore site construction projects. (The CVRWQCB has never requested compliance status reports for projects located at Site 300.) The 2001 compliance certifications (and compliance status reports) covered the period of June 2000 through May 2001. During this period, three Livermore site projects were inspected: the Decontamination and Waste Treatment Facility (DWTF), the National Ignition Facility (NIF), and the areas associated with the Soil Reuse Project. One Site 300 project, the Contained Firing Facility (CFF), was also inspected under this program. The CFF and DWTF projects were complete and their permits were terminated prior to the deadline; therefore, the annual compliance certifications were not filed for these two projects.

Sampling

For the purpose of evaluating the overall impact of the Livermore site and Site 300 operations on storm water quality, storm water flows are sampled at upstream and downstream locations. Because of flow patterns at the Livermore site, storm water at sampling locations includes runoff from other sources, such as neighboring agricultural land, parking lots, and landscaped areas. In contrast, storm water at Site 300 is sampled at locations that target specific industrial activities with no run-on from off-site sources. These samples provide information used to evaluate the effectiveness of LLNL's storm water pollution control program.



Construction site runoff is sampled to assess the impact of this type of runoff on the receiving water as specified in Resolution 2001-046. Two specific assessments are required by the permit: 1) when the runoff from the project directly enters a water body identified on the state of California's Clean Water Act 303(d) list as being impaired for sediment-related pollutants (siltation, sedimentation, or turbidity), samples must be collected for these pollutants; and 2) when construction site materials that cannot be visually detected are exposed to storm water, runoff must be sampled for the potential non-visible pollutants. LLNL projects do not have to sample for sediment-related pollutants because the receiving waters at neither the Livermore site nor Site 300 are currently identified as being impaired for sediment-related pollutants. To comply with the second required assessment, the specific nonvisible parameters to be sampled at each construction site are identified in the individual project SWPPP.

Livermore Site: As is commonly the case in urbanized areas, the surface water bodies and runoff pathways at LLNL do not represent the natural conditions. The drainage at the Livermore site was altered by construction activities several times up to 1966 (Thorpe et al. 1990) so that the current northwest flow of Arroyo Seco and the westward flow of Arroyo Las Positas do not represent historical flow paths. About 1.6 km to the west of the Livermore site, Arroyo Seco merges with Arroyo Las Positas, which continues to the west to eventually merge with Arroyo Mocho (see [Figure 7-1](#)).

The DRB was excavated and lined in 1992 to prevent infiltration of storm water that was dispersing groundwater contaminants. It also serves storm water diversion and flood control purposes. The DRB collects about one-fourth of the surface water runoff from the site and a portion of the Arroyo Las Positas drainage ([Figure 7-2](#)). When full, the DRB discharges north to a culvert

that leads to Arroyo Las Positas. The remainder of the site drains either directly or indirectly into the two arroyos by way of storm drains and swales. Arroyo Seco cuts across the southwestern corner of the site. Arroyo Las Positas follows the north-eastern and northern boundaries of the site and exits the site near the northwest corner.

The routine Livermore site storm water runoff monitoring network consists of ten sampling locations ([Figure 7-2](#)). Seven locations characterize storm water either entering (influent: ALPE, ALPO, ASS2, ASSE, and GRNE) or exiting (effluent: ASW and WPDC) the Livermore site. Locations CDB and CDB2 characterize runoff from the southeastern quadrant of the Livermore site entering the DRB, and location CDBX characterizes water leaving the DRB. Additional locations were sampled beginning in 1999 and continuing through 2001 as part of a tritium source investigation and are described in the "[Livermore Site Radioactive Constituents](#)" section in this chapter.

Only the NIF construction site at the Livermore site required sampling in 2001. Four locations ([Figure 7-3](#)) were selected to characterize runoff flowing into the construction site (influent: NIF1, NIF2, NIF3) and runoff leaving the construction site (effluent: NIF0).

Site 300: Surface water at Site 300 consists of seasonal runoff, springs, and natural and man-made ponds. The primary waterway in the Site 300 area is Corral Hollow Creek, an ephemeral stream that borders the site to the south and southeast. No naturally continuously flowing streams are present in the Site 300 area. Elk Ravine is the major drainage channel for most of Site 300; it extends from the northwest portion of the site to the east-central area. Elk Ravine drains the center of the site into Corral Hollow Creek, which drains eastward

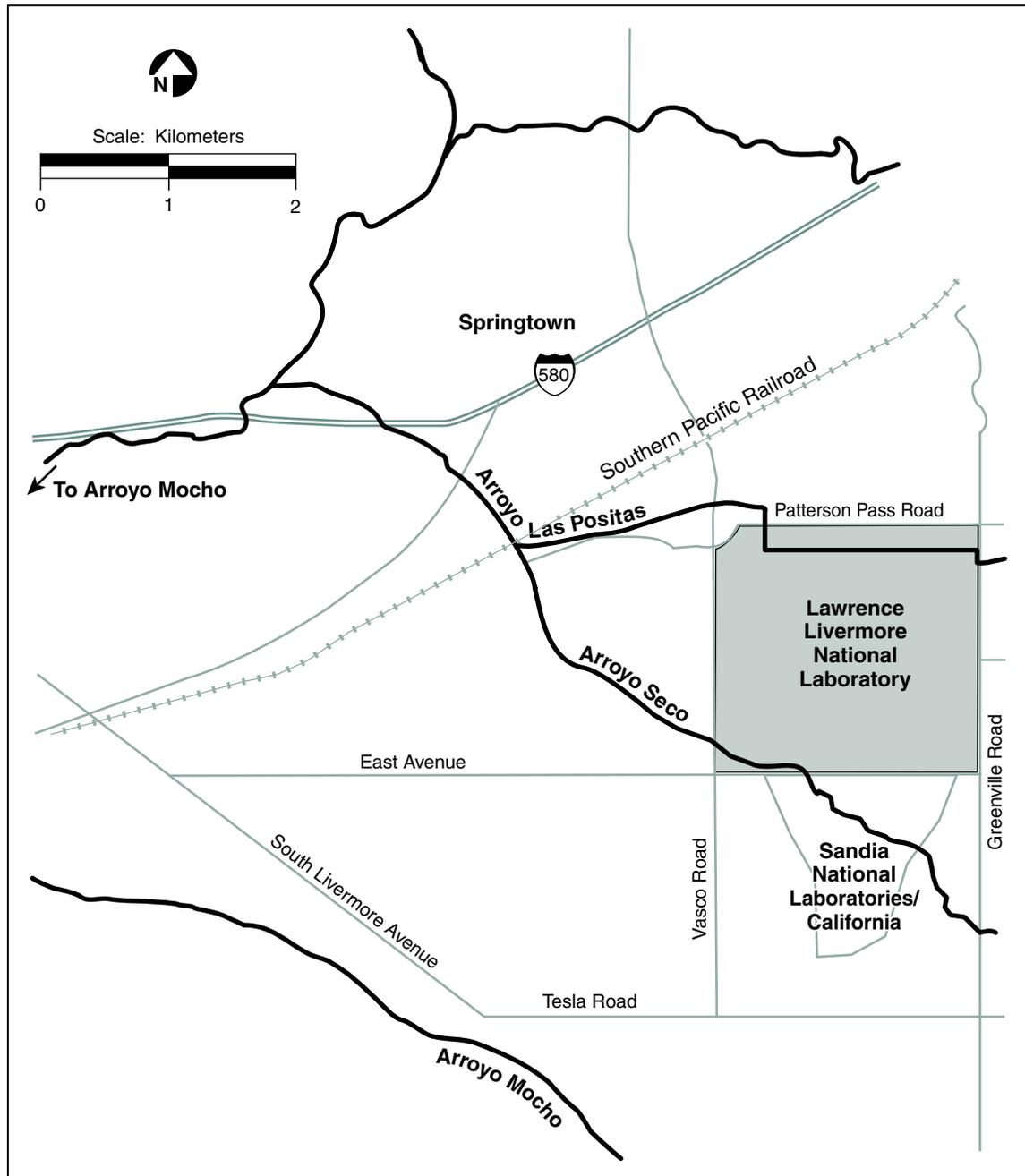


Figure 7-1. Surface waterways in the vicinity of the Livermore site

to the San Joaquin River Basin. Some smaller canyons in the northeast portion of the site drain to the north and east toward Tracy.

There are at least 23 springs at Site 300. Nineteen are perennial, and four are intermittent. Most of the springs have very low flow rates and are recognized only by small marshy areas, pools of water, or

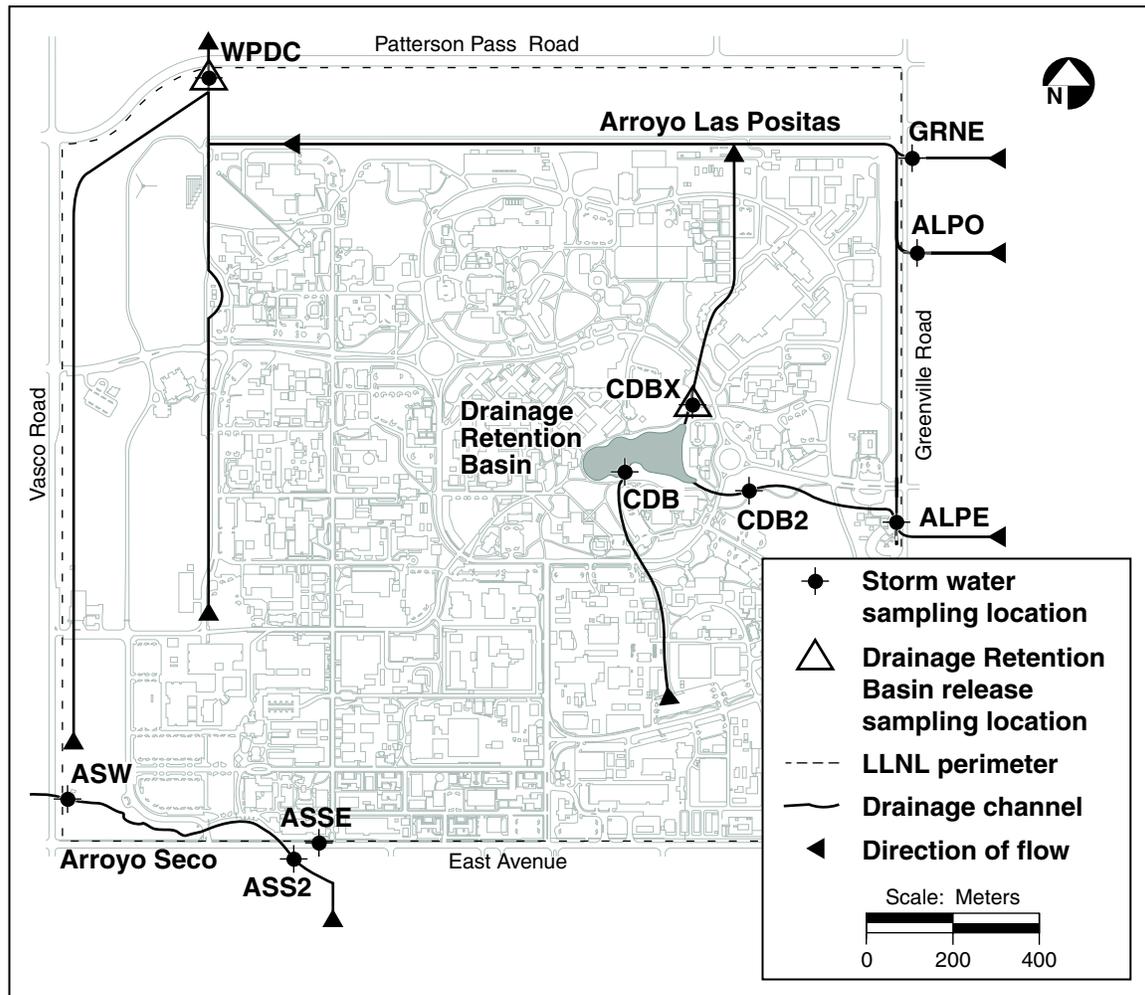


Figure 7-2. Storm water runoff and Drainage Retention Basin sampling locations, Livermore site, 2001

vegetation. Numerous artificial surface water bodies are present at Site 300. A sewage evaporation pond and a sewage percolation pond are located in the southeast corner of the site in the General Services Area (GSA), and two lined, high-explosives (HE) surface water impoundments are located to the west in the Explosives Process Area. Monitoring results associated with these facilities are reported in [Chapter 9](#). Three wetlands created by now discontinued flows from cooling towers

located at Buildings 827, 851, and 865 are currently maintained by discharges of potable water.

The on-site Site 300 storm water sampling network began in 1994 with six locations and now consists of seven locations ([Figure 7-4](#)). Locations were selected to characterize storm water runoff at locations that could be affected by specific Site 300 activities.

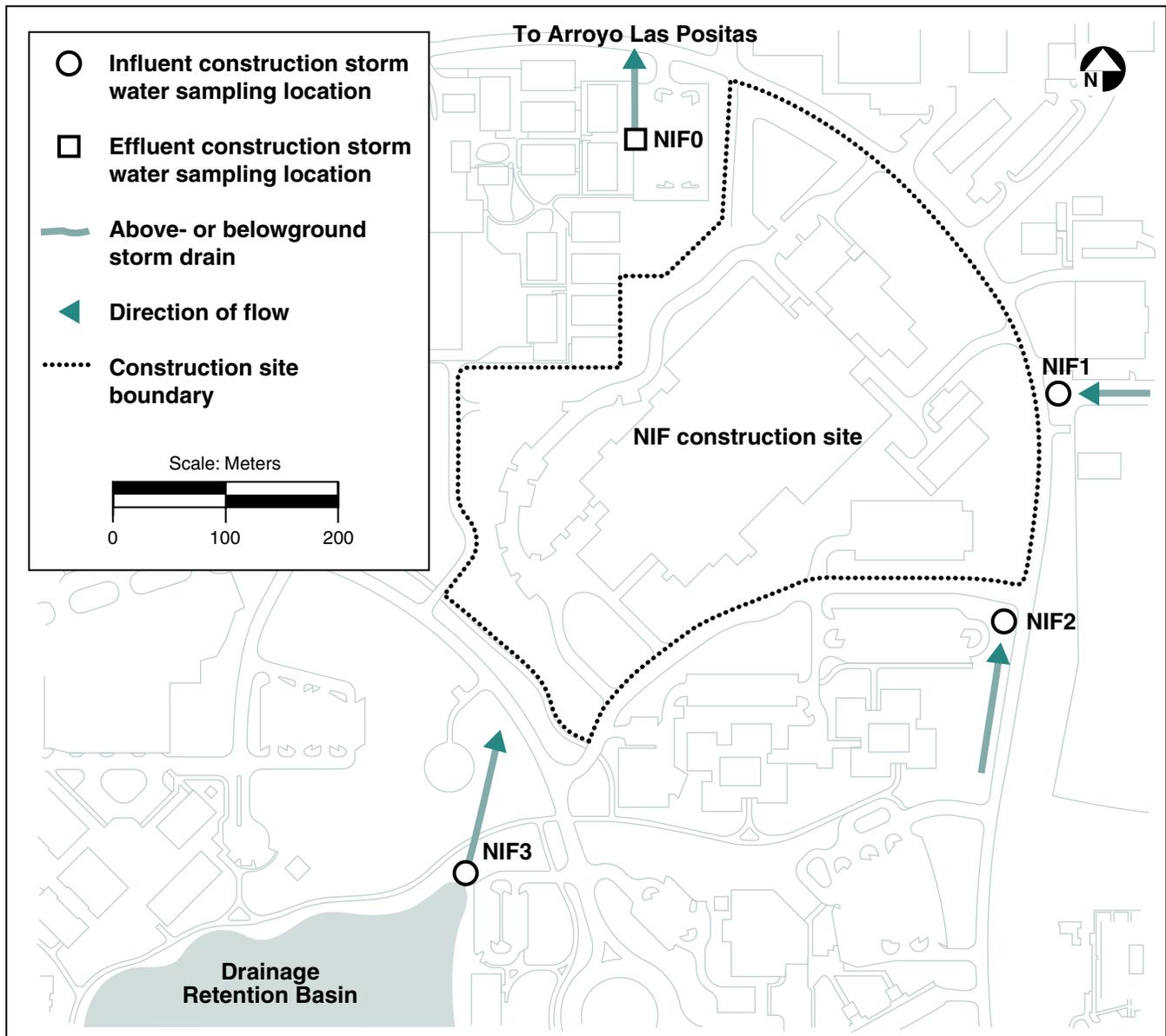


Figure 7-3. Storm water sampling locations for NIF construction project

Off-site location CARW is used to characterize runoff in Corral Hollow Creek upstream and therefore is unaffected by Site 300 industrial activities. Location GEOCRK is used to characterize runoff in Corral Hollow Creek, downstream of Site 300.

No construction projects at Site 300 required storm water sampling in 2001.

Methods

At all monitoring locations at both the Livermore site and Site 300, including construction sites, samples are collected by grab sampling from the

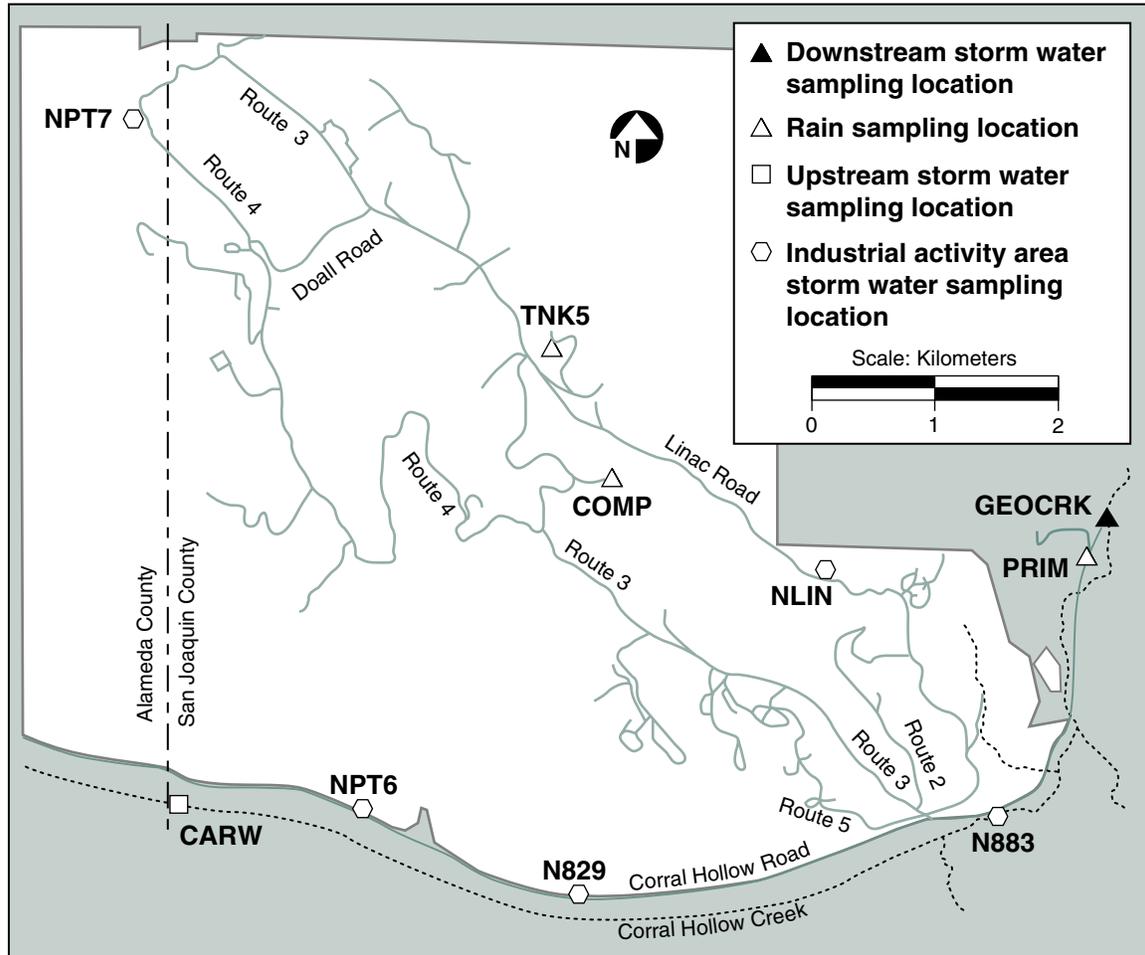


Figure 7-4. Storm water and rainwater sampling locations at Site 300, 2001

storm runoff flowing in the stream channels. Standard sample bottle requirements, special sampling techniques, and preservation requirements for each analyte are specified in the *Environmental Monitoring Plan* (Tate et al. 1999) and summarized below.

Grab samples are collected by partially submerging sample bottles directly into the water and allowing them to fill with the sample water. If the water to be sampled is not directly accessible, a stainless-steel bucket or an automatic water sampler is used for sampling. The bucket is triple-rinsed with the water to be sampled, then dipped or submerged

into the water, and withdrawn in a smooth motion. Sampling is conducted away from the edge of the arroyo to minimize the collection of sediment with water samples. Sample vials for volatile organics are filled before sample vials for all other constituents and parameters.

Results

Inspections

The Associate Director for each of the directorates certified that their facilities conducted the 2001 annual inspection of its facilities to verify implementation of the SWPPP and ensure that measures



to reduce pollutant loading to storm water runoff are adequately and properly implemented. Each directorate documents and keeps on file the annual inspection results (as required by WDR 95-174 and 97-03-DWQ). These records include the dates, places, and times of the site inspections and the names of individuals performing the inspections. Because of the large number of facilities inspected (more than 500 buildings and trailers), the detailed inspection results are not included in this report, but the individual inspection records are available for review.

All inspections were completed; findings and deficiencies are summarized in Campbell (2001a,b). There were 11 minor issues listed as the result of the inspections that were not consistent with the BMPs identified in the SWPPP. All of these issues have either been corrected or are in the process of being corrected. All other inspections at both Site 300 and the Livermore site indicated that the applicable BMPs were implemented correctly and adequately.

Additionally, LLNL conducted the permit-required inspections before, during, and after rain events at each of the permitted construction sites: three at the Livermore site and one at Site 300. The findings of these inspections indicated compliance with the permit and the construction site SWPPPs, with one exception documented in the 2000/2001 annual compliance certifications filed in July 2001 for the period of June 2000 through May 2001; the project personnel failed to document some rain event inspections and failed to perform some inspections.

Livermore Sampling

LLNL collected samples at all ten Livermore site locations on February 12, March 2, April 6, November 11, and December 12, 2001. Earlier samples were collected from five locations on January 8, and the remaining five locations were

collected on January 10, 2001. The fish and algae toxicity analyses were conducted during the January 8 and 10 samplings, and then again on the November 11 sampling in order to catch the first flush of runoff that occurs at the beginning of the wet season.

Toxicity Monitoring: As required by WDR 95-174, grab samples were collected and analyzed for acute and chronic toxicity using fathead minnows (*Pimephales promelas*) as the test species. In the acute test, 96-hour survival is observed in undiluted storm water collected from location WPDC.

The permit states that an acceptable survival rate is 20 percent lower than a control sample. The testing laboratory provides water for the quality control sample. As specified by the permit, upstream water samples from influent locations ALPO, ALPE, and GRNE are used as additional controls. Thus, a difference of more than 20 percent between location WPDC and the upstream control sample with the lowest survival rate is considered a failed test. If the test is failed, the permit requires LLNL to conduct toxicity testing during the next significant storm event. After failing two consecutive tests, LLNL must perform a toxicity reduction evaluation to identify the source of the toxicity.

During 2001, survival in the acute test at WPDC (January 8 and November, 12) ranged from 95 to 100%, while all influent locations (ALPE, ALPO, and GRNE) ranged from 80 to 100%.

In the chronic fish toxicity test, storm water dilutions of 0 (Lab Control), 6.25, 12.5, 25, 50, and 100 percent (undiluted storm water) were used to determine a dose-response relationship, if any, for both survival and growth of the fathead minnow (Table 7-3). This test is only required at effluent location WPDC and not conducted with water from corresponding influent locations. From these

data, no observed effect concentrations (NOECs) and lowest observed effect concentrations (LOECs) were calculated using EPA/600/4-91-002. The NOECs and LOECs for survival and growth were 100 percent. Thus, both the acute and chronic fish toxicity test indicated that storm water had no effect on survival or growth of fathead minnows.

Table 7-3. Fish chronic toxicity test results, Livermore site, January 2001

Sample concentration (%)	7-day survival		7-day weight (a)	
	Avg. (%)	Standard deviation	Avg. (mg)	Standard deviation
Lab control	98	5.0	0.70	0.10
6.25	85	12.9	0.54	0.08
12.5	70	24.5	0.45	0.08
25	93	9.6	0.51	0.07
50	90	8.2	0.48	0.05
100	98	5.0	0.45	0.02

a Weight of the fathead minnows at the end of the 7-day toxicity test.

In addition to the fish toxicity testing, LLNL performed chronic toxicity testing with freshwater algae (*Selenastrum capricornutum*) using water collected from Arroyo Las Positas on January 8, 2001. This chronic test uses the same set of dilutions of storm water as the fathead minnow test. In the algae test, cell counts at each dilution are compared with cell counts in the laboratory control waters.

The algae test indicated toxicity in storm water, with a NOEC of <6.25% and a LOEC of 6.25% (Table 7-4). Because this test was conducted at only a single sampling location, it was difficult to determine if the effects should be attributed to LLNL or to upstream water quality. Therefore, additional samples were collected for chronic algae toxicity tests at both the effluent (WPDC) and influent (GRNE, ALPO, and ALPE) locations

during the next significant storm event on February 12, 2001. The results of this second sample date indicated that algae growth was more inhibited in water from the influent locations (Table 7-5). An investigation into the potential causes of the algae toxicity identified a likely source, a pre-emergent herbicide, diuron.

Table 7-4. Algae chronic toxicity test results, Livermore site, January 2001

Sample concentration (%)	96-hour growth	
	Count (10 ⁶ cells/mL)	Variance (%)
control	1.76	10.3
6.25	0.94	6.5
12.5	0.75	5.4
25	0.38	14.9
50	0.10	4.0
100	0.04	7.6

On January 8, diuron concentrations at the effluent WPDC were 14 µg/L, while at influent sample locations GRNE, ALPO, and ALPE the values were 1600 µg/L, 4.6 µg/L, and 4.5 µg/L, respectively. The obviously high diuron concentration at GRNE makes the pesticide a likely source for the observed toxicity. This hypothesis was verified on February 12 when diuron concentrations were 10.0 µg/L, 79.0 µg/L, 80.0 µg/L, and 3.6 µg/L for WPDC, GRNE, ALPO, and ALPE, respectively.

An electrical transfer station upstream of the Livermore site on Greenville Road contributes significant storm water to the GRNE sampling location and some to the sampling location ALPO. A plot of historical concentrations of diuron entering the site from GRNE and leaving LLNL at WPDC reveals that influent (GRNE) concentrations are most often higher than at the effluent (WPDC) (Figure 7-5). There are a number of



Table 7-5. Chronic algae toxicity test results in Arroyo Las Positas storm water on February 12, 2001

Sample concentration (%)	96-hour growth	
	Count (10 ⁶ cells/mL)	Variance (%)
WPDC		
control	1.349	8.7
6.25	1.683	5.8
12.5	1.399	7.9
25	0.991	6.7
50	0.623	9.5
100	0.174	9.7
GRNE		
control	1.456	6.9
6.25	0.067	9.3
12.5	0.026	5.1
25	0.017	9.3
50	0.014	10.6
100	0.013	13.9
ALPO		
control	1.355	6.3
6.25	1.221	11.9
12.5	0.534	4.3
25	0.205	9.4
50	0.048	19.8
100	0.024	9.5
ALPE		
control	1.414	11.56
6.25	1.510	7.17
12.5	1.597	19.88
25	1.028	8.30
50	0.684	2.49
100	0.178	6.67

high diuron values coming on-site from an off-site source, but the values in January and December 2001 are more than two orders of magnitude greater than the comparison threshold of 14 µg/L (Table 7-2).

A source evaluation study was performed by LLNL that provided additional evidence that the upstream electrical transfer station was indeed the source of the pesticide. A complete summary of the source evaluation is presented in Campbell et al. (2002). The operators of the electrical transfer station have been contacted and informed of our findings in the pesticide source evaluation.

Livermore Site Radioactive Constituents:

Storm water sampling and analysis were performed for gross alpha, gross beta, plutonium, and tritium. Storm water gross alpha, gross beta, and tritium results are summarized in Table 7-6. Complete results are in Data Supplement Tables 7-1, 7-2, and 7-3. Tritium activities at effluent locations were less than 1% of the MCL. Radioactivity in the storm water samples collected during 2001 was generally low, with medians around background levels.

LLNL began analyzing for plutonium in storm water in 1998. Samples were analyzed from the Arroyo Seco and Arroyo Las Positas effluent locations (ASW and WPDC). The unfiltered water was analyzed when the samples were low in suspended sediments. When the analytical laboratory determined that water samples contained sufficient sediment (as it did on January 8, 2001), a portion of the runoff was analyzed unfiltered, and the remaining runoff was filtered. The filtrate and filtered water were analyzed (three analyses total from each location). Plutonium was not above the detection limit for either the liquid or sediment portion of the storm water samples in 2001. Thus, there is no evidence in the data to indicate that LLNL has contributed plutonium to runoff.

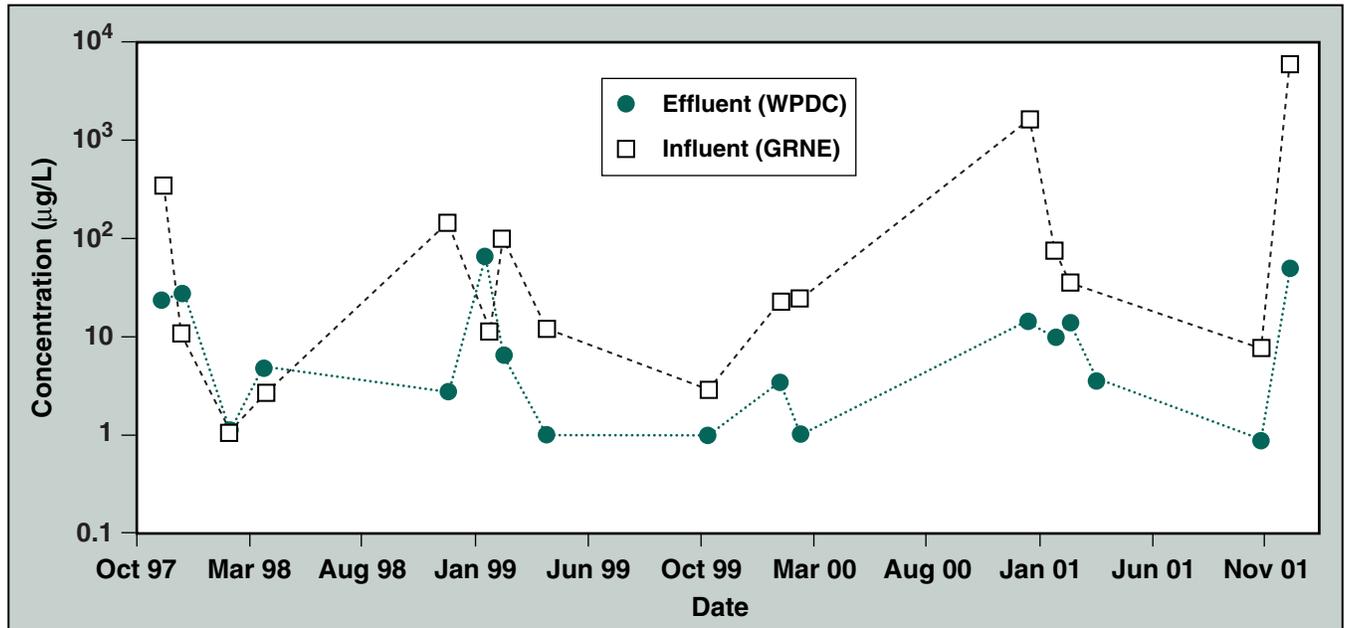


Figure 7-5. Diuron concentrations in Arroyo Las Positas storm water 1997–2001

Table 7-6. Radioactivity in storm water from the Livermore site, 2001^(a)

Parameters	Tritium (Bq/L)	Gross alpha (Bq/L)	Gross beta (Bq/L)
MCL	740	0.555	1.85
Influent			
Median	-0.04	0.02	0.09
Minimum	-2.41	-0.01	-0.19
Maximum	2.44	0.14	0.55
Effluent			
Median	0.32	0.01	0.09
Minimum	-2.51	-0.25	0.02
Maximum	-6.48	0.06	0.13

^a See Chapter 14 for a complete explanation of calculated values.

Beginning with the 1996/1997 season, the tritium activity in Arroyo Las Positas was observed to be higher in storm water leaving the site than in storm water entering the site. On May 23, 1997, at location WPDC, where effluent is measured, a single higher-than-typical result for tritium in storm water

(359 Bq/L) was measured. The historical trend in tritium levels at location WPDC is presented in Figure 7-6.

In response to the elevated effluent tritium levels, additional tritium investigations were initiated in the fall of 1998 to identify potential sources of tritium to the storm runoff. The initial approach taken to evaluate tritium flow patterns across the Livermore site was to evaluate four locations upstream of WPDC (WPDW, 196S, WPDS, and 196E), where the storm drainage channels join the main Arroyo Las Positas channel and leave the Livermore site (Figure 7-7). Samples were collected at these junctures on November 30, 1998, and reported in the *Environmental Report 1998* (Larson et al. 1999). Tritium was not detected in 2 of the 3 incoming channels (calculated values of 2.0 and 0.9 Bq/L at WPDW and 196S, respectively), but was detected at 31 Bq/L in the main Arroyo Las Positas channel.

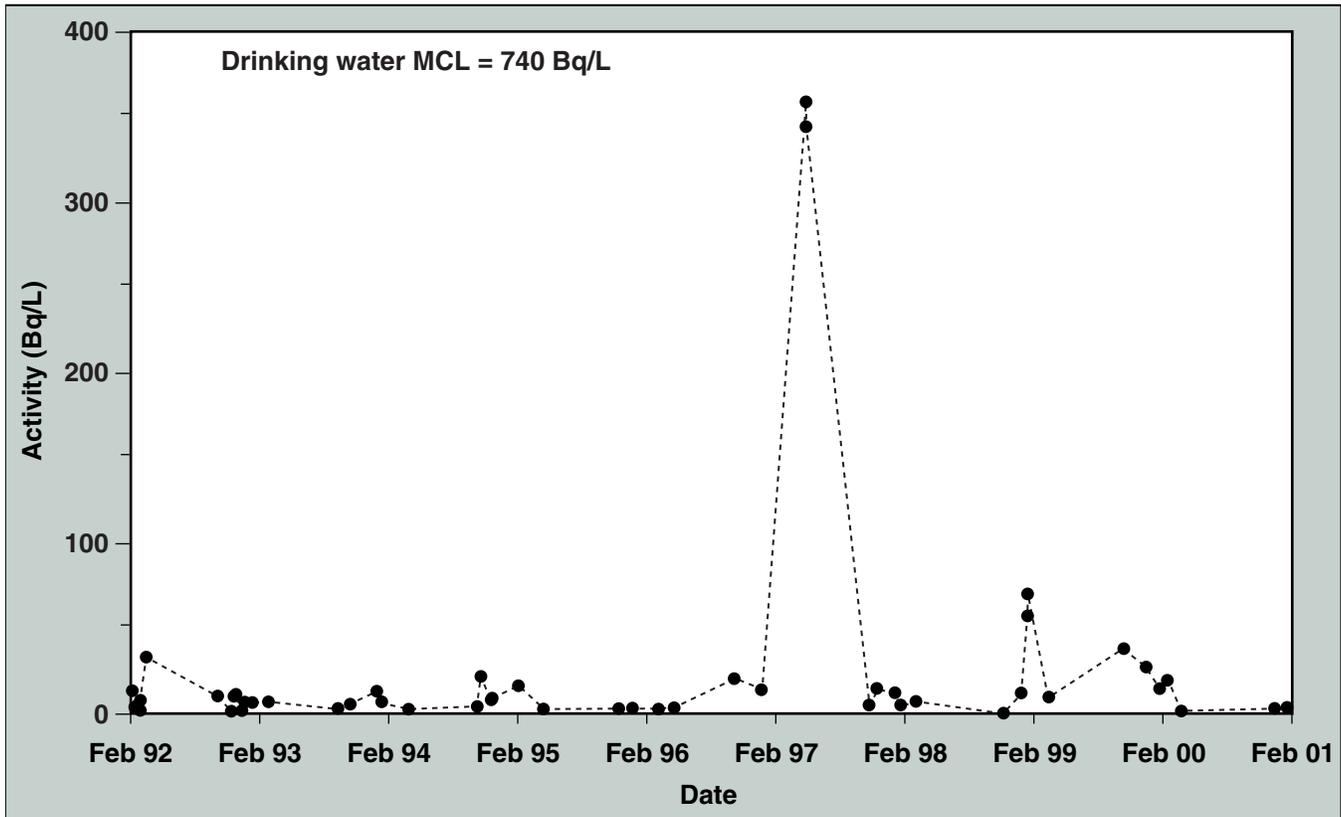


Figure 7-6. Tritium activity in Livermore storm water samples from the Arroyo Las Positas (location WPDC) 1992–2001

Detailed tritium observations from locations in the vicinity of Building 331 (Figure 7-7) and in the associated north-south storm drain, found increased tritium activities revealing the location of the source. Specifically, higher levels were found at location 3726 near Buildings 331 and 343. The source of elevated tritium was tracked to a transportainer containing materials exposed to tritium.

Sampling of surface runoff in the vicinity of the transportainer near Building 343 found tritium concentrations as high as 41,100 Bq/L in April 2000. These samples were taken in the parking lot directly down gradient from the transportainer. This radioactivity was significantly diluted in the overall site runoff so that samples collected at the

site outlet (WPDC) on the same day were not more than 4% of the drinking water standard for tritium (740 Bq/L). Continued monitoring of both surface runoff near Building 343 and sampling in the storm channels have demonstrated a rapid decrease in measured tritium activities since the transportainer was removed in August 2000 (Figure 7-8). Monitoring of this network in 2001 demonstrated that tritium activities in the north-south storm drain near Building 343 have returned to near-background levels (Figure 7-9).

Concurrent with the environmental investigation of the source of tritium in the environment, programmatic personnel conducted a conscientious and thorough review of operations, and identified

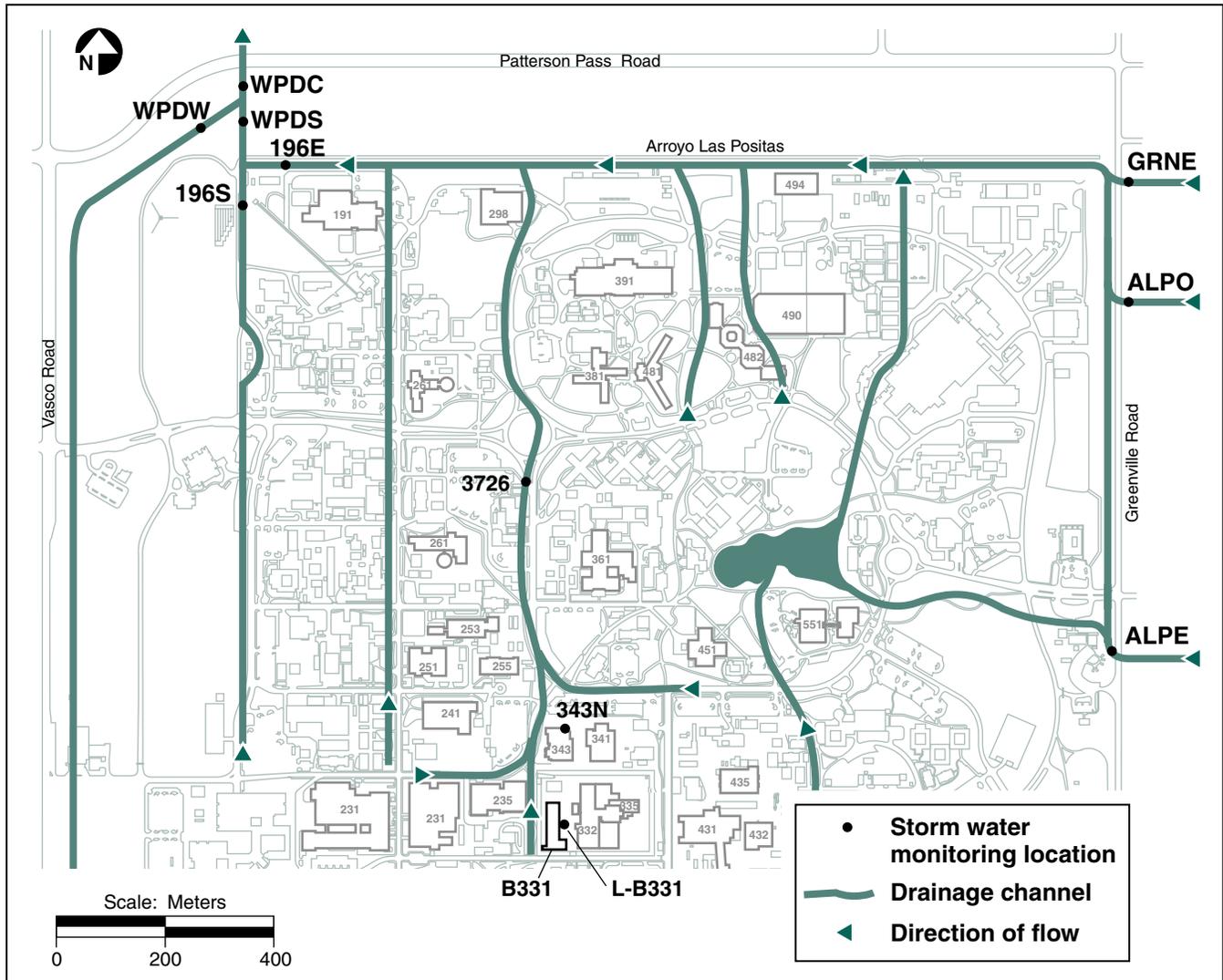


Figure 7-7. Sampling locations for the special tritium studies performed at Livermore site

mechanisms and implemented plans to prevent similar releases in the future.

Livermore Site Nonradioactive Constituents:

In addition to data on radioactivity, the results for other water quality parameters were analyzed. Sample results were compared with the comparison criteria in [Table 7-2](#); of greatest concern are the constituents that exceed comparison criteria at effluent points and whose concentrations are lower

in influent than in effluent. If influent concentrations are higher than effluent concentrations, the source is generally assumed to be unrelated to LLNL operations; therefore, further investigation is not warranted. Constituents that exceeded comparison criteria for effluent and influent locations are listed in [Table 7-7](#).

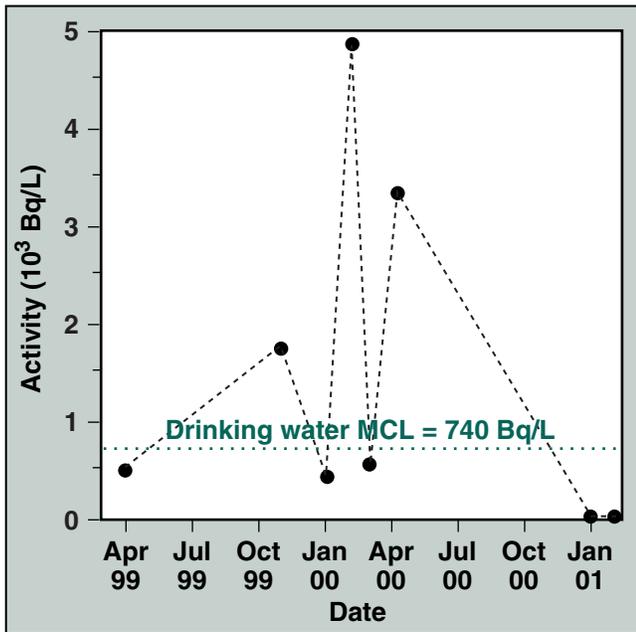


Figure 7-8. Tritium activities in storm water samples from the downstream storm drain location 3729 near the Tritium Facility

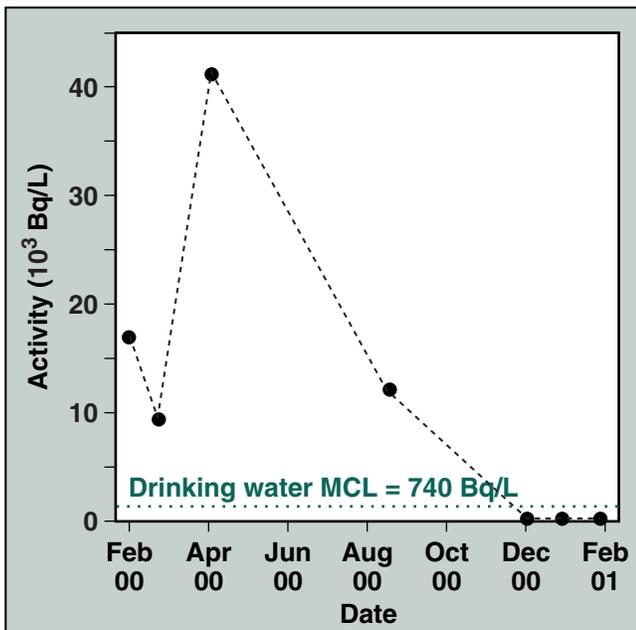


Figure 7-9. Tritium activities in storm water samples from the storm drains near Building 343

Many of the effluent values listed in [Table 7-7](#) were recorded at influent tributaries to Arroyo Las Positas and Arroyo Seco. In particular, nitrate values in storm water flowing on site in 2001 appear to be elevated. Upstream activities near the Livermore site include cattle ranching that is a potential source for nitrogen. Another influent contaminant is the herbicide diuron that was involved in the previously discussed algae toxicity.

The particularly high value of diuron at location GRNE on December 20 is the highest on record. The upstream electrical transfer station operators have been notified of this problem. A single high oil and grease value was measured at effluent location WPDC on January 8; this was an isolated incident likely resulting from roadway runoff.

Complete storm water results for nonradioactive constituents are presented in Data Supplement [Table 7-3](#).

To enhance the storm water monitoring program, in 2000 LLNL began to examine using easily measured water quality parameters as indicators for those not as easily measured. Many basic chemical characteristics (e.g., pH, dissolved oxygen, and specific conductance) of storm water may be monitored in the stream channel in real time. As a precursor to designing a storm water monitoring system to collect regular data over short sampling intervals, relationships between water quality parameters and an indicator, such as pH, must first be examined. To this end, LLNL performed regression analysis on the water quality data to relate pH and other storm water constituents.

Last year, significant correlations were found to exist between specific conductivity and other water quality parameters (Biermann et al. 2001). In 2001, various parameters were compared to pH and linear regression models, and the relative fits (R^2 values) of that model were estimated.

Table 7-7. Water quality parameters above the threshold comparison criteria shown in Table 7-2 from both the Livermore site and Site 300 in 2001

Parameter	Date	Location	Influent or Effluent	Result (mg/L)	LLNL threshold criteria (mg/L)
Livermore Site					
Nitrate (as NO ₃)	1/8	ALPO	Influent	12	10
	2/12	ALPO	Influent	13	10
	3/2	ALPO	Influent	14	10
	4/6	ALPO	Influent	11	10
	11/12	ALPO	Influent	10	10
	12/20	ALPO	Influent	22	10
	1/10	CDB	DRB	12	10
	2/12	CDB	DRB	12	10
	4/6	CDB	DRB	13	10
	11/12	CDB	DRB	13	10
	3/2	CDBX	DRB	10	10
	12/20	CDBX	DRB	15	10
	1/10	GRNE	Influent	37	10
	2/12	GRNE	Influent	10	10
	3/2	GRNE	Influent	10	10
	11/12	GRNE	Influent	69	10
	12/20	GRNE	Influent	19	10
	1/8	WPDC	Effluent	19	10
	12/20	WPDC	Effluent	12	10
	Oil and Grease	1/8	WPDC	Effluent	14
Chemical Oxygen Demand	11/12	ALPO	Influent	275	200
	12/20	CDB2	DRB	210	200
Bromacil	1/10	GRNE	Influent	2.5	none
	2/12	GRNE	Influent	1.2	none
	3/2	GRNE	Influent	0.65	none
	11/12	GRNE	Influent	0.3	none
	12/20	GRNE	Influent	6.9	none



Table 7-7. Water quality parameters above the threshold comparison criteria shown in Table 7-2 from both the Livermore site and Site 300 in 2001 (continued)

Parameter	Date	Location	Influent or Effluent	Result (mg/L)	LLNL threshold criteria (mg/L)	
Diuron	2/12	ALPO	Influent	0.08	0.014	
	3/2	ALPO	Influent	0.093	0.014	
	4/6	ALPO	Influent	0.018	0.014	
	4/6	CDB	DRB	0.021	0.014	
	4/6	CDB	DRB	0.021	0.014	
	3/2	CDB2	DRB	0.014	0.014	
	12/20	CDB2	DRB	0.015	0.014	
	1/10	GRNE	Influent	1.6	0.014	
	2/12	GRNE	Influent	0.079	0.014	
	3/2	GRNE	Influent	0.036	0.014	
	12/20	GRNE	Influent	5.3	0.014	
	1/8	WPDC	Effluent	0.014	0.014	
	12/20	WPDC	Effluent	0.051	0.014	
	Copper	11/12	ALPO	Influent	0.055	0.026
	Zinc	2/12	ASS2	Influent	0.39	0.35
Site 300						
Total suspended solids (TSS)	12/20	CARW	Influent	21000	1700	
	12/20	NPT7	Effluent	2300	1700	
Chemical Oxygen Demand	12/20	CARW	Influent	740	200	
	12/20	NPT7	Effluent	490	200	
Lead	12/20	CARW	Influent	0.14	0.015	
Mercury	12/20	CARW	Influent	0.00035	0.0002	

Good correlations were observed for total hardness, chloride, fluoride, sodium, specific conductivity, and sulfate with correlation coefficients (R^2) ranging from 0.65 to 0.53. All of these are likely correlated due to the groundwater source issue. No significant correlations exist with aluminum, iron, zinc, orthophosphate, and nitrate. This exercise demonstrates that the potential exists to use a few easily measurable water quality parameters to represent the transport distributions of other chemical

components in storm runoff. Both pH and specific conductance have been established to be reasonable indicators for general minerals (ions), some metals, total hardness, and sulfates in the storm water in the Arroyo Las Positas.

Livermore Site Construction Runoff: The NIF Construction SWPPP (Mathews 2001) documents the evaluation of the potential for nonvisible pollutants to contaminate construction site runoff.

The SWPPP includes evaluations of both the construction phase and potential previously existing pollutants. The SWPPP identifies PCBs as the only potential previously existing pollutant. No construction phase pollutants are identified because BMPs prevent exposure of the materials to storm water runoff.

Storm water samples were collected from the first three runoff-generating storm events. Samples collected on November 12 and 29, and December 20, 2001, indicated results of $<0.2 \mu\text{g/L}$ of PCBs in all influent and effluent samples. The results of this sampling, conducted during the 2001/2002 rainy season, will be reported to the SFBRWQCB in the July 2002 annual compliance certification.

Site 300 Sampling

LLNL procedures specify sampling a minimum of two storms per rainy season from Site 300. Typically, a single storm does not produce runoff at all Site 300 locations because Site 300 receives relatively little rainfall and is largely undeveloped. Therefore, at many locations, a series of large storms is required to saturate the ground before runoff occurs. In 2001, samples were collected at locations with flow on March 2, April 6, and December 20. There was no tritium above the minimum detectable activity in Site 300 storm water during 2001. The maximum values of all gross alpha and gross beta results were 0.31 and 0.96 Bq/L, respectively, approximately 55% and 52% of the drinking water MCLs (0.56 and 1.85 Bq/L). These gross alpha and gross beta values recorded on December 20, were the highest recorded for the year. Although these values are higher than those at the Livermore site, they are not unusual. This area has had relatively high background gross alpha and beta levels in stream flow that are closely associated with suspended sediment (Harrach et al. 1996).

Sampling at Pit 6 includes analyses required as part of the postclosure sampling; however, no storm runoff was sampled as the drains did not produce any runoff to collect in 2001.

Specific conductance and TSS at Site 300 locations were at times above internal comparison criteria and EPA benchmarks. However, effluent levels were lower than levels at the upstream location CARW, indicating that the levels observed in effluent are typical for the area. Suspended sediment is an issue in Corral Hollow Creek, but it is clear that activities at Site 300 are not producing a majority of that sediment. In fact, storm water from the site appears to be contributing to the dilution of the upstream water that contains higher sediment loads ([Table 7-8](#)).

Table 7-8. Total suspended solids in storm water samples from Site 300 in 2001

Sampled date	Location	Total suspended solids (mg/L)
3/2	CARW	94
3/2	GEOCRK	5.8
4/6	GEOCRK	32
4/6	NPT7	28
12/20	CARW	21000
12/20	GEOCRK	12
12/20	N883	31
12/20	NPT7	2300

All the values over the thresholds in [Table 7-7](#) at Site 300 are associated with high suspended sediment. Of particular concern is the high total suspended solids at sampling location NPT7. This sediment was reported to be fine particles resuspended from sediment traps. Regular maintenance of these traps is performed; however, in this case the maintenance was not in time to clear the sediment before this storm. In the future, careful



attention will be given to ensure sediment is removed for the traps prior to the start of the rainy season.

The valley floor is dominated by an off-road motorcycle use area and ranching activities that are potential sources for sediment. All other Site 300 results were below comparison criteria.

Rainfall

This section discusses general information about rainfall in the Livermore site, Livermore Valley, and Site 300, as well as methods for sampling rainfall and the sampling results. Rain water is collected and analyzed for tritium activities in support of DOE Orders 5400.1 and 5400.5. Currently only tritium activity measurements are required in this network as emissions from the Tritium Facility are the only activity associated with operations at LLNL that has the potential to impact rain water quality.

General Information

Livermore Site and Livermore Valley

Historically, the tritium activity measured in rainfall in the Livermore Valley results primarily from atmospheric emissions of tritiated water (HTO) from stacks at LLNL's Tritium Facility (Building 331), and from the former Tritium Research Laboratory at the Sandia National Laboratories/ California (Sandia/California). The total measured atmospheric emission of HTO from the Tritium Facility at LLNL in 2001 was 0.68 TBq (18.3 Ci) (see [Chapter 4](#)).

The rain sampling locations are shown in [Figure 7-10](#). The fixed stations are positioned to record all ranges of tritium activity including the maximum activity expected through background levels. The Building 343 rain sampling location is

near the Tritium Facility (Building 331) and has historically recorded the maximum tritium activity in rainfall.

Site 300

One off-site location (PRIM) and two on-site locations (COMP and TNK5) are used to collect rainfall for tritium activity measurements at Site 300 ([Figure 7-4](#)).

Methods

Rainfall is sampled for tritium according to written procedures described in Appendix B of the *Environmental Monitoring Plan* (Tate et al. 1999) and summarized here. Rainfall is collected in stainless-steel buckets at specified locations. The buckets are placed in open areas and are elevated about 1 m above the ground to prevent collection of splash-back water. Rainwater samples are decanted into 250-mL amber glass bottles with Teflon-lined lids. The tritium activity of each sample is measured by scintillation counting (EPA Method 906).

Results

Livermore Site and Livermore Valley

During 2001, LLNL collected sets of rain samples following 4 rainfall events at the Livermore site (31 total routine samples obtained) and Site 300 (12 total routine samples obtained). The tritium activities of rainwater samples obtained during 2001 are listed in [Table 7-6](#) of the Data Supplement.

The Livermore site rainfall has exhibited elevated tritium activities in the past (Gallegos et al. 1994). During 2001, however, no measurements of tritium activity in rainfall were above the 740 Bq/L MCL established by the EPA for drinking water. The activities of most samples were very low, and most were at background level. As in the past, the on-site rainfall sampling location 343N (the sampling location nearest the Tritium Facility)

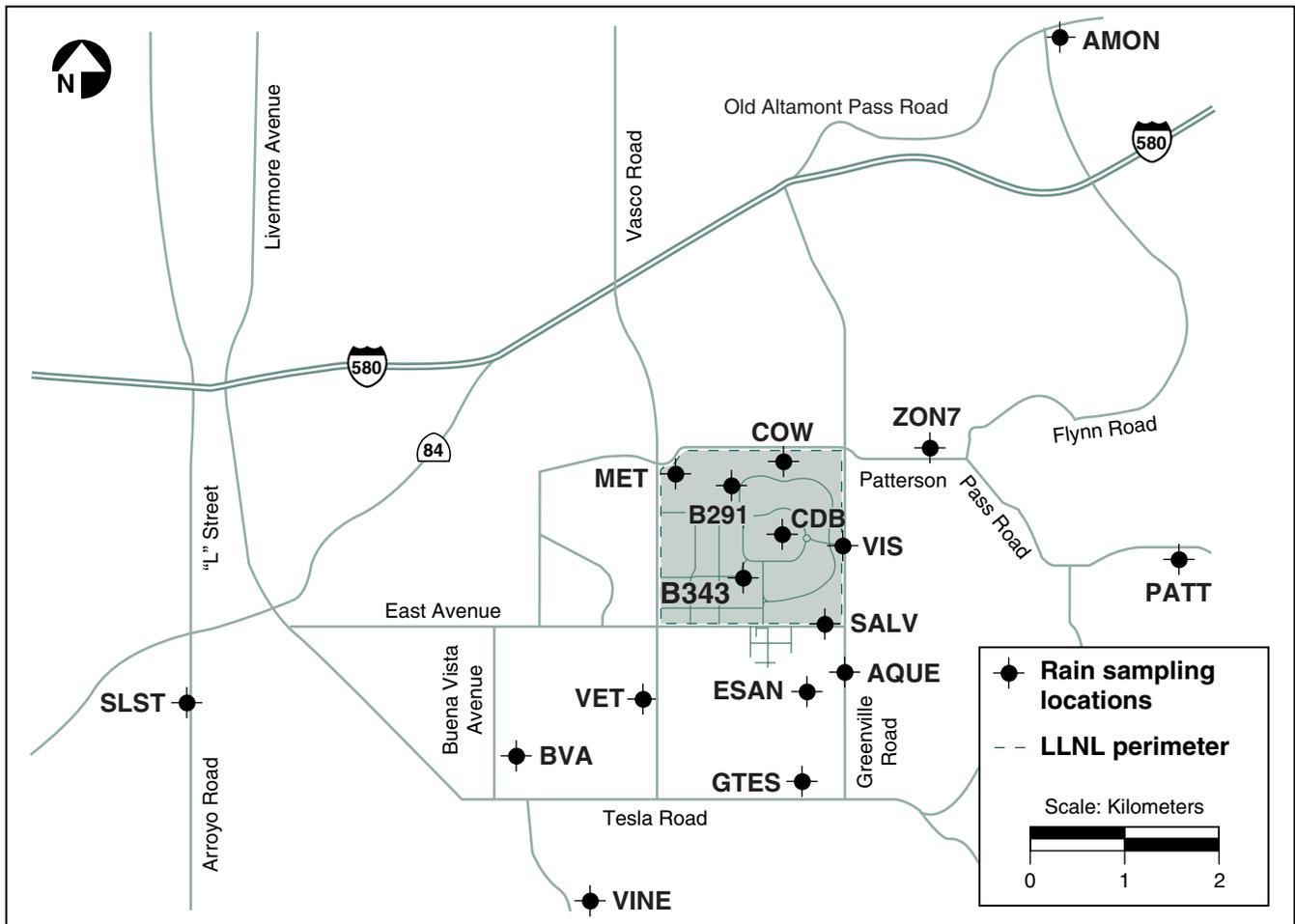


Figure 7-10. Rain sampling locations, Livermore site and Livermore Valley, 2001

showed the highest tritium activity for the year: 14.1 Bq/L (see [Table 7-9](#)) for the rainfall event that immediately preceded the February 12 collection date. The highest off-site tritium activity, measured in a routine sample during 2001, was less than 2.4 Bq/L (this sample was collected March 2 at location ESAN). All of the off-site routine rainfall samples measured during 2001 showed tritium activities less than 0.4% of the tritium MCL for drinking water.

The median tritium activity measured in rainfall at LLNL decreased from 3.7 Bq/L in 2000 to 1.97 Bq/L in 2001. This was primarily because of an overall reduction of on-site HTO emissions (see Chapter 4). The median tritium activity for rainfall at LLNL during 2001 reached its lowest level in the twelve-year period beginning in 1990 when it was 65.9 Bq/L. This decrease mirrors the downward trend in total HTO emissions from LLNL's Tritium Facility (shown in [Figure 7-11](#)).



Table 7-9. Tritium activities in rainfall for the Livermore site, Livermore Valley, and Site 300, 2001

Parameter	Livermore site (Bq/L)	Livermore Valley (Bq/L)	Site 300
Median	1.97	-0.69	0.34
Minimum	-2.65	-2.46	-2.19
Maximum	14.10	2.39	0.54
Number of samples	31	36	12

Note: Tritium activities are presented relative to a low activity standard or “dead water.” As a result, it is possible to have negative values or measurements that are lower than the reference “dead water” standard.

Tritium activities shown in [Figure 7-11](#) are derived from the on-site and valley rain sampling locations and have been placed in five groups based on their direction from the Tritium Facility. Onsite there have been elevated tritium activities in the last three years (particularly at those close to the Tritium Facility at the on-site sampling location B343 that are the likely result of the transportainer issue already discussed in the [Livermore Site Radioactive Constituents](#) section of the “Storm Water” section of this chapter). Grouping the sampling locations in this manner reveals the major direction the wind moves tritium from the stacks at the tritium facility. The locations southwest and northwest of the facility have the lowest tritium activities in rainfall. The highest tritium activities not in areas of known contamination are those northeast and southeast of the facility.

The higher values at the northeast and southeast directions are the result of tritium emissions from the Tritium Facilities at LLNL and Sandia/California. Operations at LLNL were significantly reduced after 1991, when the administrative limit for the LLNL Tritium Facility was reduced from 300 g to 30 g. Operations at the Sandia/California

Tritium Facility ceased in October 1994. The reduced measurements of tritium in rain reflect the reduction of emissions from the facilities.

Site 300

As in the past, none of the twelve routine rain samples obtained from monitoring locations at Site 300 during 2001 showed tritium activities above background activity, which is approximately 2 Bq/L (see [Table 7-6](#) in the Data Supplement).

Livermore Site Drainage Retention Basin

This section discusses general information about the DRB, sampling methods, and sampling results.

General Information

Previous environmental reports detail the history of the construction and management of the DRB (see Harrach et al. 1995, 1996, 1997). Beginning in 1997, LLNL discharges to the DRB included routine treated groundwater from Treatment Facilities D and E, and from related portable treatment units. These discharges contribute a year-round source of water entering and exiting the DRB. Storm runoff still dominates wet weather flows through the DRB, but discharges from the treatment facilities now constitute a substantial portion of the total water passing through the DRB.

The SFBRWQCB regulates discharges from the DRB within the context of the Livermore site CERCLA *Record of Decision* (ROD) (U.S. DOE 1993), as modified by the *Explanation of Significant Differences for Metals Discharge Limits at the Lawrence Livermore National Laboratory Livermore Site* (Berg et al. 1997). The CERCLA ROD establishes discharge limits for all remedial activities at the Livermore site to meet applicable, relevant, and appropriate requirements derived from laws and regulations identified in the ROD, including the

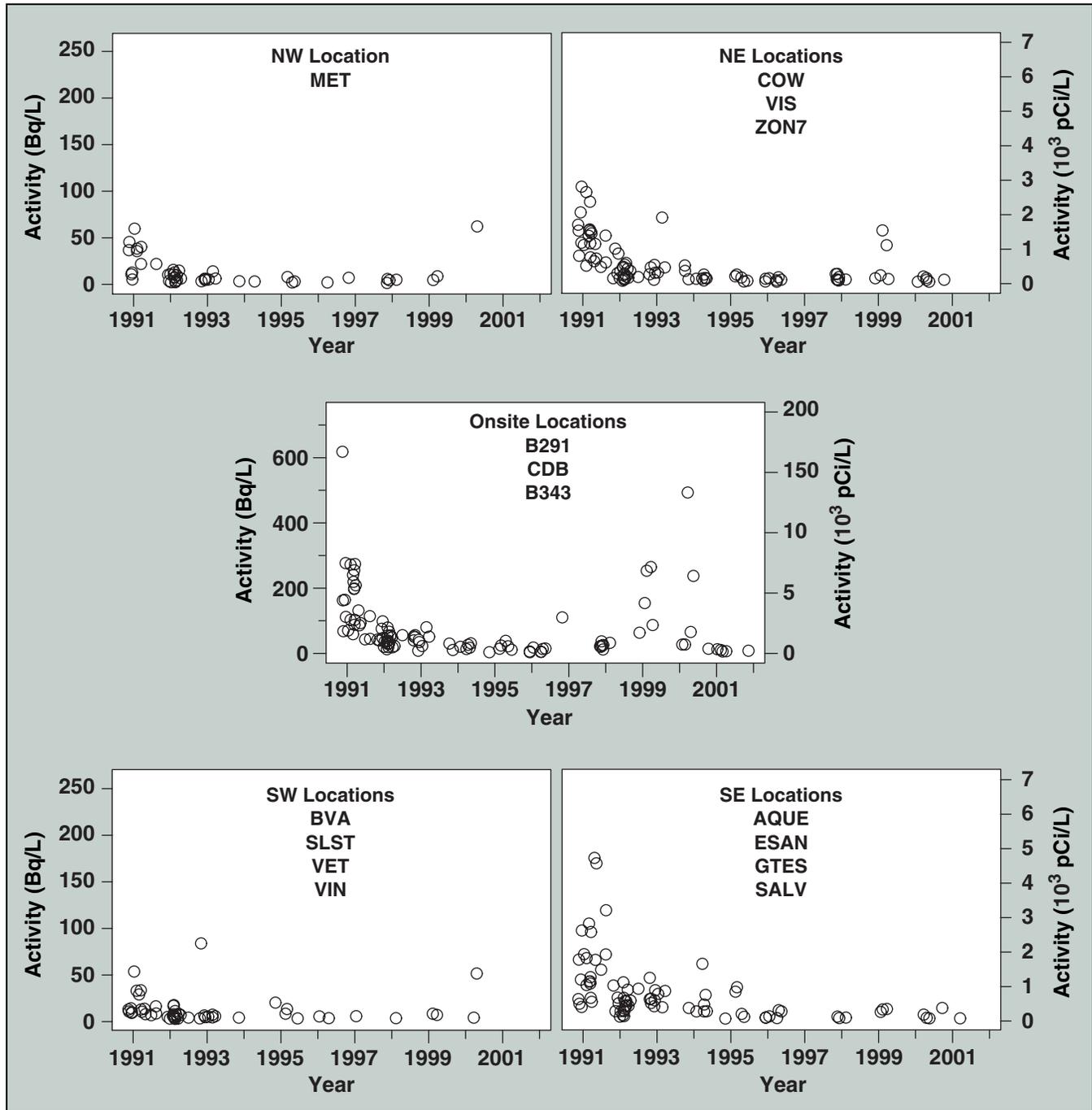


Figure 7-11. Mean tritium activities (detections only) in rain at locations in the Livermore vicinity grouped by direction from the Tritium Facility, 1990-2001



Federal Clean Water Act, the Federal and State Safe Drinking Water Acts, and the California Porter-Cologne Water Quality Control Act.

The DRB sampling program implements requirements established by the SFBRWQCB. The program consists of monitoring wet and dry weather releases for compliance with discharge limits, monitoring DRB water quality to support management actions established in the *Drainage Retention Basin Management Plan* (DRB Management Plan) (Limnion Corporation 1991), characterizing water quality before its release, and performing routine reporting. For purposes of determining discharge monitoring requirements and frequency, the wet season is defined as October 1 through May 31, the period when rain-related discharges usually occur (Galles 1997). Discharge limits are applied to the wet and dry seasons as defined in the *Explanation of Significant Differences for Metals Discharge Limits at the Lawrence Livermore National Laboratory Livermore Site* (Berg et al. 1997) (wet season December 1 through March 31, dry season April 1 through November 30).

To characterize wet-season discharges, LLNL samples DRB discharges (at location CDBX) and the corresponding site outfall (at location WPDC) during the first release of the rainy season, and from a minimum of one additional storm (chosen in conjunction with storm water runoff sampling). During the dry season, samples are collected, at a minimum, from each discrete discharge event. Discharge sampling locations CDBX and WPDC are shown in [Figure 7-2](#). LLNL collects samples at CDBX to determine compliance with discharge limits. Sampling at WPDC is done to identify any change in water quality as the DRB discharges travel through the LLNL storm water drainage system and leave the site. Sampling frequencies for

CDBX and WPDC and effluent limits for discharges from the DRB, applied at CDBX, are found in [Table 7-7](#) of the Data Supplement.

The routine management constituents, management action levels, and monitoring frequencies that apply to water contained in the DRB are identified in Data Supplement [Table 7-8](#) and were established based on recommendations made in the DRB Management Plan. LLNL collects samples at the eight locations identified in [Figure 7-12](#) to determine whether water quality management objectives are met. Dissolved oxygen content and temperature are measured at the eight locations, while samples for the remaining chemical and physical constituents are collected from sample location CDBE because of the limited variability for these constituents within the DRB. CDBE is located at the middle depth of the DRB.

The DRB Management Plan identifies biological and microbiological surveys that are used as the primary means to assess the long-range environmental impact of DRB operations. LLNL monitors plant and animal species at the DRB, the drainage channels discharging into the DRB, and downstream portions of Arroyo Las Positas. LLNL's biologist conducts semiannual surveys to identify the presence or absence of amphibians, birds, and fishes, and annual surveys for mammals and plants.

Beginning in December 2000 and continuing into January 2001, LLNL drained the DRB as part of LLNL's bullfrog control strategy related to managing facility operation impacts on the California red-legged frog (*Rana aurora draytonii*), a federally listed threatened species. The draining was conducted following a plan submitted to and approved by the SFBRWQCB. Sediment-laden discharges were routed through sediment filter bags prior to discharging to the storm drainage system.

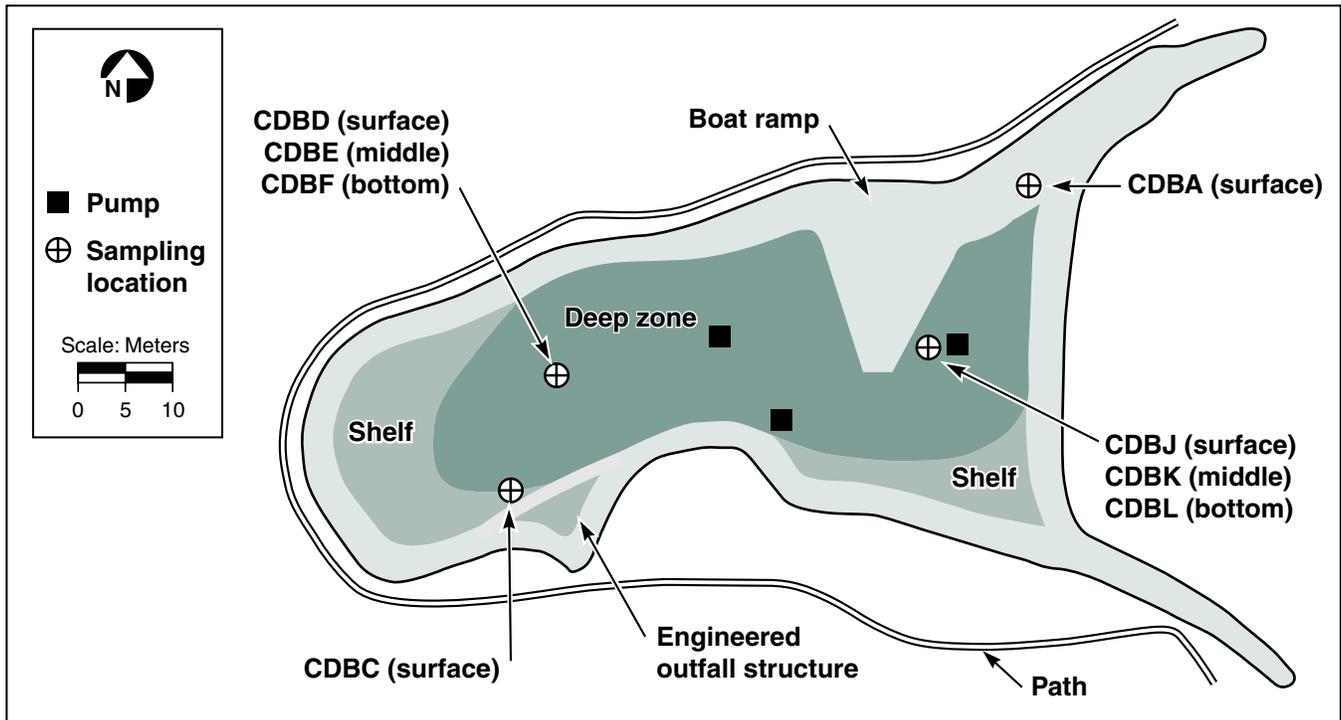


Figure 7-12. Sampling locations within the Drainage Retention Basin, 2001

Methods

Sample collection procedures are discussed in Appendix B of the *Environmental Monitoring Plan* (Tate et al. 1999). All samples from the DRB are collected as grab samples. Field measurements for dissolved oxygen and temperature are made using a dissolved oxygen/temperature meter, turbidity is measured using a Hach brand test kit, and transparency is measured using a Secchi disk. Certified laboratories analyze the collected samples for additional chemical and physical parameters.

Biological and microbiological methods are discussed in detail in the *Environmental Monitoring Plan* (Tate et al. 1999). Biological surveys are conducted by LLNL's biologist. Animal surveys follow standard survey protocols such as *Raptor Management Techniques Manual* (Pendleton et al.

1987), *Inventory and Monitoring of Wildlife Habitat* (Cooperrider et al. 1986), and *Wildlife Management Techniques Manual* (Schemnitz 1980). Vegetation surveys use protocols identified in the *U.S. Army Corps of Engineers Wetlands Delineation Manual* (Environmental Laboratory 1987). Because of a lack of resources, LLNL was again unable to conduct the microbiological survey in 2001.

Results

Samples collected during 2001 within the DRB at CDBE for dissolved oxygen saturation, temperature, transparency, nitrate (as N), total dissolved solids (TDS), total phosphorus (as P), ammonia nitrogen (as N), chemical oxygen demand, pH, and specific conductance ([Table 7-10](#)) did not meet the management action levels and triggered



administrative review. Water releases were scheduled to adjust nutrient levels. Samples collected at CDBX and WPDC exceeded only the pH discharge limit (**Table 7-10**).

Data for maintenance and release monitoring at sampling locations CDBA, CDBC, CDBD, CDBE, CDBF, CDBJ, CDBK, CDBL, CDBX, and WPDC, and from the biological survey are presented in **Tables 7-11** through **7-14** in the Data Supplement.

Chemical and Physical Monitoring

Monthly averages for surface-level dissolved oxygen saturation were at or above the management action level of at least 80% oxygen saturation for 4 of 12 months. Oxygen saturation represents the oxygen available to aquatic organisms and is determined by the water temperature and the dissolved oxygen concentration. Dissolved oxygen concentrations can be manually increased using aeration pumps. These pumps are started whenever oxygen concentrations at any level of the DRB drop close to or below the management action level of 5 mg/L.

Chemical oxygen demand was above management action levels during the third and fourth quarters of 2001. Chlorophyll-a, though below the management action level of 10,000 µg/L, had one summer peak indicating an algae bloom (**Figure 7-13**).

The chlorophyll-a levels can be used as an indicator of algae populations and of the duration and intensity of algae blooms. The elevated pH level within the DRB corresponds to the peak of the fall bloom and may be associated with the occurrence of increased photosynthesis. The highest pH readings seen in the DRB discharge samples also correspond to the peak of the fall bloom.

Beginning during the summer of 1994, transparency was below the management action level of 0.91 meters. Through January 2001, it continued to be mostly below 0.91 meters clarity (**Figure 7-14**). However, throughout the remainder of 2001, the transparency in the DRB began to increase, with July and December showing the only measurements exceeding the action level. (Secchi disk depth readings became larger, indicating clearer water). The loss of transparency seen during the warmer summer months is most likely the result of algae growth (Harrach et al. 1996).

Beginning in the 1999/2000 wet season and throughout 2001, LLNL began to operate the DRB to minimize the water level fluctuations and maintain the water level as much as possible between 1 and 2 feet above the shelf. This management strategy allowed both submergent and emergent vegetation to be established throughout the DRB for the first time, which may explain the trend toward increased clarity.

Nutrient levels continued to be high during 2001 (**Figure 7-15**). Concentrations were well above management action levels throughout the year, but decreased concentrations occurred in the periods when chlorophyll-a was high (**Figure 7-13**), possibly indicating an uptake of nutrients during algae growth. Total phosphorus remained fairly constant throughout 2001, ending in concentrations near the management action levels. Sources of nitrate and phosphorous include external sources, storm water runoff, treated groundwater discharges, and an internal source of nutrient cycling related to algae and plant growth.

During 2001, total dissolved solids continued to exceed the management action levels with the concentration exceeding 360 mg/L in all 11 months when samples were collected. Specific conductance exceeded the management action

Table 7-10. Summary of Drainage Retention Basin monitoring not meeting management action levels

Parameter	Management action level	Jan	Feb	Mar	Apr	May	June
Sampling location CDBE							
Ammonia nitrogen (as N) (mg/L)	>0.1	0.3	— ^(a)				
Dissolved oxygen saturation (%) ^(b)	<80% saturation	70	— ^(a)				
Temperature (degrees C) ^(b)	<15 and >26	9.4	10.3	14.6	— ^(a)	— ^(a)	— ^(a)
Transparency (m) ^(b)	<0.91	0.254	0.749	— ^(a)	— ^(a)	— ^(a)	— ^(a)
Nitrate (as N) (mg/L)	>0.2	2.3	— ^(c)	2	1.7	1.1	0.66
Specific conductance (μS/cm)	>900	— ^(a)	— ^(c)	— ^(a)	— ^(a)	— ^(a)	950
Total dissolved solids (TDS) (mg/L)	>360	423	— ^(c)	503	490	470	563
Total phosphorus (as P) (mg/L)	>0.02	0.14	— ^(c)	0.06	0.07	<0.05	0.18
Chemical oxygen demand (mg/L)	>20	— ^(a)	— ^(d)	— ^(d)	— ^(a)	— ^(d)	— ^(d)
		July	Aug	Sep	Oct	Nov	Dec
Sampling location CDBE (continued)							
Dissolved oxygen saturation (%) ^(b)	<80% saturation	— ^(a)	— ^(a)	70	— ^(a)	64	79
Temperature (degrees C) ^(b)	<15 and >26	— ^(a)	10.7				
Transparency (m) ^(b)	<0.91	— ^(a)					
Nitrate (as N) (mg/L)	>0.2	— ^(a)	— ^(a)	— ^(a)	1.8	1.5	— ^(a)
pH (pH units)	not <6.0 and >9.0	9.04	— ^(a)	9.06	— ^(a)	— ^(a)	— ^(a)
Specific conductance (μS/cm)	>900	991	1070	1070	1120	1100	1040
Total dissolved solids (TDS) (mg/L)	>360	580	617	690	663	667	613
Total phosphorus (as P) (mg/L)	>0.02	0.06	0.06	0.06	0.07	0.1	0.07
Chemical oxygen demand (mg/L)	>20	41	— ^(d)	— ^(d)	22	— ^(d)	— ^(d)
	Discharge limit	2 Mar	26 Jun	11 Jul	6 Aug	6 Sep	12 Nov
Sampling location CDBX							
pH (pH units)	not <6.5 and >8.5	— ^(a)	8.66	9.07	8.93	9.02	— ^(a)
Sampling location WPDC							
pH (pH units)	not <6.5 and >8.5	— ^(a)	— ^(a)	9.03	8.72	— ^(a)	— ^(a)
		20 Dec					
Sampling location CDBX							
pH (pH units)	not <6.5 and >8.5	— ^(a)					
Sampling location WPDC							
pH (pH units)	not <6.5 and >8.5	— ^(a)					

a Concentrations met management action level or discharge limit.

b Monthly average, measurements taken weekly

c February samples were collected on January 30, 2001.

d Chemical oxygen demand was analyzed once per quarter.

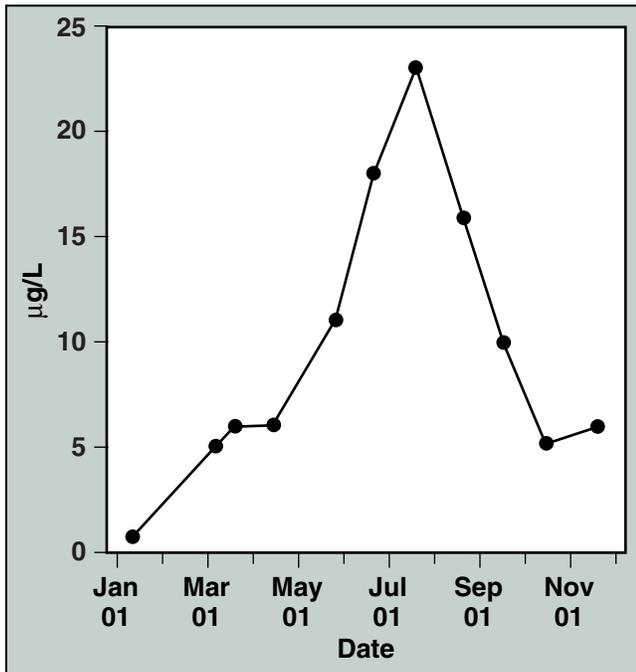


Figure 7-13. Monthly chlorophyll-a in the Drainage Retention Basin, 2001

level of 900 $\mu\text{S}/\text{cm}$ for 7 months, showing a relation between the increase in TDS and the increase seen in specific conductance.

LLNL collects and analyzes samples for acute fish toxicity and for the chronic toxicity of three species (fathead minnow, water flea, and algae) a minimum of once per year from sample location CDBE and upon the first wet-season release at CDBX. In addition, LLNL collects acute fish toxicity samples from each discrete dry-season release. Samples collected in October from sample location CDBE showed minor algae toxicity (2 toxic units). All other toxicity samples collected showed no toxic effects.

Biological Monitoring

Biological monitoring has not been conducted long enough to identify any trends resulting from operation of the DRB. However, biological monitoring has revealed an expansion in the wetland areas in

Arroyo Las Positas; this increase appears to be a result of the continuous discharges of water from the DRB and other sources of treated groundwater throughout the dry season. The California red-legged frog is found in Arroyo Las Positas and the DRB. A number of other species routinely use the DRB, its tributaries, and receiving water; they are listed in Data Supplement [Table 7-14](#).

Site 300 Cooling Towers

This section discusses general information about the Site 300 cooling towers, sampling methods, and sampling results.

General Information

The CVRWQCB rescinded WDR 94-131, NPDES Permit No. CA0081396, on August 4, 2000, which previously governed discharges from the two primary cooling towers at Site 300. The CVRWQCB determined that these cooling towers discharge to the ground rather than to surface water drainage courses. Therefore, the CVRWQCB is amending WDR 96-248 to incorporate these cooling tower discharges, and other low-threat discharges, going to ground. Pending the incorporation of the cooling tower discharges into WDR 96-248, LLNL continues to monitor the cooling tower wastewater discharges following the WDR 94-131 monitoring requirements.

Two primary cooling towers, located at Buildings 801 and 836A, regularly discharge to the ground. Cooling tower locations are shown in [Figure 7-16](#). Blowdown flow is monitored biweekly from the cooling towers located at Buildings 801 and 836A. TDS and pH are monitored quarterly at both of these locations.

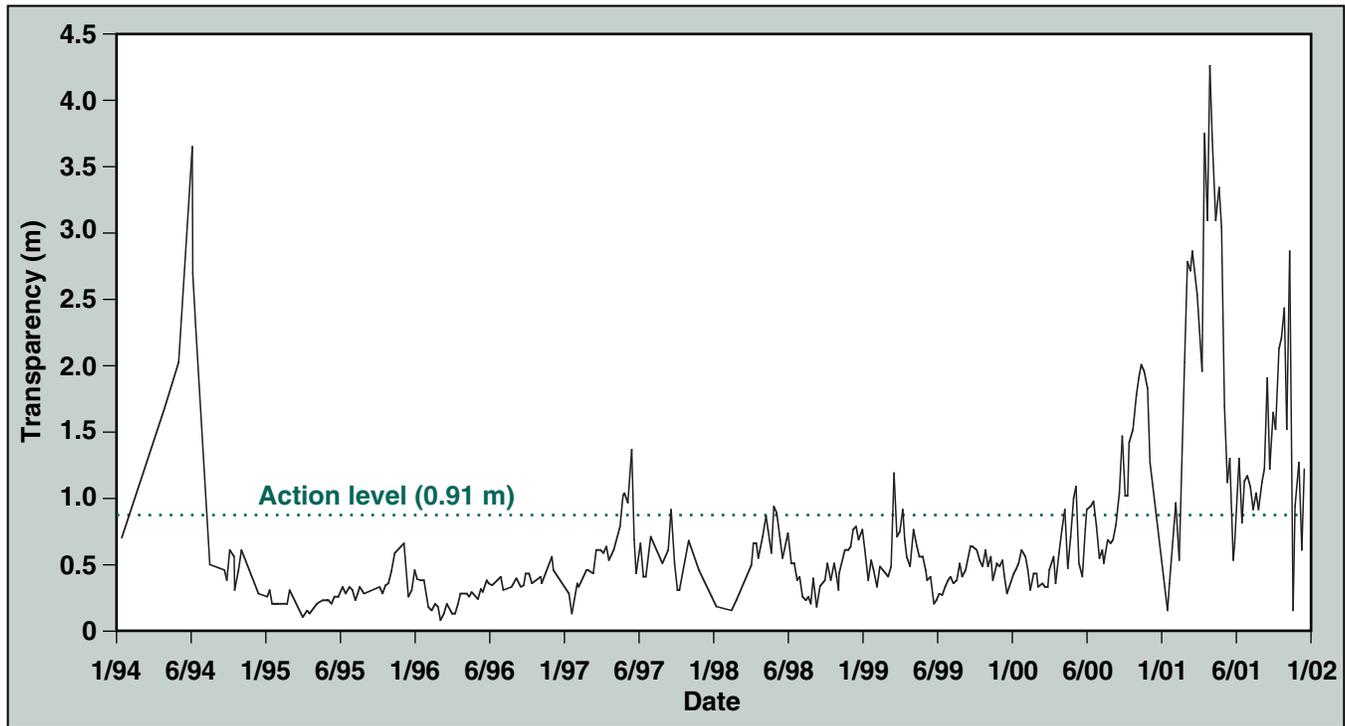


Figure 7-14. Transparency in Drainage Retention Basin, 1994–2001

The 13 secondary cooling towers routinely discharge to percolation pits under a waiver of Waste Discharge Requirements from the CVRWQCB. However, the percolation pit at Building 827A malfunctioned on October 3, 2000, and construction of a new percolation pit was not completed until March 2001. During the demolition and construction processes, blowdown from cooling towers 827-1 and 827-2 was recirculated or otherwise discharged to ground to prevent discharge to surface water. During this period, blowdown from the Building 827A cooling towers was monitored for flow, TDS and pH. These results are discussed below. On March 21, 2001, blowdown from the Building 827A cooling towers was routed into the new percolation pit.

Methods

Sample collection procedures are discussed in Appendix B of the *Environmental Monitoring Plan* (Tate et al. 1999) and summarized here. To determine the effects of the cooling tower blowdown on Corral Hollow Creek, the permit requires quarterly pH monitoring of the creek, both upstream (background) and downstream of the cooling tower discharges, whenever the creek is flowing. CARW is the upstream sampling location, and GEOCRK is the downstream sampling location ([Figure 7-16](#)).

The GEOCRK sampling location is also fed by discharges of treated groundwater from LLNL. Therefore, even when the upstream location is dry, there is often flow at GEOCRK. Field pH measurements, taken by LLNL technicians using calibrated

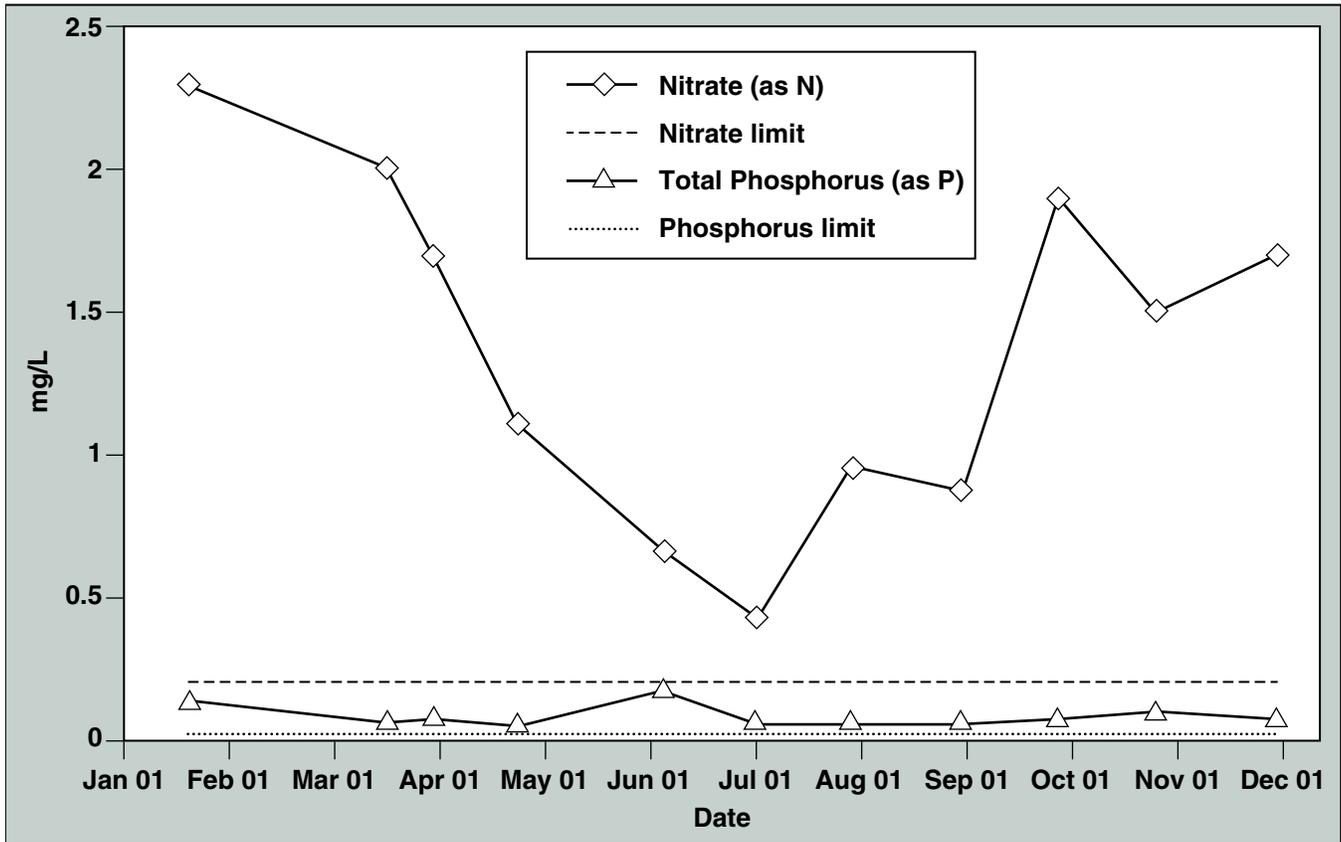


Figure 7-15. Nutrient levels in the Drainage Retention Basin, 2001

meters, are used to monitor Corral Hollow Creek. These technicians also perform the required visual observations that are recorded on the field tracking forms along with the field pH measurements.

If the blowdown flow from any of the 13 secondary cooling towers is diverted to a surface water drainage course, the discharge is sampled for pH and TDS immediately. If the discharge continues, that location is monitored for the same constituents and on the same schedule as the primary cooling towers.

Results

Monitoring results indicate that all discharges from the Buildings 801 and 836A cooling towers were below the maximum permitted values, previously imposed for discharges to surface water drainage courses, under WDR 94-131. [Table 7-11](#) summarizes the data from the quarterly TDS and pH monitoring, as well as the biweekly measurements of blowdown flow. Because the Building 801 cooling tower was out of service during the first quarter of 2001 for installation of a new cooling tower, and flow meters on the new tower were not operational until June, the [Table 7-11](#) summary data for tower 801 consist of only June through December monitoring results.

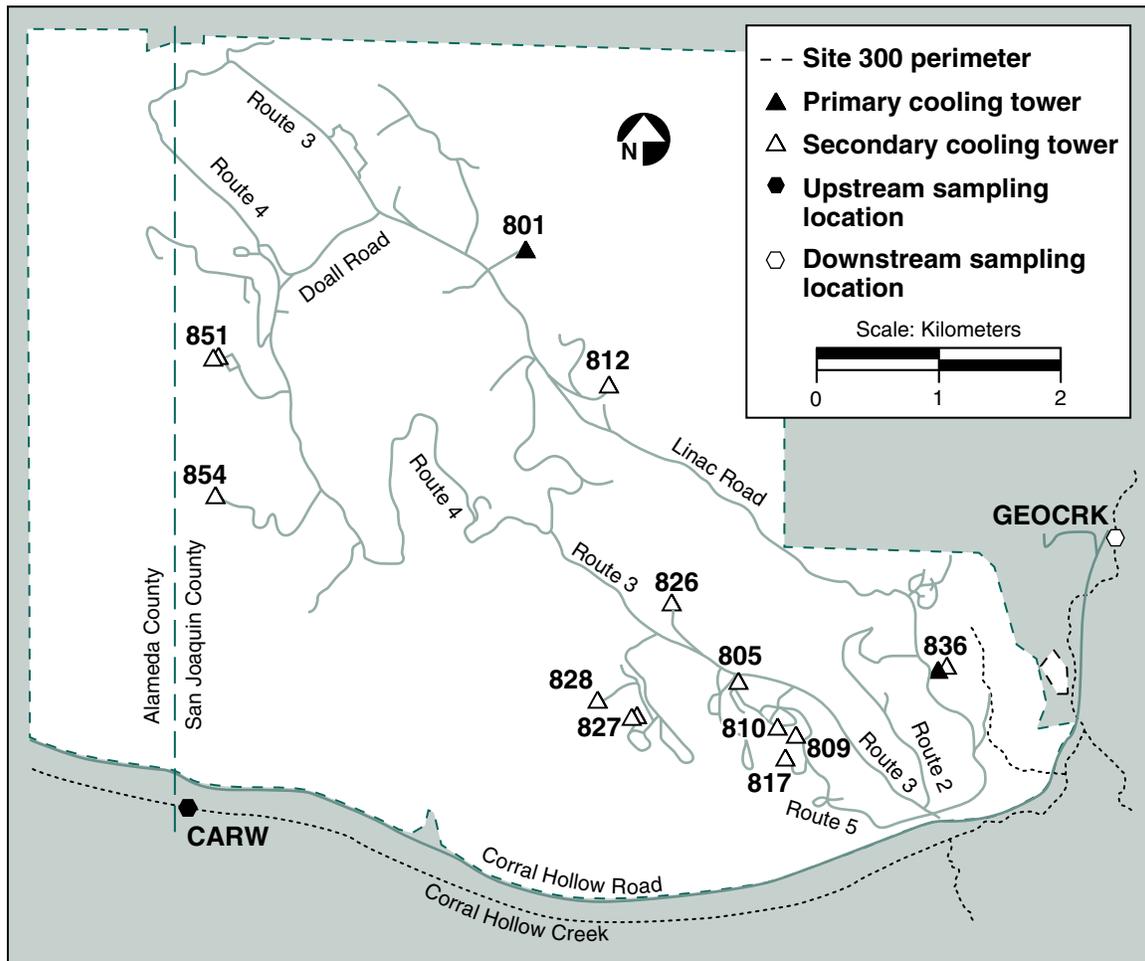


Figure 7-16. Cooling tower locations and receiving water monitoring locations, Site 300, 2001

As previously discussed, blowdown from cooling towers 827-1 and 827-2 was recirculated or otherwise discharged to ground to prevent discharge to surface water during the demolition and reconstruction of the Building 827A percolation pit. On March 21, 2001, blowdown from the Building 827A cooling towers was routed into the new percolation pit. Prior to that date, first quarter pH and TDS samples had been collected and six biweekly flow measurements had been recorded.

Independent analytical results were 9.5 pH and 5600 mg/L TDS for the combined discharge from both cooling towers. The pH value of 9.5 is below

the former limit of 10 for discharge to surface waters. Although the TDS value is above the former limit (5000 mg/L) for discharges to surface waters, LLNL biweekly field measurements, performed during the first quarter of 2001, report TDS values ranging from 750 to 5000 mg/L for blowdown from the Building 827A towers. Furthermore, the CVRWQCB has determined that these now rescinded WDR 94-131 limits do not apply to cooling tower discharges to the ground. Biweekly flow data, prior to March 21, 2001, show a range of 1356 to 9429 L/day discharged from the combined operation of towers 827-1



Table 7-11. Summary data from monitoring of primary cooling towers, Site 300, 2001

Test	Tower no.	Minimum	Maximum	Median	Interquartile range	Number of samples
Total dissolved solids (TDS) (mg/L)	801	1400	1400	1400	— ^(a)	3
	836A	1200	1400	1400	— ^(a)	4
Blowdown flow (L/day)	801	1802	13783	7022	9244	15
	836A	0	3149	1348	1536	26
pH (pH units)	801	9.0	9.1	9.1	— ^(a)	3
	836A	8.8	9.1	9.0	— ^(a)	4

^a Not enough data points to determine

and 827-2, below the former permit limit of 11,355 L/day for the combined flow from these two towers.

The biweekly observations at CARW and GEOCRK reported conditions ranging from low flow to dry for both sampling locations throughout 2001. Only on March 1 was there adequate flow to measure pH. The resulting field pH measurements were 8.85 and 8.93 for CARW and GEOCRK locations, respectively, indicating essentially no change between the upstream and downstream locations. Visual observations of Corral Hollow Creek were performed each quarter, and no visible oil, grease, scum, foam, or floating suspended materials were noted in the creek during 2001.

Site 300 Drinking Water System Discharges

This section discusses general information about the monitoring requirements for discharges from the Site 300 drinking water system, including permit information, sampling methods, and sampling results.

General Information

LLNL samples large-volume discharges from the Site 300 drinking water system that reach surface water drainage courses in accordance with the requirements of WDR 5-00-175, NPDES General Permit No. CAG995001. LLNL obtained coverage under this general permit for drinking water system discharges to surface waters when WDR 94-131 was rescinded in August 2000. The monitoring and reporting program that LLNL developed for these discharges was approved by the CVRWQCB.

Discharges that are subject to sampling under WDR 5-00-175 include:

Drinking Water Storage Tanks: monitor all discharges that have the potential to reach surface waters.

System flushes: monitor one flush per pressure zone per year for flushes that have the potential to reach surface waters.



Dead-end flushes: semiannually monitor all flushes that have the potential to reach surface waters, and for any discharge that continues for more than four months.

Discharges must comply with the effluent limits for residual chlorine established by the permit, which require that it must not be greater than 0.02 mg/L, and that the pH must be between 6.5 and 8.5. Discharges are also observed to ensure that no erosion results and no other pollutants are washed into surface waters. To meet the chlorine limit, drinking water system discharges with the potential to reach surface waters are dechlorinated.

Methods

Sample collection procedures are discussed in *Lawrence Livermore National Laboratory Site 300 Water Suppliers' Pollution Prevention and Monitoring and Reporting Program* (Mathews 2000). Grab samples are collected in accordance with Operations and Regulatory Affairs Division (ORAD) procedures EMP-W-S and EMP-WSS-WSD. Residual chlorine and pH are immediately analyzed in the field, using a spectrophotometer and calibrated pH meter, respectively.

Samples are collected at the point of discharge and at the point where the discharge flows into a surface water. If the discharge reaches Corral Hollow Creek, samples are collected at the upstream sampling location, CARW, and the downstream sampling location, GEOCRK (see [Figure 7-17](#)).

Results

Monitoring results are detailed in the quarterly self-monitoring reports to the CVRWQCB. No drinking water system discharges occurred under the requirements of WDR 5-00-175 in calendar year 2001.

Other Waters

This section discusses general information about monitoring network requirements, sampling methods, and sampling results.

General Information

Additional surface water monitoring is required by DOE Order 5400.1, *General Environmental Protection Program*, and DOE Order 5400.5, *Radiation Protection of the Public and the Environment*. Surface and drinking water near the Livermore site and in the Livermore Valley are sampled at the locations shown in [Figure 7-18](#). Sampling locations DEL, ZON7, DUCK, ALAG, SHAD, and CAL are surface water bodies; of these, DEL, ZON7, and CAL are drinking water sources. BELL, GAS, PALM, ORCH, and TAP are drinking water outlets. Location POOL is the on-site swimming pool. Radioactivity data from drinking water sources and drinking water outlets are used to calculate drinking water statistics (see [Table 7-12](#)) and doses.

Methods

Samples are analyzed for gross alpha, gross beta, and tritium, according to procedures set out in Appendix B of the *Environmental Monitoring Plan* (Tate et al. 1999). LLNL sampled these locations semiannually, in February and July 2001, for gross alpha, gross beta, and tritium. The on-site swimming pool location (POOL) was sampled semiannually for gross alpha and gross beta, and quarterly for tritium.

Results

The median activity for tritium in surface and drinking waters, with the exception of one of the quarterly POOL samples, was estimated from calculated values to be below the laboratory's

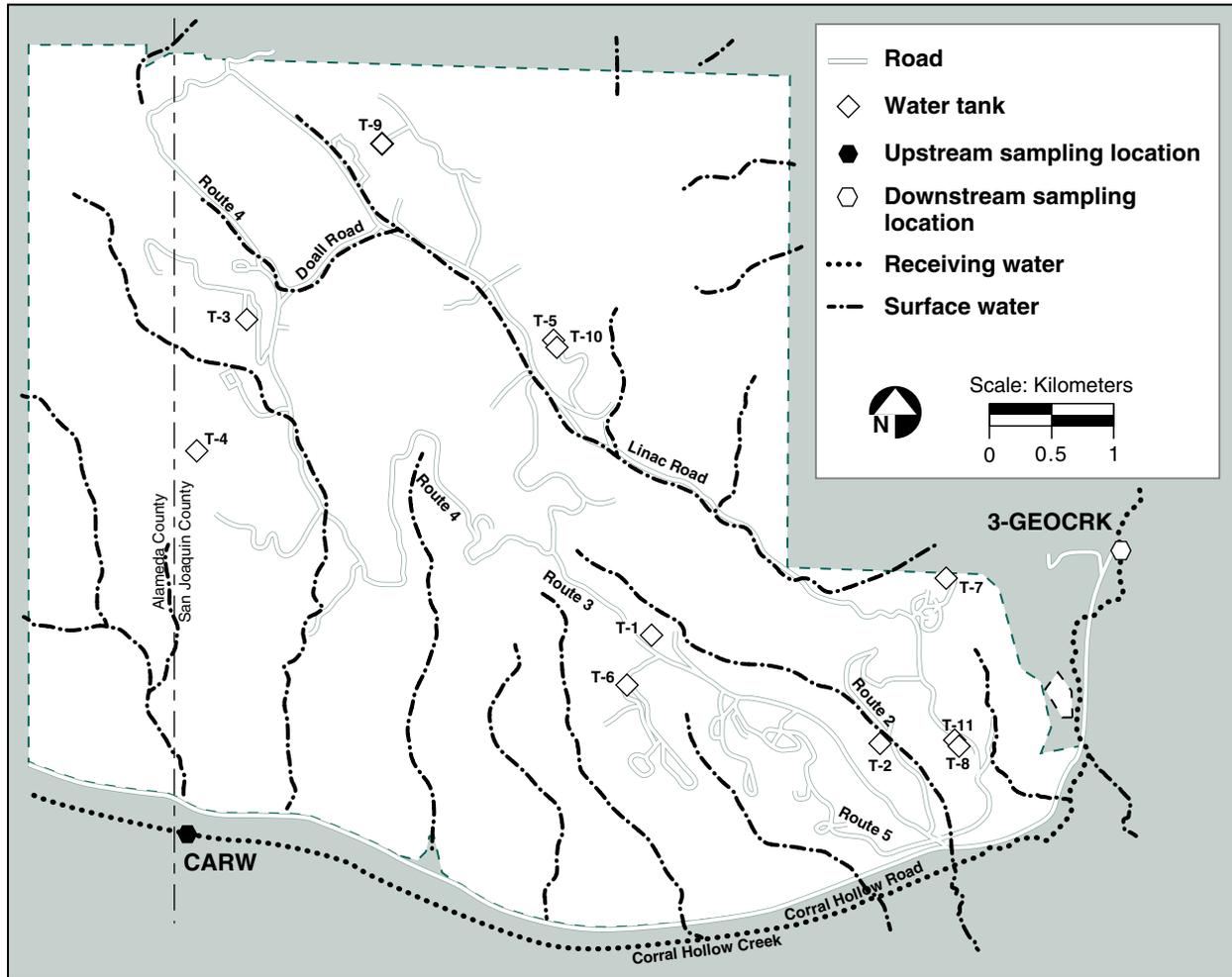


Figure 7-17. Site 300 surface waters, drinking water tanks, and receiving water monitoring locations

minimum detectable activities, or minimum quantifiable activities. The maximum tritium activity detected was less than 0.5% of the MCL in LLNL's on-site swimming pool. Median activities for gross alpha and gross beta radiation in surface and drinking water samples were both less than 5% of their respective MCLs. However, maximum activities detected for gross alpha and gross beta, respectively, were 0.099 Bq/L and 0.177 Bq/L; both less than 20% of their respective MCLs (see [Table 7-12](#)). Detailed data are in [Table 7-15](#) of the Data Supplement. Historically, gross alpha and gross beta radiation have fluctuated around the

laboratory minimum detectable activities. At these very low levels, the counting error associated with the measurements are nearly equal to the measured values so that no trends are apparent in the data.

Historical median tritium values in surface and drinking waters in the Livermore Valley since 1988 are shown in [Figure 7-19](#). Since 1988, when measurements began, water in the LLNL swimming pool has had the highest tritium activities because it is closest to tritium sources within LLNL. The highest individual tritium activity measured in the pool was 87.3 Bq/L in a sample collected in the

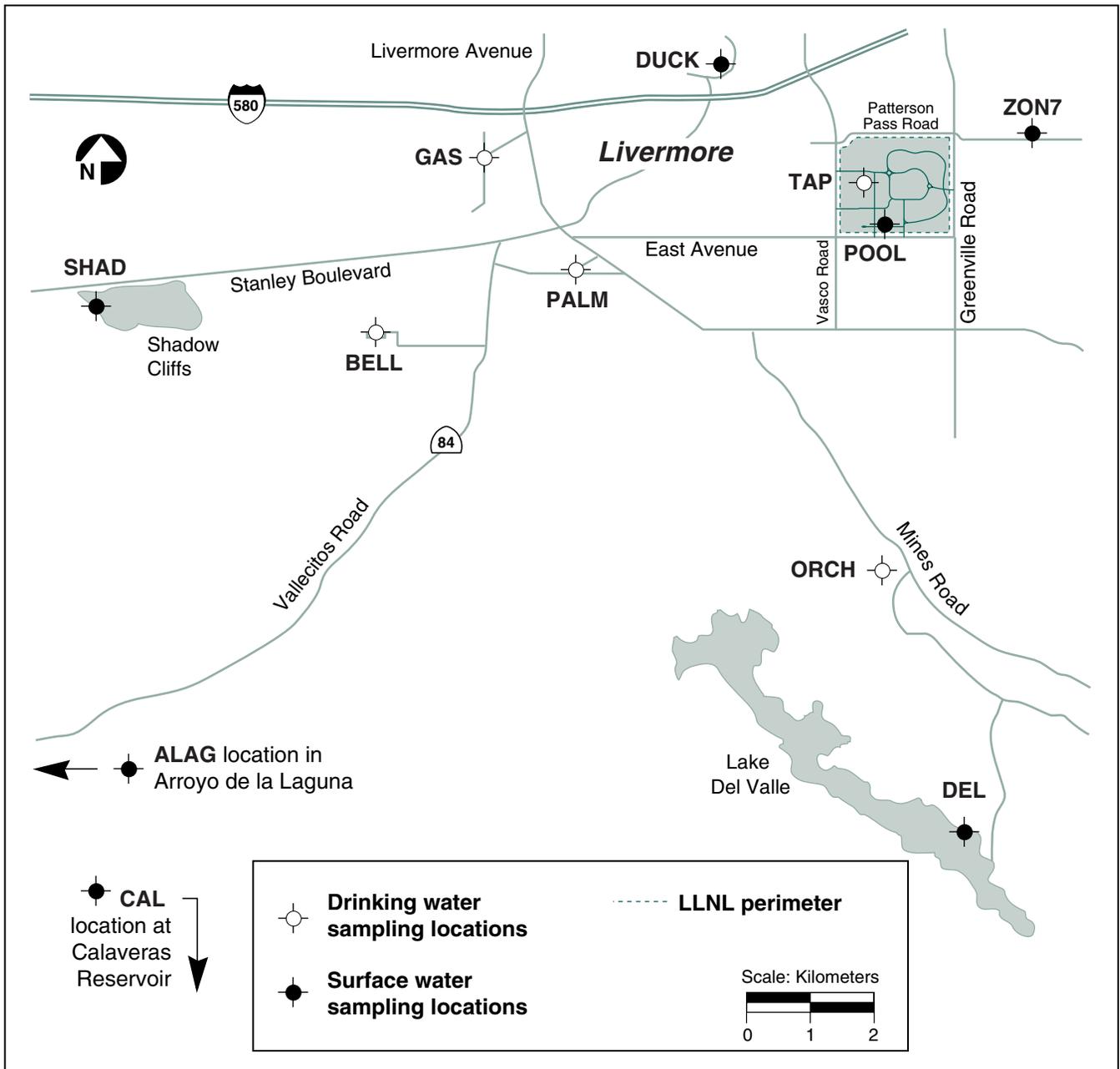


Figure 7-18. Surface and drinking water sampling locations, Livermore Valley, 2001

second quarter of 1988 (equal to about 12% of the drinking water MCL). The highest historical drinking water activity measured for tritium was 3.03 Bq/L or about 0.4% of MCL, in a first quarter

1988 sample from location ORCH, a well used for drinking water. Tritium activities in the LLNL pool and in the other surface and drinking water locations have been decreasing since that time.



Table 7-12. Radioactivity in surface and drinking water in the Livermore Valley, 2001

Locations	Tritium (Bq/L)	Gross alpha (Bq/L)	Gross beta (Bq/L)
All locations			
Median	-0.568	0.008	0.064
Minimum	-2.3	-0.031	-0.026
Maximum	2.89	0.099	0.177
Interquartile range	1.055	0.035	0.084
Drinking water locations			
Median	-0.689	0.015	0.040
Minimum	-1.8	-0.016	0.000
Maximum	0.918	0.040	0.177
Interquartile range	0.624	0.018	0.082
Drinking water MCL	740	0.56	1.85

Note: Radioactivities are reported as the measured concentration and either an uncertainty ($\pm 2\sigma$ counting error) or as being less than the detection limit. If the concentration is less than or equal to the uncertainty or the detection limit, the result is considered to be a nondetection.

Arroyo Las Positas Maintenance Project

This section discusses general information about the monitoring requirements for discharges occurring during maintenance activities within Arroyo Las Positas, including permit information, sampling methods, and sampling results.

General Information

LLNL performs annual maintenance activities within the flood-control channel that diverts the flow of Arroyo Las Positas around the perimeter of the Livermore site. Maintenance activities include phased desilting of the 7000-linear-foot stretch of Arroyo Las Positas on LLNL property over five years, trimming cattail heights, and conducting bank stabilization/erosion control activities. These activities are regulated by:

- WDR 99-086 issued by the SFBRWQCB in 1999
- A Biological Opinion issued by U.S. Fish and Wildlife Service in 1999
- A streambed alteration agreement issued by California Department of Fish and Game in 1998
- A nationwide permit for the construction of six check dams issued by the Army Corps of Engineers in 2000

Work is done in pre-identified zones (**Figure 7-20**). Each year, no more than 20% of the arroyo length is desilted following the pre-identified patchwork pattern. During August and early September 2001, LLNL conducted maintenance work in Zones 3H, 5H, 2H, Area 5, and the eastern portion of Area 19.

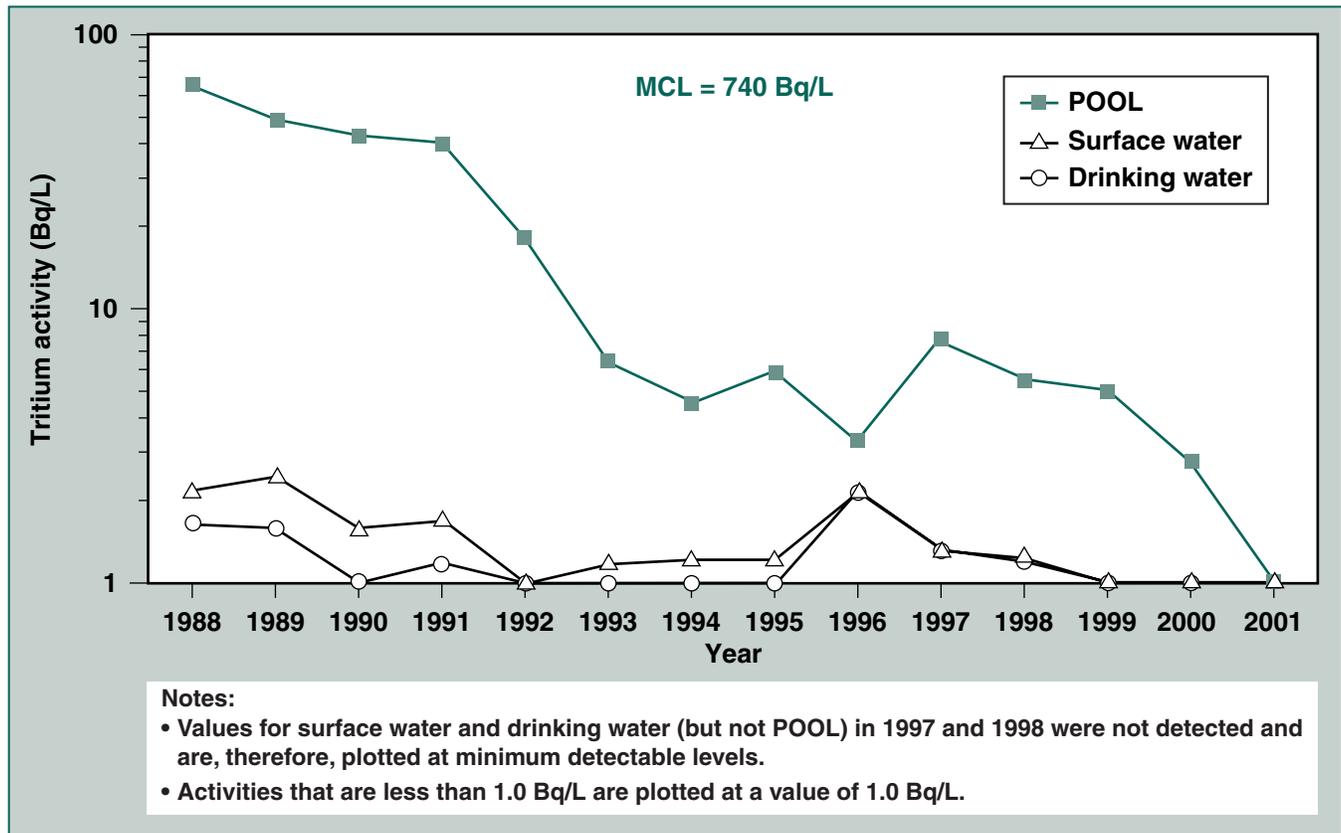


Figure 7-19. Annual median tritium activity in Livermore Valley surface and drinking water, 1988 to 2001

Discharges occur as a result of dewatering or water diversions, but they cannot cause the receiving water limits, specified in WDR 99-086, to be exceeded. Monitoring is conducted following requirements established in Self-Monitoring Program 99-086 to document compliance with effluent requirements and prohibitions established in WDR 99-086. LLNL submits self-monitoring reports to the SFBRWQCB annually when any receiving water limit is exceeded while work occurred.

Methods

Samples are collected following procedure EMP-W-S and Water Sampling Supplement EMP-WSS-ALP SOP, set up by ORAD. Turbidity,

pH, and dissolved oxygen are immediately analyzed in the field using calibrated meters. Weekly duplicate samples are collected and sent to a certified laboratory for analysis.

Receiving water (downstream) samples are collected at the work site twice a day at times evenly spaced during work hours. Receiving water samples are collected no more than 50 feet downstream of the work site while water is diverted around or dewatered from the work site. Upstream samples are collected to characterize background conditions. These samples are collected at least 500 feet above the work site. Prestart background samples are also collected to characterize the receiving water and help evaluate the impact of discharges on the receiving water.

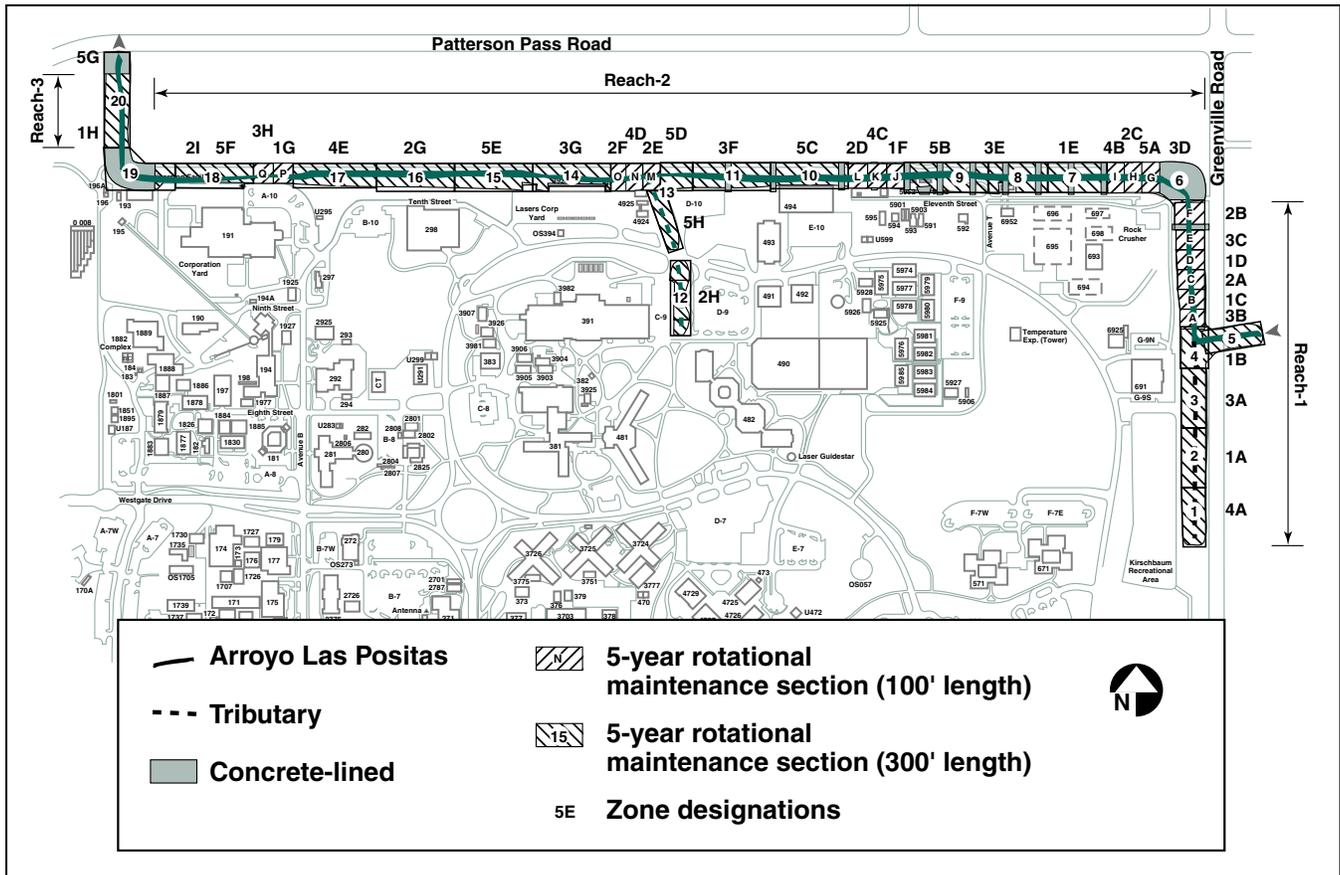


Figure 7-20. Arroyo Las Positas maintenance zones

Results

Monitoring results are presented in [Table 7-13](#). Annual self-monitoring reports are required if any of the receiving water limits are exceeded. When the background turbidity is greater than 50 NTU, discharges from the Arroyo Las Positas maintenance project cannot exceed 10% of the background measurement. These discharges must also have a dissolved oxygen concentration of 5.0 mg/L, unless natural factors cause a lower concentration of dissolved oxygen. If background samples do have a dissolved oxygen concentration less than 5.0 mg/L, the Arroyo Las Positas maintenance activities cannot cause further reduction in the concentration of dissolved oxygen

at the point of discharge. Furthermore, the pH at the point of discharge cannot vary from the background pH by more than 0.5 pH units. No receiving water limits were exceeded in 2001 so no annual self-monitoring report to the SFBRWQCB was required. Water diversion during desilting activities occurred only at Zone 3H and Area 19. All other sections were dry during the work period, and monitoring was not required.

No flow diversions were required around Zones 2H and 5H. The majority of irrigation flows and treated groundwater discharges were reduced during the duration of the Arroyo Las Positas maintenance project. Sandbag cofferdams and rubber plugs in upstream storm drains prevented

Table 7-13. Arroyo Las Positas maintenance project monitoring data, 2001

Location and Date	Time	Turbidity (NTU)	pH (pH units)	Dissolved oxygen (mg/L)
Location: Area 19, prestart (background)				
August 6, 2001	1430	8.0	8.92	6.2
Location: Area 19, downstream				
August 8, 2001	1500	14.3	8.89	7.5
August 8, 2001	1500	7.2	8.2	8.0
Location Zone 3H, prestart (background)				
August 6, 2001	1024	2.7	8.13	6.9
Location: Zone 3H, upstream				
August 27, 2001	1340	8.5	8.64	6.4
August 27, 2001	1340	7.0	8.79	9.7
August 27, 2001	1530	2.8	9.0	10.8
August 28, 2001	0912	3.1	7.95	15.4
August 29, 2001	0938	2.1	8.30	6.0
Location: Zone 3H, downstream				
August 27, 2001	1300	17.8	8.27	7.1
August 27, 2001	1300	6.0	8.60	11.6
August 27, 2001	1510	2.6	8.8	11.9
August 28, 2001	0856	3.9	7.89	12.0
August 28, 2001	1300	2.9	8.20	6.5
August 29, 2001	0900	2.6	7.89	5.0

remaining irrigation flows from discharging to the Arroyo Las Positas. A water-bag cofferdam and straw-bale cofferdam were used at Zone 3H and Area 19 respectively, where water was diverted around the work area. Flow from Arroyo Las Positas coming onto the Livermore site was successfully held behind a straw-bale cofferdam installed just upstream of Area 5.

Environmental Impacts

This section discusses the environmental impacts of storm water, rainfall, the DRB, cooling towers, and other waters.

Storm Water

Storm water runoff from the Livermore site and Site 300 did not have any apparent environmental impacts in 2001. Tritium activities in storm water runoff effluent (location WPDC) were less than 1% of the drinking water MCL during 2001. Most values were below detection limits for tritium. Gross alpha and gross beta activities in Livermore site storm water effluent were both less than 11% of their respective MCLs.

Storm water quality runoff from Site 300 is similar to background levels. Although some 2001 storm water results were above comparison criteria at the



Livermore site, there is no evidence of any impact to off-site biota. The acute and chronic fish toxicity tests conducted during 2001 showed no toxicity in Livermore site storm water runoff, further supporting this conclusion. Algae toxicity tests did reveal growth inhibition for algae in the storm water. However, it has been demonstrated that this was caused by upstream pesticide applications not associated with LLNL activities.

Construction site storm water sampling results indicate that the NIF construction site is not contributing PCBs to storm water runoff as a result of construction activities.

Rainfall

Tritium in rainfall had a negligible impact on the environment at the Livermore site, in the Livermore Valley, and at Site 300. The median tritium activity measured in rainfall at LLNL decreased from 3.7 Bq/L in 2000 to 1.97 Bq/L in 2001. The measured tritium activities of rainfall samples taken at Site 300 were all less than the minimum detectable activity (or less than the 2σ counting uncertainty). The tritium activity measured in rainfall at Site 300 continues to be indistinguishable from atmospheric background levels (2 Bq/L).

Drainage Retention Basin

There is no evidence of adverse environmental impact resulting from releases from the DRB. Because of the frequent dry season discharges that occurred from the DRB, discharges from groundwater treatment facilities, and the wetter rainfall years that occurred from 1997 through 1999, wetland vegetation has increased both upstream and downstream of the DRB. The federally listed threatened California red-legged frog has colonized these wetland areas.

Cooling Towers

During 2001, the monitoring results for flow, pH, and TDS from both primary cooling towers remained within previously established (WDR 94-131) limits. Because blowdown flow from the cooling towers does not reach Corral Hollow Creek, it is unlikely to have a negative impact on the receiving water.

Site 300 Drinking Water System Discharges

There were no releases from the Site 300 drinking water system during 2001.

Other Waters

The potential impact of tritium on drinking water supplies was estimated by determining the effective dose equivalent (EDE) (see [Appendix A](#)). Maximum tritium activity in drinking waters was 0.918 Bq/L. The EDE to an adult who ingested 2 L/day of water at this maximum concentration for a year would be 0.012 μ Sv, or 0.03% of the DOE standard allowable dose of 40 μ Sv for drinking water systems. Gross alpha and gross beta activities (as well as tritium activities) were below their MCLs. The sample data indicate that the impact of Livermore site operations on surface and drinking waters in the Livermore Valley is negligible.

Arroyo Las Positas Maintenance Project

Discharges of diverted water related to the Arroyo Las Positas maintenance project did not adversely impact receiving water quality. No receiving water quality criteria were exceeded throughout the duration of the project.



GROUNDWATER INVESTIGATION AND REMEDIATION

*Richard G. Blake
Michael J. Taffet*

Introduction

During 2001, groundwater investigations and remediations under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) continued at both the Livermore site and Site 300. LLNL regularly samples and analyzes groundwater from areas of known or suspected contamination. Portions of the two sites that contain groundwater with concentrations of chemicals of concern are actively investigated to determine the magnitude of the contamination and its source. Remediation strategies are developed and evaluated in preparation for a CERCLA removal action or through the feasibility study process. An approved remedy for each study area is developed in consultation with the regulatory agencies and the community.

This chapter reviews the distribution of contaminants in groundwater, and the progress LLNL has made in removing contaminants from groundwater and from the unsaturated zone (soil vapor) at the Livermore site and Site 300.

Livermore Site Groundwater Project

Physiographic Setting

The general topography of the Livermore site is described in Chapter 1. The Livermore Valley groundwater system is a sequence of semiconfined aquifers

in which groundwater moves downslope from the valley uplands toward the east-west axis of the valley. It then flows generally westward toward the southwest portion of the basin. From there, groundwater has historically flowed south into the Sunol Valley Groundwater Basin.

The largest quantities of groundwater are pumped from the central and western portions of the Livermore Valley, where the valley fill sediment is thickest. These sediments make up two aquifers: the Livermore Formation and its overlying alluvium.





The Livermore Formation averages about 1000 m in thickness and occupies an area of approximately 250 km². The alluvium, which is about 100 m thick, is the principal water-producing formation within the valley.

Hydrogeology

Sediment types at the Livermore site are grouped into four categories—clay, silt, sand, and gravel—based on the dominant particle type. Groundwater flow beneath the site is primarily in alluvial sand, gravel lenses, and channels, bounded by the less permeable clay and silt.

The alluvial sediments have been mapped into seven hydrostratigraphic units (HSUs) beneath the Livermore site, using data collected over the years. HSUs can be defined as sedimentary sequences whose permeable layers show evidence of hydraulic connection. The HSUs of concern beneath the Livermore site are the Quaternary alluvial deposits of the upper Livermore member of the Livermore Formation (see [Figure 8-1](#)). HSUs 1B, 2, 3A, 3B, 4, and 5 contain contaminants that are primarily solvents (Blake et al. 1995; Hoffman et al. 1998).

Background

Initial releases of hazardous materials occurred at the Livermore site in the mid-to-late 1940s when the site was the Livermore Naval Air Station (Thorpe et al. 1990). There is also evidence that localized spills, leaking tanks and impoundments, and landfills contributed volatile organic compounds (VOCs), fuel hydrocarbons (FHCs), lead, chromium, and tritium to the groundwater and unsaturated sediment in the post-Navy era. The Livermore site was placed on the Environmental Protection Agency (EPA) National Priorities List in 1987.

A screening of all environmental media showed that groundwater and unsaturated sediment are the only media that require remediation (Thorpe et al. 1990). The identified compounds that currently exist in groundwater at various locations beneath the site at concentrations above drinking standards are trichloroethylene (TCE), perchloroethylene (PCE), 1,1-dichloroethylene (1,1-DCE), chloroform, 1, 2-dichloroethylene (1,2-DCE), 1,1-dichloroethane (1,1-DCA), 1,2-dichloroethane (1,2-DCA), trichlorotrifluoroethane (Freon 113), trichlorofluoromethane (Freon 11), and carbon tetrachloride.

Remedial Activities

In 2001, the Livermore site Groundwater Project (GWP) treated more than 1056 million liters of groundwater and removed approximately 142 kg of volatile organic compounds (VOCs). The GWP also brought new treatment facilities on line, installed wells, conducted hydraulic tests, developed groundwater models, published required documents, and maintained close contact with regulatory agencies and the community.

LLNL removes contaminants from groundwater and from the unsaturated zones (soil vapor) at the Livermore site through a system of 27 treatment facilities located throughout the 6 HSUs containing contaminants of concern. Within each facility, extraction wells are used to extract groundwater, which is then treated to remove VOCs.

Treatment usually consists of removing VOCs with a large capacity air-stripping system, after which any VOCs present in the stripper's effluent air are removed with granular activated carbon filters. Methods are noted in the following discussion of treatment facilities. [Table 8-1](#) lists the extraction wells, according to the HSU in which they are screened, and the total flow rate for each treatment area.



Table 8-1. 2001 extraction wells and extraction rates

Treatment facility area	Hydrostratigraphic Unit	Extraction wells	Average extraction rate (L/min) ^(a)
TFA	HSU 1B	W-254, W-262, W-408, W-520, W-601, W-602, W-1001, W-1004	776.4
	HSU 2	W-109, W-415, W-457, W-518, W-522, W-603, W-605, W-609, W-614, W-714, W-903, W-904, W-1009	
	HSU 3A	W-712	
TFB	HSU 1B	W-610, W-620, W-704	223.3
	HSU 2	W-357, W-621, W-1423	
TFC	HSU 1B	W-701, W-1015, W-1102, W-1103, W-1104,	143.8
	HSU 2	W-1213	
TFD	HSU 2	W-906, W-1215, W-1216, W-1303, W-1306, W-1308, W-1510, W-1550, W-1602, W-1603	526.2
	HSU 3A/3B	W-1208, W-1301, W-1504, W-1551, W-1552, W-1601, W-1651, W-1654	
	HSU 4	W-314, W-351, W-1206, W-1307, W-1503, W-1523	
	HSU 5	W-907	
TFE	HSU 2	W-1109, W-1409, W-1518, W-305	238.5
	HSU 3A/3B	W-1422, W-1522, W-292	
	HSU 4	W-1211, W-1418, W-1520	
	HSU 5	W-359, W-566	
TF406	HSU 4	W-1310	76.5
	HSU 5		
TFG	HSU 1B/2	W-1111	10.6
TF518	HSU 3B/4	W-1410	12.1
	HSU 5		
VTF518		SVB-518-204	0.0057 (scmm) ^(b)
TF5475	HSU 2	W-1415	0.72
	HSU 3A	W-1302, W-1606, W-1608	
	HSU 5	W-1610	
VTF5475		SVI-EST-504	0.46 (scmm)

a L/min= Liters per minute

b scmm = Standard cubic meters per minute

Table 8-2. Volatile organic compounds (VOCs) removed from groundwater and soil at the Livermore site

Treatment facility ^(a)	Startup date	2001		Cumulative total	
		Water treated (ML) ^(b)	VOCs removed (kg)	Water treated (ML)	VOCs removed (kg)
TFA	9/89	408	10.2	3468.6	147
TFB	10/90	117.3	6.9	662.4	52.2
TFC	10/93	75.7	7.2	480	47.3
TFD	9/94	276.3	90	1229.1	432
TFE	11/96	124.9	25.4	438.7	121
TFG	4/96	5.7	0.3	57.9	3.0
TF406	8/96	37.9	0.9	174.9	6.7
TF518	1/98	6.4	0.7	32.2	3.7
TF5475	9/98	0.379	1.1	1.6	4.2
Total ^(c)		1058	143	6924	817
		Soil vapor treated (10 ³ m ³)	VOCs removed (kg)	Soil vapor treated (10 ³ m ³)	VOCs removed (kg)
VTF518 ^(d)	9/95	2.94	2.6	425	153
VTF5475 ^(d)	1/99	240.7	70.2	516	268
Total ^(c)		244	73	941	421

a Includes fixed and portable units

b ML = 1 million liters

c Totals rounded to nearest whole number

d Vapor treatment facility

mass removal at the Livermore site since 1989 is presented in **Figure 8-2**. Concentrations of total VOCs in the third quarter 2001 are depicted as isoconcentration maps in the six HSUs in **Figures 8-3** through **8-8**. The VOC plumes in HSUs 1B, 2, 3A, 3B, 4, and 5 continue to be hydraulically controlled based on trends in groundwater chemistry, capture zone analysis, and the total VOC isoconcentration maps for each HSU (**Figures 8-3** through **8-8**).

The numbers and associated treatment facility areas of new wells installed in 2001 are shown in **Table 8-3**. Well construction details, well closure data, and results of drawdown tests are provided in

the *LLNL Groundwater Project 2001 Annual Report* (Dibley et al. 2002).

Treatment Facility A

Treatment Facility A (TFA) is a fixed facility located in the southwestern quadrant of the Livermore site near Vasco Road and East Avenue (**Figure 8-1**). Groundwater is treated using the large-capacity air-stripping system installed in June 1997. VOCs are stripped from the groundwater, and the effluent air from the stripper is passed through granular activated carbon filters to remove VOCs. The treated effluent air is then vented to the atmosphere.

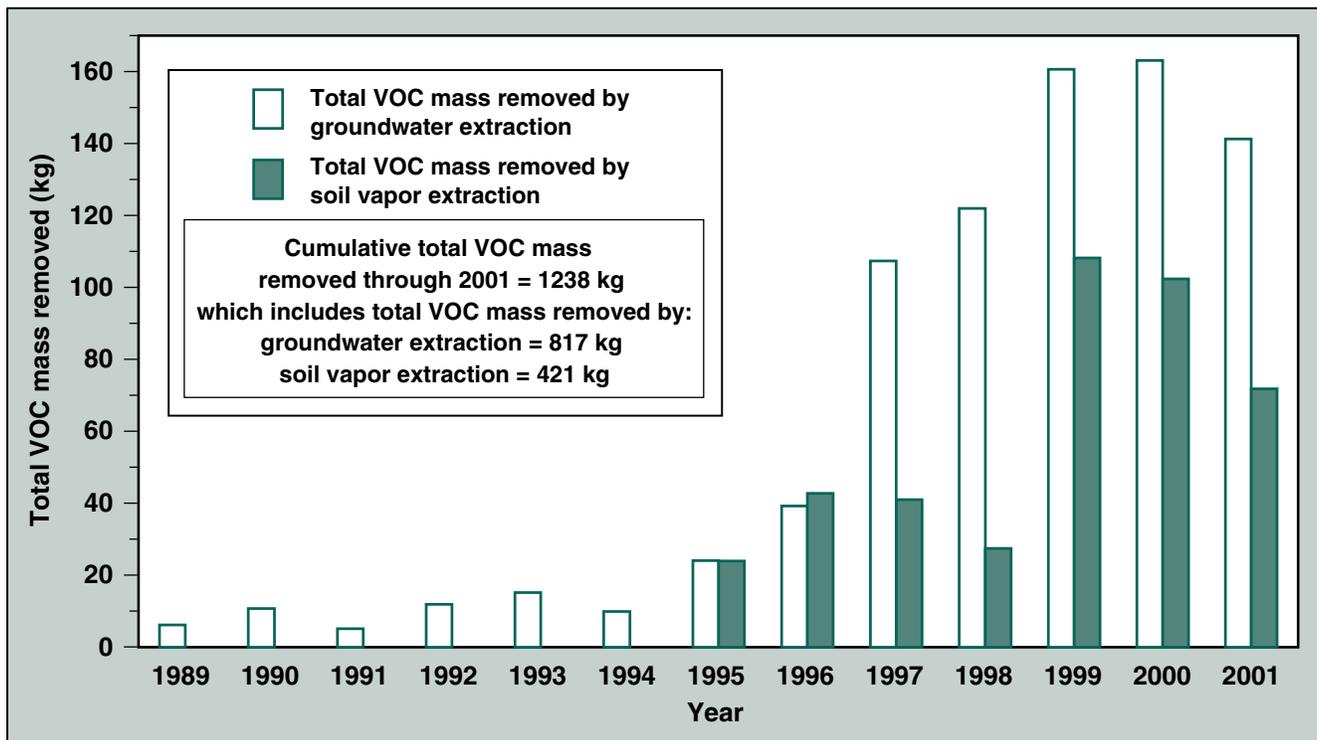


Figure 8-2. Total VOC mass removed from the subsurface of the Livermore site, 1989–2001

The San Francisco Bay Regional Water Quality Control Board (SFBRWQCB) permits LLNL to treat up to 1890 L/min of groundwater. Treated groundwater from TFA is discharged to the Recharge Basin, located about 600 m southeast of TFA on Department of Energy (DOE) property administered by Sandia National Laboratories/California (Sandia/California). Since the startup of the new system, TFA has not exceeded the 5 parts per billion (ppb) total VOC discharge limit.

Solar treatment unit (STU) TFA East (TFA-E) is located east of TFA and processes VOCs in groundwater using granular activated carbon. TFA-E was in compliance with all permits through 2001.

In 2001, wells at TFA and TFA-E pumped at a combined flow rate of about 776 L/min and treated 408 million liters of groundwater containing an estimated 10.2 kg of VOCs.

One new monitor well (W-1701) was installed in the TFA area in 2001 (see [Table 8-3](#)).

Treatment Facility B

Treatment Facility B (TFB) is located in the west-central portion of the Livermore site ([Figure 8-1](#)). Groundwater is treated using the large-capacity air-stripping system installed in October 1998. This unit replaced an ultraviolet/hydrogen peroxide (UV/H₂O₂) system that had been in use since 1990. Groundwater is also treated for chromium(VI) in an ion-exchange unit, during December through March, based on the current

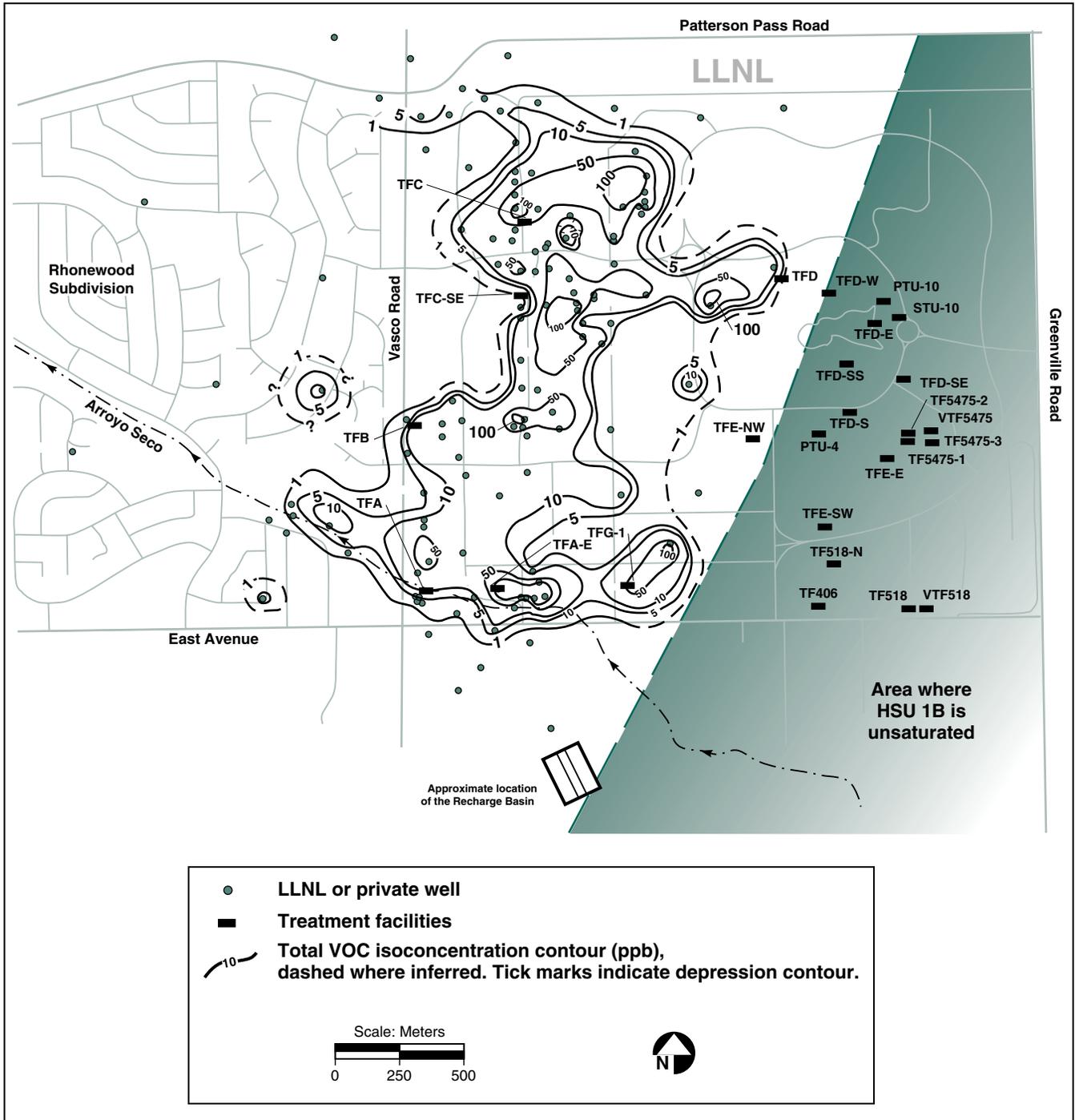


Figure 8-3. Isoconcentration contour map of total VOCs within HSU 1B, 2001

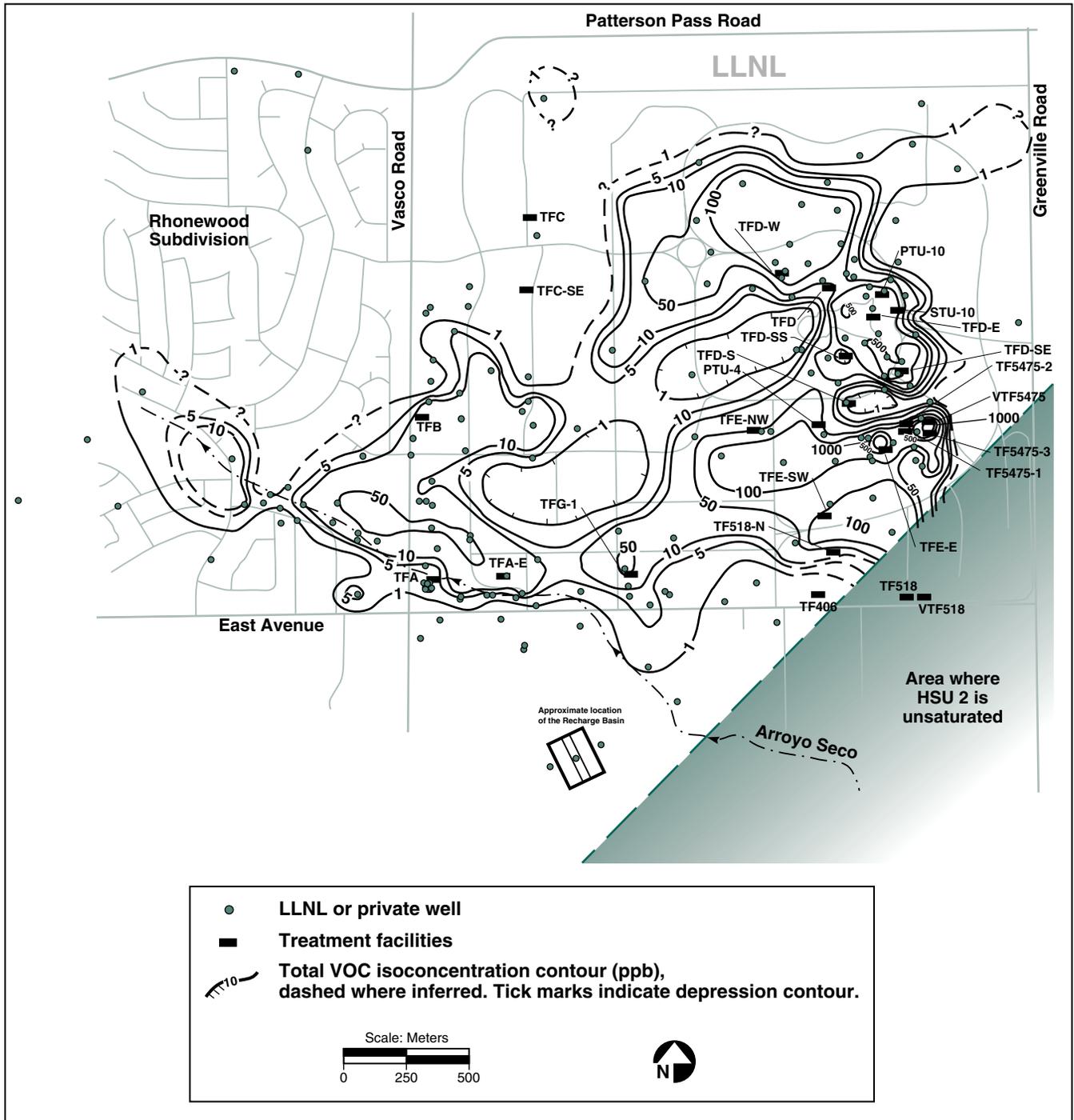


Figure 8-4. Isoconcentration contour map of total VOCs within HSU 2, 2001

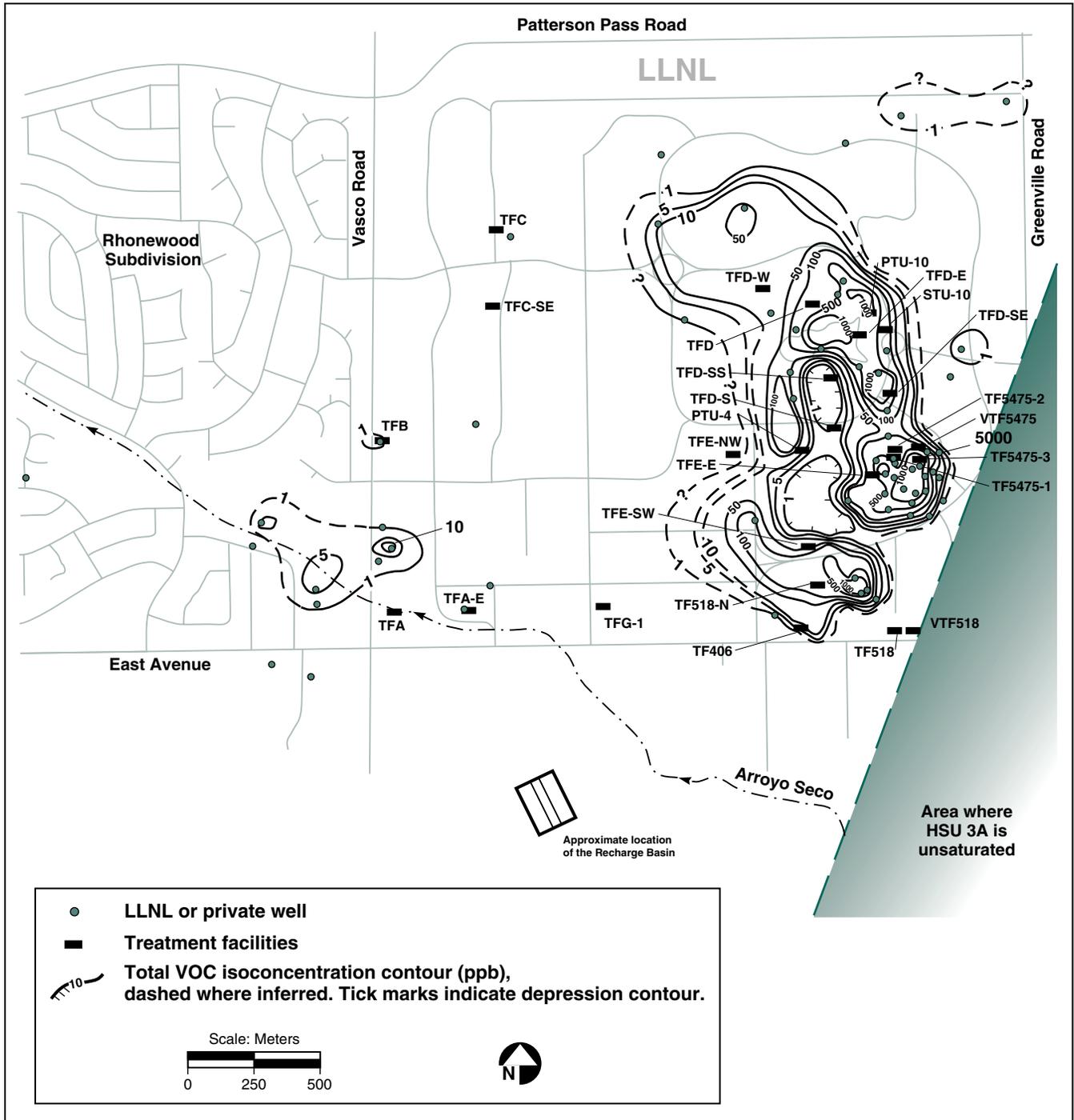


Figure 8-5. Isoconcentration contour map of total VOCs within HSU 3A, 2001

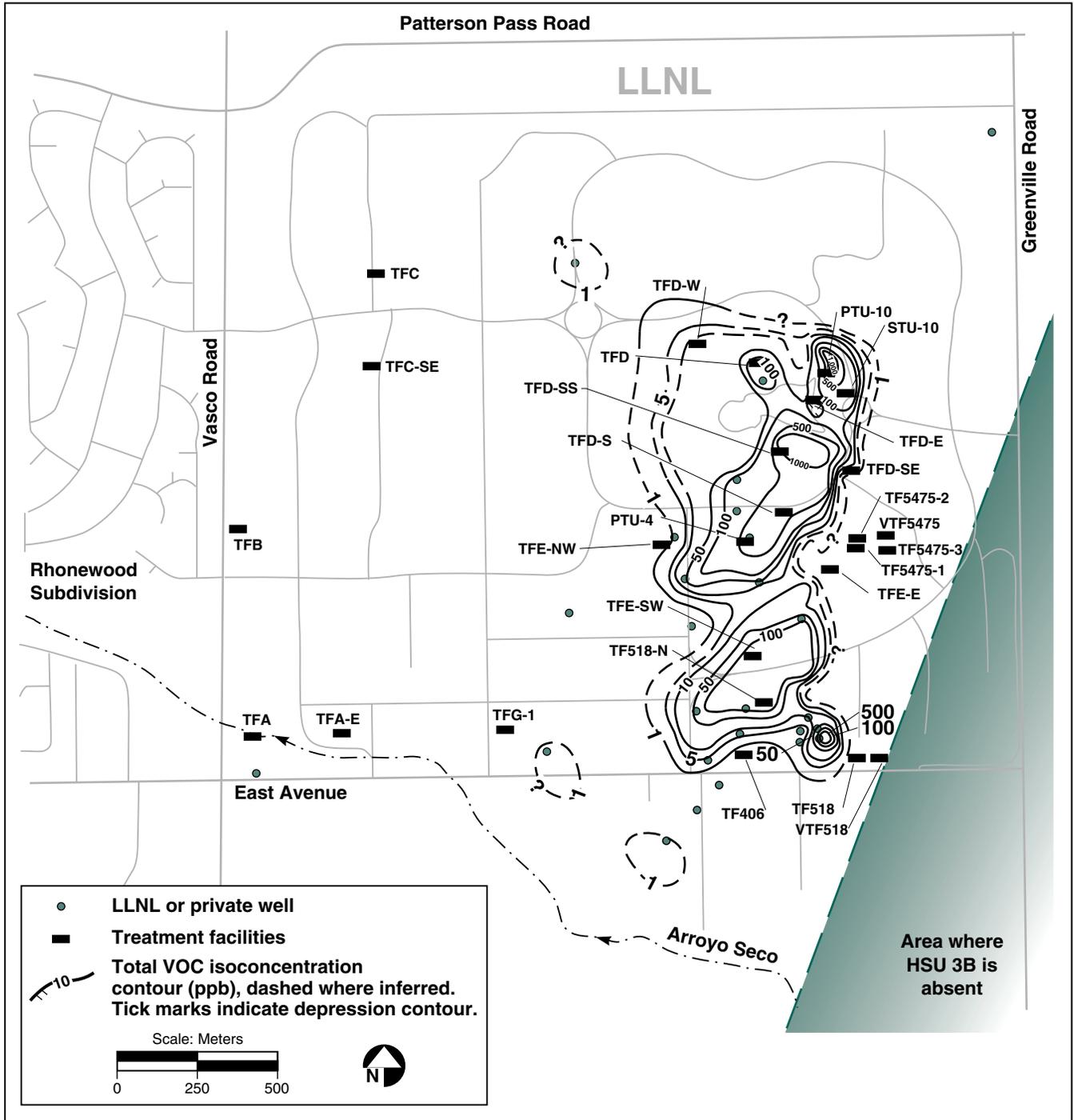


Figure 8-6. Isoconcentration contour map of total VOCs within HSU 3B, 2001

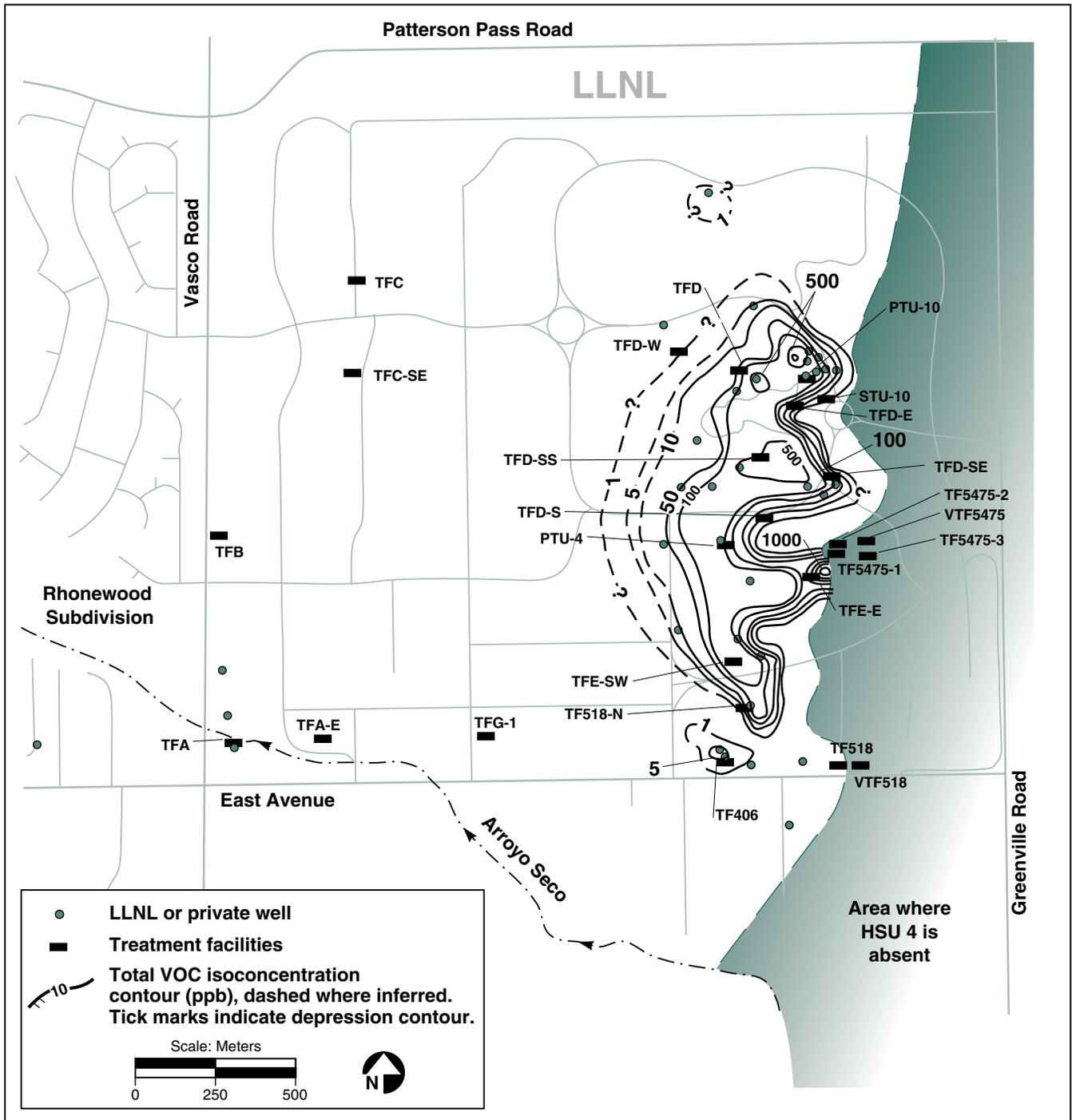


Figure 8-7. Isoconcentration contour map of total VOCs within HSU 4, 2001

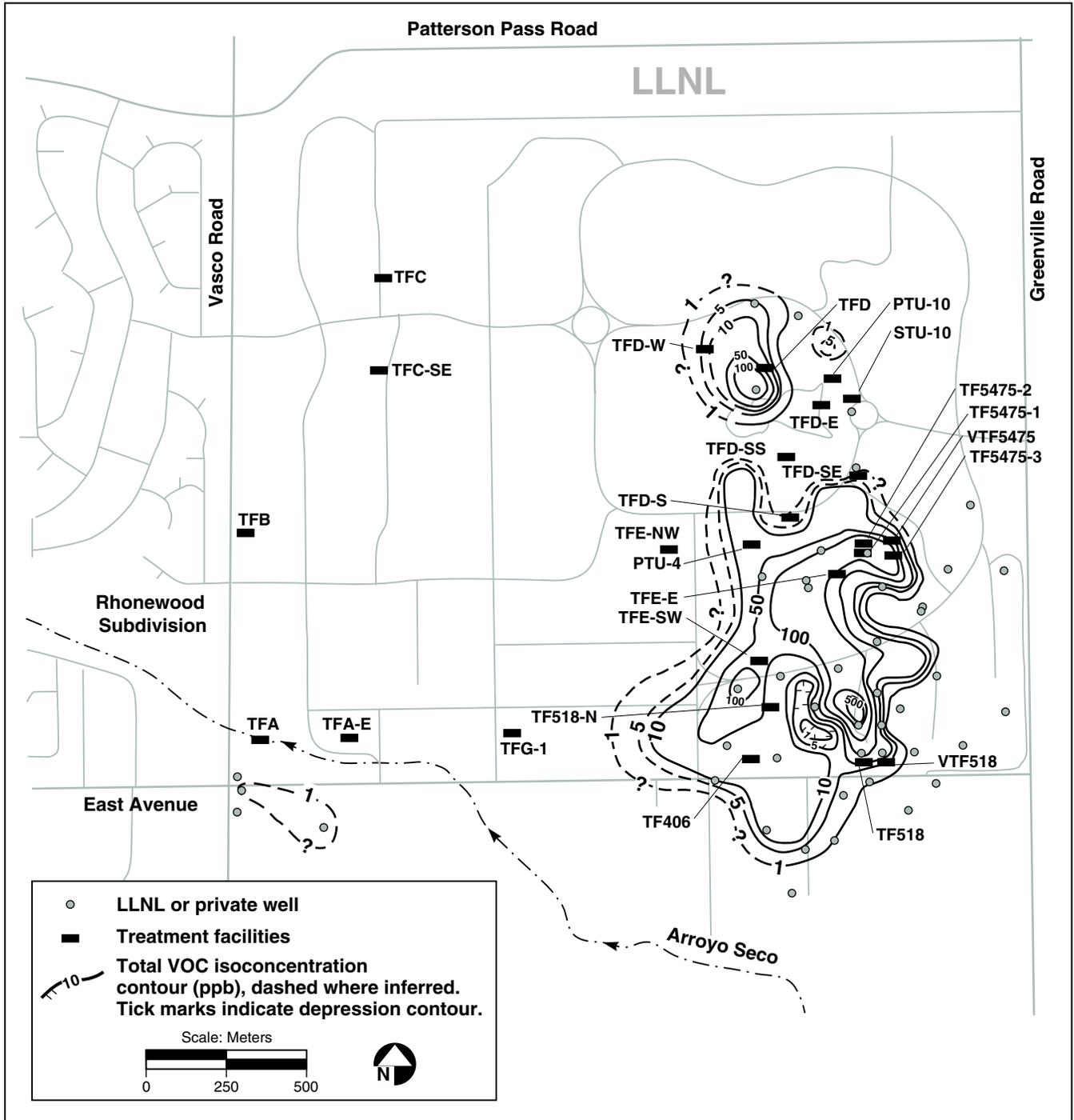


Figure 8-8. Isoconcentration contour map of total VOCs within HSU 5, 2001

Table 8-3. Wells installed in 2001

Treatment facility area	Hydrostratigraphic unit	Monitoring/extraction well
TFA	HSU 2	W-1701
TFB		None
TFC		W-1704
TFD	HSU 6	W-1703
TFE		None
TF406	HSU 2, 3B, 3B, 5	W-1705
TFG		None
TF518	HSU1B	W-1702
TF5475		None

RWQCB discharge substantive requirements. Treated groundwater from TFB is discharged into the north-flowing drainage ditch parallel to Vasco Road that empties into Arroyo Las Positas to the north.

The six wells at TFB pumped at a combined flow rate of about 223 L/min, and treated about 117 million liters of groundwater containing an estimated 6.9 kg of VOCs in 2001.

TFB was in compliance through 2001, and no new wells were installed at TFB during 2001.

Treatment Facility C

Treatment Facility C (TFC) is located in the north-west quadrant of the Livermore site ([Figure 8-1](#)). Portable Treatment Unit (PTU) location TFC Southeast (TFC-SE) is located near the intersection of Avenue A and Sixth Street in the northwest quadrant of the Livermore site.

TFC and TFC-SE process VOCs in groundwater using air stripping. The effluent air from the stripper is treated with granular activated carbon prior to discharge to the atmosphere. Groundwater is treated for chromium(VI) in an ion-exchange unit during the wet season, December through

March, in order to meet the current RWQCB discharge substantive requirements. Treated groundwater from TFC is discharged into Arroyo Las Positas; from TFC-SE, groundwater is discharged into a north-flowing drainage ditch that empties into Arroyo Las Positas to the north. The TFC effluent chromium(VI) concentration was below the wet season discharge limit of 22 ppb during 2001. TFC and TFC-SE complied with all permits throughout 2001.

Wells in the TFC area pumped at a combined flow rate of about 144 L/min and treated about 75 million liters of groundwater containing an estimated 7.2 kg of VOCs. Since system start up in 1993, the combined TFC area facilities have treated more than 475 million liters of groundwater and removed about 47 kg of VOC mass from the subsurface.

One new well (W-1704) was installed in the TFC area during 2001 ([Table 8-3](#)).

Treatment Facility D

The Treatment Facility D (TFD) area is located in the northeast quadrant of the Livermore site (see [Figure 8-1](#)). During 2001, eight treatment



facilities operated in the TFD area. The TFD area extraction wells hydraulically control VOCs in HSUs 2, 3A, 3B, 4, and 5.

Fixed and portable facilities operating in the TFD area process VOCs in groundwater using air stripping, although the STU uses granular activated carbon. The effluent air from the air strippers is treated with granular activated carbon prior to discharge to the atmosphere. Treated groundwater from TFD and TFD-East (TFD-E) is discharged either into the drainage retention basin (DRB), or into an underground pipeline downstream of the DRB weir, flowing northward to Arroyo Las Positas. Treated groundwater from TFD-West (TFD-W) is discharged into a nearby storm sewer that also empties into Arroyo Las Positas. Treated groundwater from TFD-South (TFD-S) and TFD-Southeast (TFD-SE) is discharged into drainage ditches, each flowing north into the DRB.

Electroosmosis (EO) was tested from September 2000 to February 2001 to evaluate its ability to help remove VOCs from fine-grained sediments in a source area near the Helipad in the TFD area. EO uses a direct current passed between electrodes to induce water flow from the anode (positive electrode) to the cathode (negative electrode). Contaminated groundwater is then extracted from the cathode well(s) and treated.

At the Helipad site, a nine-well array was constructed with three cathode wells in the center and three anode wells on each side. Groundwater was extracted at the cathode wells and treated at PTU10. Results from this test suggest a measurable increase in contaminant influx to the extraction wells when EO operated (McNab et al. 2001).

When not connected to the EO pilot test, PTU10, located northeast of the DRB at the TFD Helipad area, continued to operate by treating groundwater from wells W-1551, W-1552, W-1651, and

W-1654 (all in HSU 3A/3B) in 2001 to expedite VOC mass removal and source area cleanup. In 2001, PTU10 operated at a flow rate of about 5.7 L/min, and treated about 3 million liters of groundwater containing an estimated 3.7 kg VOCs. These data are included in the TFD groundwater volume and VOC mass totals are presented in [Table 8-2](#).

The combined TFD facilities operated at an average flow rate of 526 L/min in 2001. During 2001, these units treated about 276 million liters of groundwater containing an estimated 90.1 kg of VOCs. Distal VOC plumes in the western TFD area should be hydraulically controlled once planned TFC-E and TFFC-Northeast (TFC-NE) treatment facilities are operating; they were scheduled to begin operation in January 2002 and May 2003, respectively, but have been postponed due to budget shortfalls.

All TFD facilities were in compliance through 2001. One well (W-1703) was installed in the TFD area during 2001 ([Table 8-3](#)) and a one-hour drawdown test was conducted on the well (Dibley et al. 2002).

Treatment Facility E

The Treatment Facility E (TFE) area is located in the southeastern quadrant of the Livermore site ([Figure 8-1](#)). In 2000, TFE-East (TFE-E) continued treating groundwater using a PTU. TFE-E is located in the east-central portion of the Livermore site and provides hydraulic containment of some portions of VOC plumes in HSUs 2, 4, and 5. TFE-Northwest (TFE-NW) treats groundwater from extraction wells in HSU 2 and HSU 4 and is located south of the Inner Loop Road, immediately west of Southgate Drive.

TFE-E and TFE-NW treat VOCs using an air stripper. Before the effluent air is vented to the atmosphere, it is treated using granular activated

carbon to remove VOCs. Treated groundwater from TFE-E is discharged into a drainage ditch that flows north into the DRB. Treated groundwater from TFE-NW is discharged into a storm drain that flows north into Arroyo Las Positas.

Two new treatment facilities were added to the TFE area in 2001. Operation of TFE-Southeast (TFE-SE), located south of the DRB and South Outer Loop Road, was delayed with regulatory concurrence until March 19, 2001, due to the Federal Continuing Budget Resolution. TFE-West (TFE-W), located south of South Inner Loop Road and east of Southgate Drive was activated April 30, 2001, four days ahead of the Remedial Action Implementation Plan (RAIP) milestone date. Treated groundwater from TFE-SE is discharged into an underground storm drain that flows west and then north into Arroyo Las Positas. Treated groundwater from TFE-W is discharged into an underground storm drain that flows north into Arroyo Las Positas.

In 2001, wells at TFE pumped at a combined flow rate of about 238 L/min and treated about 125 million liters of groundwater containing an estimated 25.4 kg of VOCs. Since system startup in 1996, the combined TFE facilities have treated more than 435 million liters of groundwater and removed about 121 kg of VOC mass from the subsurface.

All TFE treatment facilities were in compliance in 2001. No new wells were installed in the TFE area during 2001.

Treatment Facility G-1

Treatment Facility G-1 (TFG-1) is located in the south-central portion of the Livermore site ([Figure 8-1](#)) and treats groundwater from one well at Treatment Facility G-1 (TFG-1), located near Avenue B, about 90 m north of East Avenue. Under the current RWQCB discharge substantive

requirements, water from TFG-1 requires treatment for chromium(VI) only during December through March. Treated groundwater from TFG-1 is discharged to a storm drain located about 15 m north of TFG-1, which empties into Arroyo Seco.

Before May 1999, TFG-1 processed groundwater for VOC treatment using an air stripper, and the effluent air was treated using granular activated carbon to remove VOCs before they were vented to the atmosphere. In May 1999, the PTU at TFG-1 was replaced by a granular activated carbon treatment unit (GTU). A year-long treatability study conducted in 1998 and 1999 demonstrated that the granular activated carbon treatment was effective in the efficient removal of VOCs from TFG area groundwater. Groundwater is no longer treated for chromium(VI) because concentrations from March 1997 through November 1999 were consistently below the discharge limit of 22 ppb.

During 2001, TFG-1 operated at an average flow rate of 10.79 L/min, treating 5.7 million liters of groundwater containing an estimated 0.3 kg of VOCs ([Table 8-2](#)). Since system startup in 1996, TFG-1 has treated almost 57 million liters of groundwater and removed about 3 kg of VOC mass from the subsurface.

The TFG-1 treatment facility was in compliance in 2001. No new boreholes or wells were drilled and no hydraulic tests were conducted in the TFG area during 2001.

Treatment Facility 406

TF406 is located in the south-central portion of the Livermore site, east of Southgate Drive near East Avenue ([Figure 8-1](#)). In 2001, TF406 treated groundwater from HSU 5 extraction well W-1310. Pumping was discontinued in September 2000 from HSU 4 extraction wells GSW-445 and W-1309 since concentrations had declined below MCLs for all VOCs of concern, and to reduce the



dewatering of HSU 4 in the southeastern corner of the site. These wells were not pumped in 2001 because TCE concentrations in both wells remained below MCLs.

TF406 uses PTU5 equipped with an air stripper to treat VOCs in groundwater. Granular activated carbon removes VOCs from effluent air prior to discharge to the atmosphere. All treated groundwater is discharged to an underground storm drain that flows north to Arroyo Las Positas. TF406 was in compliance with all permits throughout 2001.

When activated in August 1996, TF406 processed groundwater from extraction wells GSW-445 and W-1114. In 1997, well W-1114 was inadvertently damaged and destroyed by adjacent drilling activities, and new extraction wells W-1309 and W-1310 were installed. TF406 began processing groundwater from wells W-1309 and W-1310 in February 1998. As described above, water is no longer pumped from wells GSW-445 and W-1309.

Passive bioremediation continued in the TF406 area during 2001 to remediate FHCs in HSUs 3A and 3B. Active groundwater extraction and treatment for residual dissolved FHCs at former Treatment Facility F (TFF) was discontinued in 1996 with regulatory agency concurrence (RWQCB 1996).

During 2001, TF406 operated at an average flow rate of 76 L/min, treating more than 38 million liters of groundwater containing an estimated 0.9 kg of VOCs (see [Table 8-2](#)). Since system startup in 1996, TF406 has treated about 42.2 ML of groundwater and removed about 6.7 kg of VOC mass from the subsurface (see [Table 8-1](#)).

A multiple-screen monitor well, W-1705, was installed in the future TF406-Northwest (TF406-NW) area in 2001 ([Table 8-3](#)). Well W-1705 is equipped with a Water FLUTE, an instrumented

membrane system (IMS) that allows collection of depth-specific water level and groundwater chemistry data from multiple HSUs at one location. Well W-1705 is screened in HSUs 2, 3A, 3B, and 5. Data from this well will be used to design TF406-NW.

No hydraulic tests were performed in the TF406 area in 2001, and TF406 was in compliance through 2001.

Groundwater Treatment Facility 518

One groundwater treatment facility, TF518 North (TF518-N), operated in the TF518 area in 2001. TF518-N is located south of South Outer Loop Road, north of Building 411 ([Figure 8-1](#)). TF518-N treats groundwater from HSU 4 extraction well W-1410. Another treatment facility, TF518, ([Figure 8-1](#)) extracted groundwater from wells W-211 and W-112 but was removed in June 2000 after HSU 5 became dewatered in the southeastern portion of the Livermore site. HSU 5 remained dewatered throughout 2001.

TF518-N employs a series of aqueous-phase granular activated carbon canisters to treat VOCs in groundwater. Treated groundwater from TF518-N is discharged into an underground storm drain that flows north and ultimately empties into Arroyo Las Positas.

During 2001, TF518-N operated at an average flow rate of 12 L/min, treating 12 million liters of groundwater containing an estimated 0.7 kg of VOCs. Since system startup in January 2000, TF518-N has processed approximately 32 million liters of groundwater containing an estimated 3.7 kg of VOCs ([Table 8-2](#)).

The extraction wells provide hydraulic control of VOC plumes in HSUs 4 and 5 based on the capture zone analysis shown on the groundwater elevation contour maps and the total VOC isoconcentration maps ([Figure 8-7](#) and

Figure 8-8). The sustained de-watering in HSU 5 impacts hydraulic control by widening the capture areas.

One new well (W-1702) was installed in 2001 (**Table 8-3**). No hydraulic tests were conducted in the TF518 area during 2001.

Vapor Treatment Facility 518

Vapor treatment facility 518 (VTF518) is located north of East Avenue in the southeast portion of the Livermore site (**Figure 8-1**). Soil vapor extracted from the vadose zone is passed through a series of granular activated carbon canisters to remove VOCs, and the effluent air is discharged to the atmosphere. VTF518 was in compliance with its Bay Area Air Quality Management District permit throughout 2001.

VTF518 began operation in September 1995 by treating soil vapor from extraction well SVB-518-201. In 1997, extraction well SVB-518-303 was added to the system. Since 1998, the flow rate from primary extraction well SVB-518-201 has dropped from about $0.82 \text{ m}^3/\text{min}$ to less than $0.05 \text{ m}^3/\text{min}$. The majority of vapor flow during this period was from secondary extraction well SVB-518-303. VTF518 was shut down in August 1999, due to lack of flow from primary extraction well SVB-518-201. Field investigations indicated that the reduced vapor flow was most likely due to a significant increase in moisture in shallow sediments, which severely restricted air flow from the vadose zone. It is suspected that above average rainfall since 1995 resulted in the re-appearance of a perched water-bearing zone that had been observed in the 1980s.

Soil vapor extraction (SVE) was restarted at about $0.017 \text{ m}^3/\text{min}$ in July 2000 using existing well SVB-518-204. The vacuum produced by VTF518 caused an upwelling of the perched water which contained up to 80 parts per million (ppm) VOCs.

The perched water was extracted from vapor extraction wells SVB-518-204 and SVB-518-303 on a periodic basis during 2001 to expedite mass removal and to attempt to remove the excess moisture. This water was collected in a tank and transported to TFD for treatment.

From January through May 2001, VTF518 operated at an average flow rate of $0.006 \text{ m}^3/\text{min}$, treating about 2912 m^3 of vapor containing an estimated 2.6 kg of VOCs (**Table 8-2**). In addition, approximately 1420 liters of water, containing about 0.02 kg of VOCs, was extracted from the two vapor extraction wells at VTF518 in 2001. Since system start up in 1995, VTF518 has treated approximately 420 m^3 of vapor and removed about 153 kg of VOC mass from the subsurface (**Table 8-2**).

In November 2001, a new IMS was installed in borehole B-1616, now referred to as IMS-518-1616. The IMS is used to monitor soil moisture and vapor pressures and collect soil vapor samples at various depths. Since 1995, two other IMS sampling/monitor wells, SEA-518-301 and SEA-518-304, have been used for similar vadose zone monitoring.

Data collected in November and December 2001 from IMS-518-1616 indicate that recharge from rainfall occurs much more rapidly than expected. Moisture responses were seen within an hour at a depth of 2.4 m, and up to depths of 12 m within a few hours of rainfall events. Potential explanations for this rapid infiltration are currently being evaluated.

Treatment Facility 5475

Three groundwater treatment facilities operated in 2001 in the Trailer 5475 (T5475) area, located in the east-central portion of the Livermore site (**Figure 8-1**). TF5475-1, activated in September 1998, treats groundwater by in situ catalytic



reductive dehalogenation (CRD) from HSU 3A extraction well W-1302. TF5475-2 (STU5), activated in March 1999, is located west of T5475 and treats groundwater from HSU 2 well W-1415. TF5475-3, activated in September 2000, is located west of T5475 and treats groundwater from two HSU 3A extraction wells, W-1606 and W-1608.

Phase 3 of CRD treatment at T5475, completed nine days ahead of the September 28, 2001, RAIP milestone date, added HSU 5 well W-1610 to TF5475-3.

TF5475-1 uses a down-hole CRD unit (CRD-1) to treat VOCs in groundwater. This technology treats VOCs in groundwater while keeping the groundwater containing tritium in the T5475 area in the subsurface.

CRD technology is based on the reaction of dissolved hydrogen on a palladium catalyst. When in contact with VOC-bearing groundwater, the VOCs are reduced to ethane, methane, or ethene, and free chloride ions. Because of the relatively rapid CRD reaction rates, treatment takes place during one pass through the unit.

CRD-1 operates in extraction well W-1302, a dual-screened well where groundwater containing VOCs and tritium is extracted from the lower screened interval for VOC treatment and is reinjected into the same HSU, via the upper screened interval, after treatment. CRD-1's destruction efficiency ranged from 95.0 to 98.1% in 2001.

TF5475-2 employs STU5 that uses a direct current (DC)-powered pump to extract groundwater through a series of aqueous-phase granular activated carbon canisters for treatment. Since tritium is not a contaminant of concern at TF5475-2, treated groundwater from TF5475-2 is discharged

into an underground storm drain that flows north into Arroyo Las Positas via the DRB. TF5475-2 complied with all permit requirements throughout 2001.

TF5475-3 uses CRD-2 to treat VOCs in groundwater. It is similar in design to CRD-1 except that it is an above-ground treatment unit rather than deployed in a well.

TF5475-3 was designed as a closed-loop system to prevent tritium in HSU 3A from being released above ground. Following activation in 2000, groundwater was extracted from wells W-1606 and W-1608, processed in CRD-2, and then returned to the subsurface using reinjection wells W-1605 and W-1607. TF5475-3 was shut down in May of 2001 to prepare for Phase 3 of TF5475 CRD.

Phase 3 of CRD treatment at facility TF5475-3 uses the CRD-2 treatment unit to treat groundwater pumped from HSU 5 extraction well W-1610 in a closed-loop system. The treated water is then re-injected into HSU 5 well W-1609. The CRD-2 destruction ranged from 93.4 to 99.3% in 2001. HSU 3 extraction well W-1606 is currently inactive because it cannot sustain flow due to de-watering of HSU 3A in the T5475 area. TF5475-3 resumed operation on September 19, 2001.

During 2001, groundwater tritium activities in all T5475 area wells remained below the MCL and continued to decrease by natural decay. VOC concentrations in T5475 area wells were stable or decreasing in 2001.

During 2001, the TF5475 area facilities operated at an average flow rate of 0.72 L/min to treat about 0.4 million liters of groundwater containing an estimated 1.1 kg of VOCs. Since system start up in 1998, the combined TF5475 facilities have

treated about 1.6 million liters of groundwater and removed about 4.2 kg of VOC mass from the subsurface ([Table 8-2](#)).

No new boreholes or wells were drilled and no hydraulic tests were conducted in the T5475 area during 2001.

Vapor Treatment Facility 5475

VTF5475 is located north of TF5475-3 in the east-central portion of the Livermore site, and treats soil vapor from vadose zone well SVI-ETS-504 ([Figure 8-1](#)). VTF5475 began operation in January 1999.

Soil vapor is extracted from the vadose zone and treated at VTF5475 using granular activated carbon. Due to elevated tritium concentrations in the vadose zone, VTF5475 is a closed-loop system to prevent aboveground tritium releases. The vapor stream is heated to reduce the humidity of the tritiated vapor prior to entering the granular activated carbon. This minimizes the absorption of tritium containing water on the granular activated carbon.

Following removal of VOCs from the air-stream, tritiated vapor is re-injected into the subsurface at soil vapor inlet well SVI-ETS-505. Tritium absorbed by the granular activated carbon during VOC treatment is handled as mixed waste. Because no effluent vapor from VTF5475 is released to the atmosphere, the Bay Area Air Quality Management District has granted the facility an exemption from air discharge requirements.

During 2001, VTF5475 operated at an average flow rate of $0.461 \text{ m}^3/\text{min}$ and treated over $241,000 \text{ m}^3$ of vapor containing an estimated 70.2 kg of VOCs. Since system start up in 1999, VTF5475 has treated about $516,000 \text{ m}^3$ of vapor containing an estimated 268 kg of VOCs ([Table 8-2](#)).

Two IMS sampling/monitor wells, SEA-ETS-506 and SEA-ETS-507, continued to monitor vadose zone remediation in the VTF5475 area. The IMS system is used to collect vapor pressure, soil temperature, soil moisture, and soil vapor concentration data from various discrete depths.

Groundwater Flow and Transport Modeling

Groundwater flow and contaminant transport models are used at the Livermore site to optimize remediation system design and operation, to support ongoing subsurface characterization activities, and to improve our ability to forecast, monitor, and interpret the progress of the groundwater remediation program. In 2001, LLNL continued to improve the three-dimensional (3-D) groundwater models for the Livermore site, and began developing new models to extend our evaluation capabilities to include deeper HSUs. Continued use of the existing models and development of new models in 2001 are described below.

HSU 1B /2 Model

In 2001, DOE/LLNL continued to use the 3-D groundwater flow and transport model of HSUs 1B and 2 to evaluate perchloroethylene (PCE) and trichloroethylene (TCE) transport throughout the Livermore site. The model was used to optimize well extraction rates, evaluate potential capture zones of proposed extraction wells, and evaluate plume migration and hydraulic interference patterns under increased pumping conditions. Prior to drilling, the proposed location of extraction well W-1701 was evaluated using the model to help ensure that the well would capture the leading edge of the PCE plume along Arroyo Seco. The long-term hydraulic test conducted in this well showed that model predictions were representative and that well W-1701 fully captures the PCE plume. The model was also used to evaluate the role of the Recharge Basin on the overall remediation of HSUs



1B and 2. This model was revised to include recent well pumping histories, changing boundary conditions, and refined flow and transport parameters to improve simulation results.

Deeper HSU Models

In 2001, four new two-dimensional (2-D) models were developed for deeper HSUs 3A, 3B, 4, and 5. The primary purpose of the individual 2-D models is to understand the flow and transport characteristics of each HSU separately before incorporating them into a larger 3-D model for the entire site. The 2-D models proved very useful in identifying the boundary conditions of these HSUs in terms of recharge and discharge locations, as well as areas of vertical communication. To accurately simulate the impact of source areas in these HSUs, distributed hydraulic conductivity fields were used. The hydraulic conductivity fields were generated using inverse modeling techniques utilizing groundwater elevation data. Preliminary calibration results indicate a general correlation between simulated and measured TCE distributions. Due to the hydrogeologic complexity of the deeper HSUs, some differences in TCE distribution are observed, mostly in the source areas, and LLNL is in the process of resolving discrepancies between the simulated and measured data.

Further refinement and improved calibration to minimize the differences will enable production level use of these models to support remediation decisions.

Electroosmosis Modeling

DOE/LLNL continued to develop a mathematical model to simulate flow and transport that couples groundwater and electroosmosis flow processes. The model is intended to aid in evaluating the field data from the electroosmotic remediation pilot test site in the Helipad area to optimize extraction and injection rates. For further results of this study, see *Field Measurements of Electro-osmotic Transport of*

Ground Water Contaminants in a Lithologically Heterogeneous Alluvial-Fan Setting (McNab et al. 2001).

Environmental Impact

In 2001, the decrease in size and concentration observed in the Livermore site VOC plumes is consistent with the 142 kg of VOC removed by the groundwater extraction wells during 2001. Most of the observed trends in VOC concentrations are attributed to active groundwater extraction and remediation. Notable results of VOC analyses of groundwater received from January 2001 through December 2001 are discussed below.

Concentrations on the western margin of the site either declined or remained unchanged during 2001, indicating continued effective hydraulic control of the western site boundary plumes in the TFA, TFB, and TFC areas. The size of the off-site TFA HSU 1B and 2 VOC plumes remained largely unchanged in 2001, although the concentrations have declined. However, all off-site TFA HSU 3A wells are now below MCLs for all VOCs of concern. In the TFB area, significant concentration reductions were observed in both HSUs 1B and 2. Total VOC concentrations declined below 50 ppb in all monitor wells in the TFB area in 2001. TCE concentrations in HSU 1B well W-269 declined from 20 ppb in 2000 to 10 ppb in 2001, and TCE concentrations in HSU 2 well W-308 declined from 26 ppb in 2000 to 2 ppb. In the TFC area, HSU 1B concentrations remained essentially unchanged.

In the central and eastern parts of the TFD area, HSU 2 VOC concentrations continued to decline in response to pumping the TFD extraction wells. TCE concentrations in HSU 2 extraction well W-906 decreased from 750 ppb in 1995 to 37 ppb in October 2001, and TCE in nearby monitor well W-355 decreased from 3100 ppb in April 1992 to



37 ppb in November 2001. In the northern TFD area, Freon 11 concentrations have declined below the 150 ppb MCL in all HSU 2 monitor wells except well W-423, where the Freon 11 concentration in July 2001 was 420 ppb.

VOC concentrations in HSU 3A TFD area wells also continued to decline in 2001. TCE in extraction well W-1550 decreased from 4,000 ppb in October 1999 to 870 ppb in November 2001. TCE in extraction well W-1552 declined from 9900 ppb in September 1999 to 1500 ppb in October 2001.

In the southern TFD and northern TFE areas, VOC concentrations in HSU 4 continue to show significant decreases due to pumping at HSU 4 extraction wells W-1418 and W-1503. TCE in well W-1418 declined from 750 ppb in 1998 to 85 ppb in November 2001. TCE in well W-1503 declined from 2100 ppb in 1999 to 290 ppb in October 2001.

Westward migration of the HSU 2 VOC plume was observed along the western margin of the TFE area in 2001. TCE in piezometer SIP-331-001 increased from below 0.5 ppb in July 1999 to 20 ppb in March 2001. Hydraulic containment of the western TFE HSU 2 VOC plume was established in April 2001 when TFE-W was activated and groundwater extraction began at HSU 2 extraction well W-305. We anticipate that concentrations should begin to stabilize then decline over the next several years in response to pumping well W-305.

In the TFE-E area, HSU 2 VOC concentrations continued to decline in response to groundwater extraction. TCE in HSU 2 extraction well W-1109 decreased from 1744 ppb in January 1998 to 250 ppb in October 2001. In nearby HSU 2

monitor well W-257, TCE concentrations decreased from a maximum of 6400 ppb in 1988 to 130 ppb in July 2001.

In the TF5475 area, significant VOC concentration decreases continued in 2001. TCE in piezometer SIP-ETS-204 declined from a maximum of 21,000 ppb in November 1997 to 110 ppb in May 2001. TCE in monitor well W-1225 declined from 2900 ppb in March 1997 to 70 ppb in September 2001. However, TCE in monitor well W-1117 increased from 43 ppb in November 1995 to 1600 ppb in November 2001.

In the TF518 and TF406 areas, the off-site HSU 5 VOC concentrations continued to decrease in response to pumping the TF406 extraction wells. TF518 was dismantled and removed after HSU-5 became de-watered in the southeastern portion of the Livermore site. TCE, in off-site monitor well W-219, declined from 100 ppb in October 1997 to 1.4 ppb in October 2001. TCE, in another off-site monitor well, W-225, declined from over 2100 ppb in 1987 to 2.5 ppb in October 2001.

In the TFG area, VOC concentrations in HSU 2 wells continued to decline in response to pumping HSU 2 extraction well W-1111. TCE is the only VOC of concern that is not below its MCL in all HSU 2 wells. TCE in well W-1111 declined from 54 ppb in March 1996 to 5.1 ppb in November 2001. TCE in nearby monitor well W-464 declined from 110 ppb in March 1992 to 1.2 ppb in November 2001. With continued groundwater extraction at well W-1111, we anticipate that TCE should fall below the 5 ppb MCL in all HSU 2 wells during 2002.

During 2001, tritium groundwater activities in all wells remained below the MCL and continued to decrease in activity due to natural decay in the T5475 area.



Site 300 CERCLA Project

Environmental investigations and cleanup activities at Site 300 began in 1981. Site 300 became a CERCLA/Superfund site in 1991, when it was placed on the National Priorities List (NPL). The CERCLA environmental restoration operable units (OUs) are shown in [Figure 8-9](#). All contaminant release sites have been assigned to one of eight OUs based on the nature and extent of contamination, and topographic and hydrologic considerations. The major contaminants of concern are listed in [Table 8-4](#).

Geology of Site 300

Site 300 is located in the sparsely populated Altamont Hills, which are part of the Coast Ranges Physiographic Province and separate the Livermore Valley to the west from the San Joaquin Valley to the east. Site 300 stratigraphy is shown in [Figure 8-10](#). Rocks exposed in the region are classified into three groups:

- Late Tertiary-Quaternary (0–5 million years ago)—alluvium and semilithified sediments, mainly of continental origin.
- Early to late Tertiary (5–65 million years ago)—shallow marine and continental sedimentary and volcanoclastic rocks.
- Jurassic-Cretaceous (65–180 million years ago)—Great Valley sequence (marine sedimentary rocks and ophiolites) and Franciscan Complex (sheared and variably metamorphosed sedimentary and igneous rocks).

Distinctive blue-gray to brown weathering volcanoclastic sandstone and sandy siltstone, interbedded with light gray weathering tuffaceous claystone and conglomerate, are exposed extensively within

Site 300. These rocks are mapped as the late Miocene Neroly Formation (Huey 1948; Dibblee 1980). The Neroly Formation is also present in the subsurface beneath Site 300.

The Neroly Formation is the principal hydrologic unit within Site 300 and has been the focus of the detailed geologic and hydrogeologic studies conducted during recent years (summarized in the *Final Site-Wide Remedial Investigation Report, Lawrence Livermore National Laboratory Site 300*, [Webster-Scholten 1994]). The complete section of the Neroly Formation is about 150 m thick beneath Site 300.

The floodplain of Corral Hollow Creek lies along the southern boundary of Site 300 and borders portions of the General Services Area (GSA), the High Explosives Process Area, and the area of closed landfill Pit 6. Floodplain alluvium consists dominantly of coarse cobble and boulder-bearing terrace gravel derived from sources to the south, with lenses and local cappings of sandy silt and silty clay.

The bedrock sequence within Site 300 has been slightly deformed into several gentle, low-amplitude folds. The locations and characteristics of these folds, in combination with the regional fault and fracture patterns, locally influence groundwater flow within the site and have therefore been studied in great detail as part of the CERCLA investigations.

Hydrogeology of Site 300

Site 300 is semiarid, with an average annual rainfall of 27 cm. The site is underlain by gently dipping sedimentary bedrock dissected by steep ravines. The bedrock consists of interbedded conglomerates, sandstones, siltstones, and claystones (see [Figure 8-10](#)).

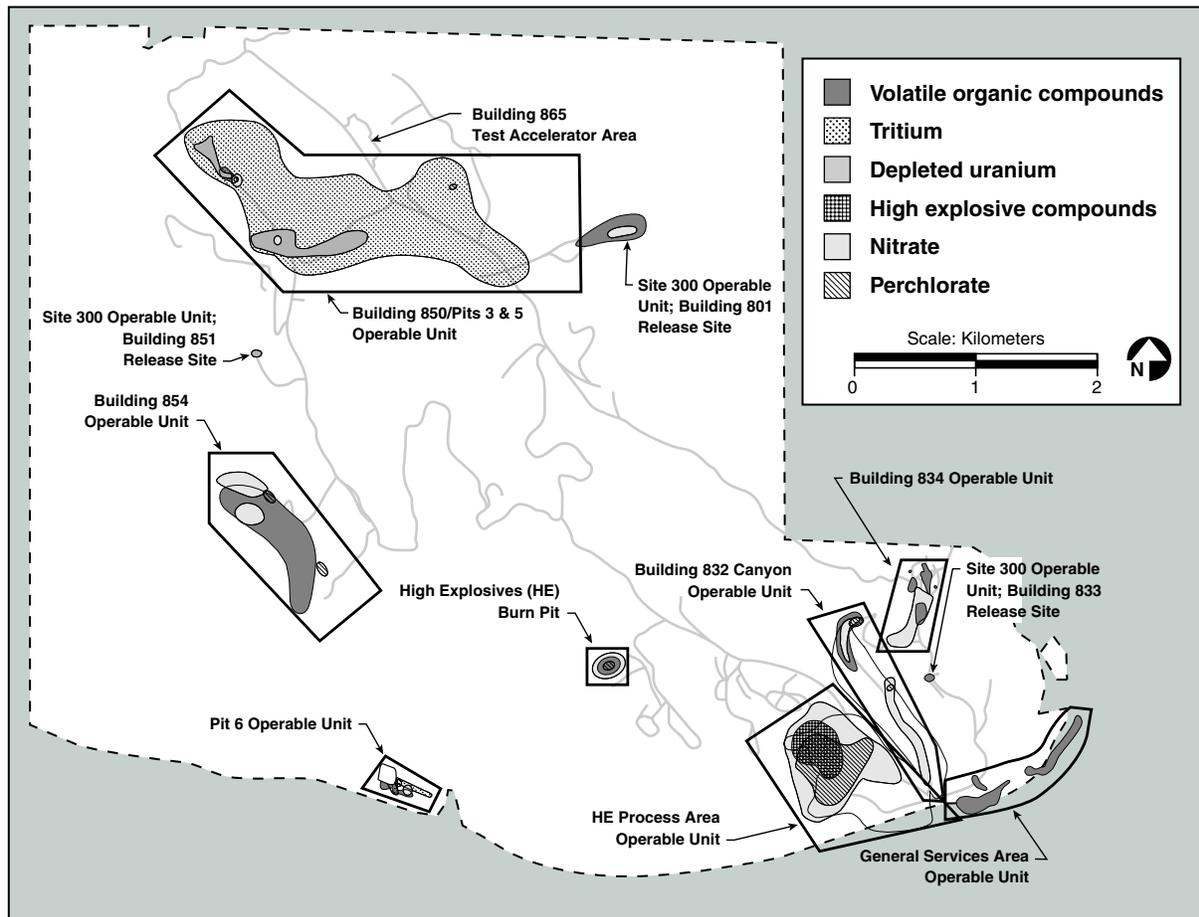


Figure 8-9. Environmental restoration operable units at Site 300

Groundwater primarily occurs in the Neroly Formation upper and lower blue sandstone units ($Tnbs_2$ and $Tnbs_1$) and in the underlying Cierbo Formation ($Tmss$). Saturated conditions also exist in two units that occur at the base of the Neroly Formation in the Building 854 and Pits 3 and 5 areas, respectively ($Tnsc_0$ and $Tnbs_0$). Groundwater can also be present in permeable Quaternary alluvium valley fill (Qal) during the winter rainy season.

Some groundwater is present as perched water-bearing zones beneath hilltops. The perched water-bearing zones primarily occur in the unconsolidated sediments of the Miocene-age nonmarine

unit (Tps) in the Building 833 and 834 areas and in the Explosives Process Area. An extensive perched water-bearing zone also occurs in $Tnbs_1$ sandstones in the northwestern portion of the East and West Firing Area. Fine-grained siltstone and claystone interbeds in $Tnbs_1$ and $Tmss$ act as aquitards, confining layers, or perching horizons. Portions of the bedrock section at Site 300 are abundantly fractured, and thus much of the groundwater flow occurs in fractures as well as in pores. Bedrock-hosted groundwater is typically present under confined conditions in the southern half of the site but is often unconfined elsewhere. [Figure 8-11](#) is a map of the potentiometric surface for the first

**Table 8-4. Major contaminants of concern found in soil, rock, and groundwater at Site 300**

Operable Unit (OU)	Contaminant of concern ^(a)
General Services Area (GSA) (OU1)	VOCs (primarily TCE)
Building 834 Complex (OU2)	VOCs (primarily TCE), Organosilicate oil, Nitrate
High Explosives Process Area (OU4)	VOCs (primarily TCE), HE (primarily HMX), Nitrate, Perchlorate
Building 850/Pits 3 & 5 (OU5)	Tritium, Depleted uranium, VOCs (primarily TCE), Nitrate, Perchlorate
Building 854 (OU6)	VOCs (primarily TCE), Nitrate, Perchlorate
Pit 6 (OU3)	VOCs (primarily TCE), Tritium, Nitrate, Perchlorate
Building 832 Canyon (OU7)	VOCs (primarily TCE), Nitrate, Perchlorate
Site 300 (OU8)	VOCs (primarily TCE and Freon 113), Nitrate, Perchlorate, Depleted uranium

^a See [Acronyms and Abbreviations](#) for list of acronyms

continuous water-bearing zone at Site 300, which principally occurs in the Neroly lower blue sandstone aquifer (Tnbs₁).

Recharge occurs where saturated alluvial valley fill is in contact with underlying permeable bedrock, and where bedrock strata crop out. Local recharge occurs on hilltops, creating the perched water-bearing zones in the Building 832, 834, 854, and 829/HE Burn Pit areas. Low rainfall, high evapotranspiration rates, steep topography, and intervening aquitards generally preclude direct vertical recharge to the deeper bedrock aquifers.

Groundwater flow in the bedrock follows the inclination, or dip, of the layers. The tectonic forces that uplifted the Altamont Hills faulted, gently folded, and tilted the once-horizontal sedimentary strata. A major structure, the east-west trending Patterson anticline, occupies a central location within the site. North of the anticline, bedrock generally dips east-northeast. South of the anticline, bedrock dips south-southeast.

The Cierbo Formation (Tmss) is saturated beneath Doall Ravine, the Building 851 and 854 areas, and the southern part of the East Firing Area. The Tmss unit is unsaturated or does not otherwise yield water to wells in other parts of the East and West Firing Areas. The thickness of the Cierbo Formation is not well known because most boreholes are not deep enough to completely penetrate this formation. Some of the deeper wells in the GSA penetrate the uppermost Tmss. The continuity of saturation in the Tmss between the northwest and southeast areas of Site 300 is undetermined. Groundwater in the Tmss occurs under unconfined to artesian conditions.

The Tps unit is the youngest bedrock unit identified at Site 300 and is generally present only on hilltops. Where present, groundwater is typically perched, discontinuous, and ephemeral. The exception to this condition exists in the Explosives Process Area, where the extent of saturation in Tps sediments is significant. Groundwater in the Tps unit is generally unconfined, although water under confined conditions does occur locally.

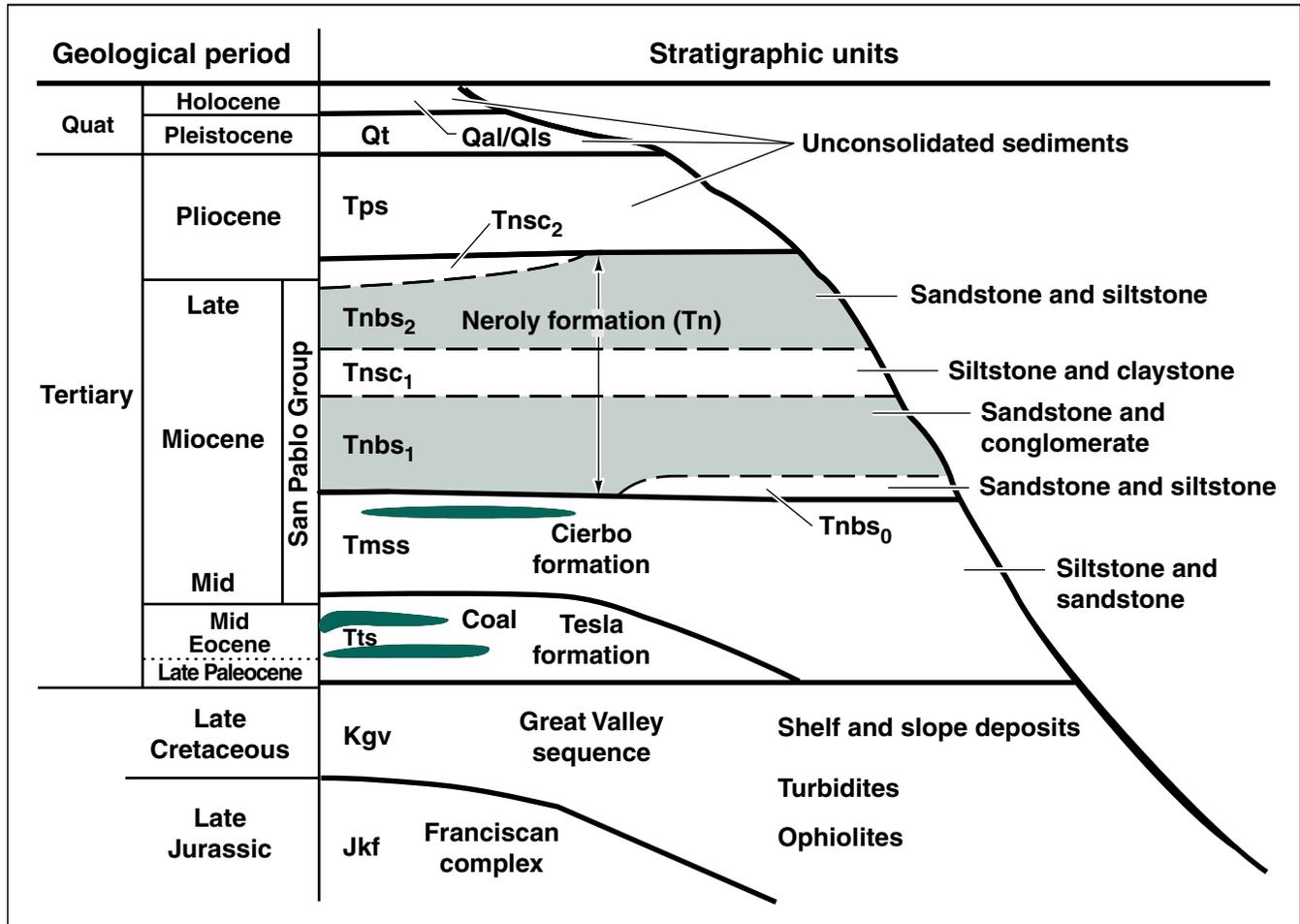


Figure 8-10. Site 300 stratigraphy (Webster-Scholten 1994)

Quaternary alluvium (Qal) is present as valley fill in ravines throughout Site 300 but is perennially saturated only in the Corral Hollow Creek stream channel, in Doall Ravine, and in southern Elk Ravine in the vicinity of Building 812. Qal in the Pits 3 and 5 area is only saturated during rainy seasons and for extended periods of higher than normal rainfall. Saturated Quaternary terrace alluvium deposits (Qt) are present at Pit 6, in the General Services Area (GSA,) and in the Building 832 Canyon area; some of these groundwater occurrences are ephemeral. Small quantities of groundwater are present in some local landslide (Qls) deposits.

All groundwater contaminant plumes at Site 300 occur in Neroly Formation (Tn) rocks, unnamed Pliocene nonmarine sediments (Tps), or unconsolidated Quaternary sediments (Qal, Qls, or Qt) stratigraphic units. The extent of groundwater contamination at Site 300 is shown on Figure 8-12.

Operable Unit Highlights and Activities

Background information for LLNL environmental characterization and restoration activities at Site 300 can be found in the *Final Site-Wide Remedial Investigation Report, Lawrence Livermore National Laboratory Site 300* (Webster-Scholten 1994). LLNL submitted all required

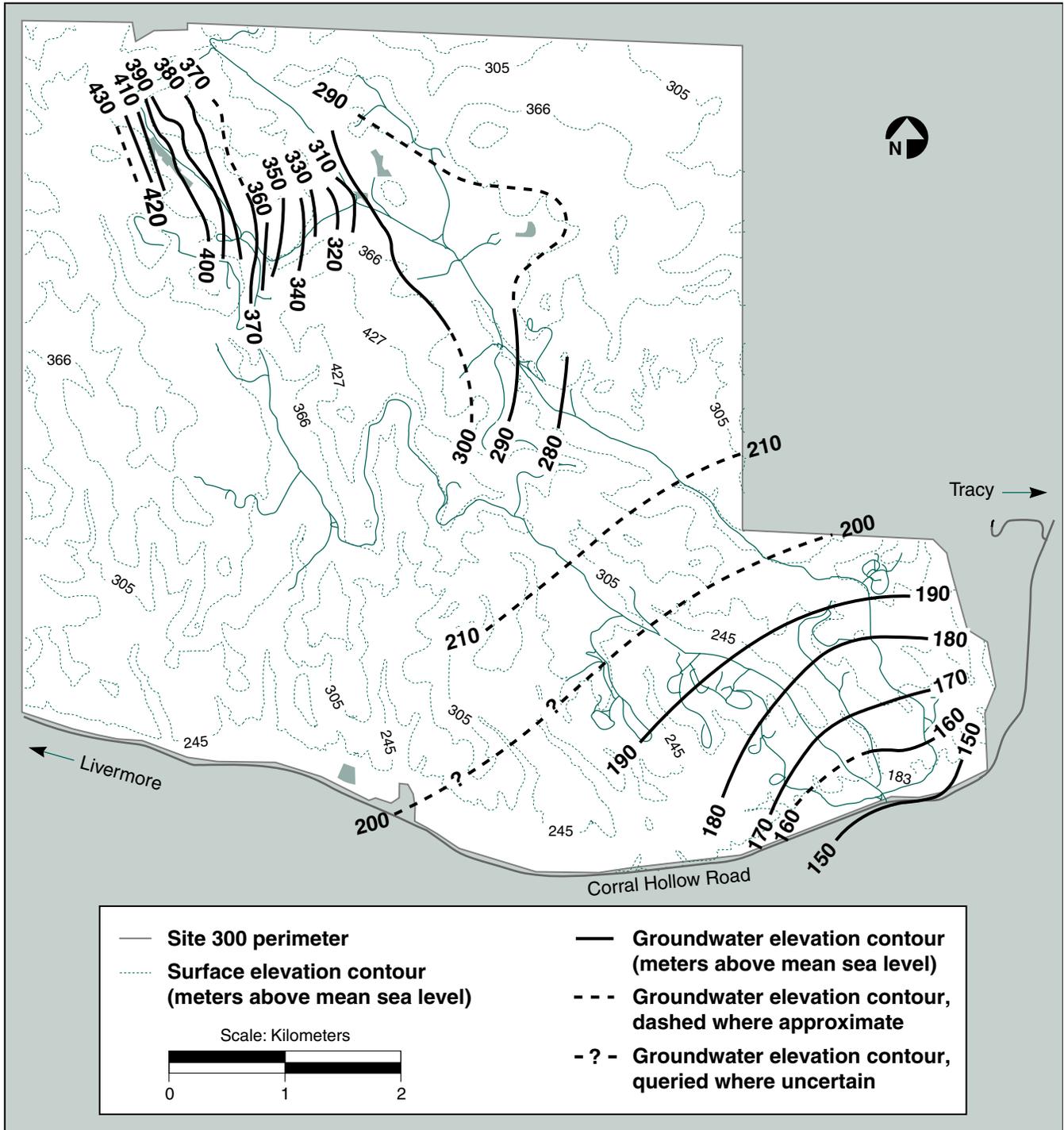


Figure 8-11. Approximate groundwater elevations in the principal continuous water-bearing zone at Site 300

documentation to oversight agencies on time in 2001. The *Draft Final Interim Site-Wide Record of Decision for Lawrence Livermore National Laboratory Site 300* (U.S. DOE 2001), *Five-Year Review Report for the General Services Area Operable Unit* (Ferry et al. 2001b), *Remedial Design Work Plan for Interim Remedies at Lawrence Livermore National Laboratory Site 300* (Ferry et al. 2001c), *Draft Five-Year Review Report for the Building 834 Operable Unit* (Ferry et al. 2001c), *Draft Final Interim Remedial Design for the Building 834 Operable Unit Treatment Facility* (Gregory et al. 2001), quarterly reports, and other work plans were among the documents submitted.

Background information and a summary of characterization activities for each of the OUs are described in the following sections. Groundwater remediation for Site 300 is discussed in more detail later in this chapter. See [Chapter 9](#) for a discussion of 2001 groundwater monitoring.

General Services Area Operable Unit

In the General Services Area (GSA), past leaks of solvents from storage areas and buried debris have resulted in several plumes of volatile organic compounds (VOCs) in groundwater. There are three major TCE plumes and two treatment facilities located within the GSA OU, which is divided into the central GSA and the eastern GSA.

The VOC groundwater plume in the eastern GSA is present in subsurface stream channel alluvium (Qal) at 3–9 m below the ground surface; the plume, as defined by the 1 µg/L concentration contour, is about 538 m long ([Figure 8-13](#)). Groundwater in the alluvium flows east and north-east below the Corral Hollow Creek streambed. The maximum 2001 total VOC concentration in groundwater from the eastern GSA wells was 7.3 µg/L. The Qal is hydraulically connected to the Neroly Formation lower blue sandstone (Tnbs1) unit.

Two VOC groundwater plumes in the central GSA are present in terrace alluvium (Qt) and the Neroly Formation upper blue sandstone (Tnbs₂) at a depth of 3–9 m below the surface. These VOC plumes are about 137 m and 396 m long ([Figure 8-14](#)), respectively. Maximum 2001 total VOC concentrations in alluvial groundwater were 757 µg/L. Deeper groundwater in the bedrock regional aquifer also contained total VOCs at a maximum concentration of 6 µg/L in 2001. This groundwater occurs at depths of 11–56 m below the surface.

Details of current and planned environmental restoration activities at the GSA are summarized in the *Final Remedial Design* (RD) document (Rueth et al. 1998). This document includes the Contingency Plan and Compliance Monitoring Plan for the GSA OU.

By analyzing chemical, hydrogeologic, and hydraulic test data, LLNL determined that the direction of plume migration likely follows a previously unidentified buried stream channel. After 8 years of treatment, by the fall of 1999, the eastern GSA off-site plume (as defined by the 5 µg/L TCE contour line) had been restricted to the Site 300 property. Before the treatment commenced in 1991, the plume had previously extended more than a mile down the Corral Hollow stream channel in the direction of the City of Tracy.

After determining that the eastern GSA VOC plume was restricted to the site, LLNL reconsidered the need for an off-site treatment facility as outlined in the RD. TCE concentrations have decreased to below drinking water standards in groundwater from all off-site wells. Thus, LLNL has determined that an off-site extraction and treatment system is not needed or justified. The regulatory agencies have concurred that the off-site

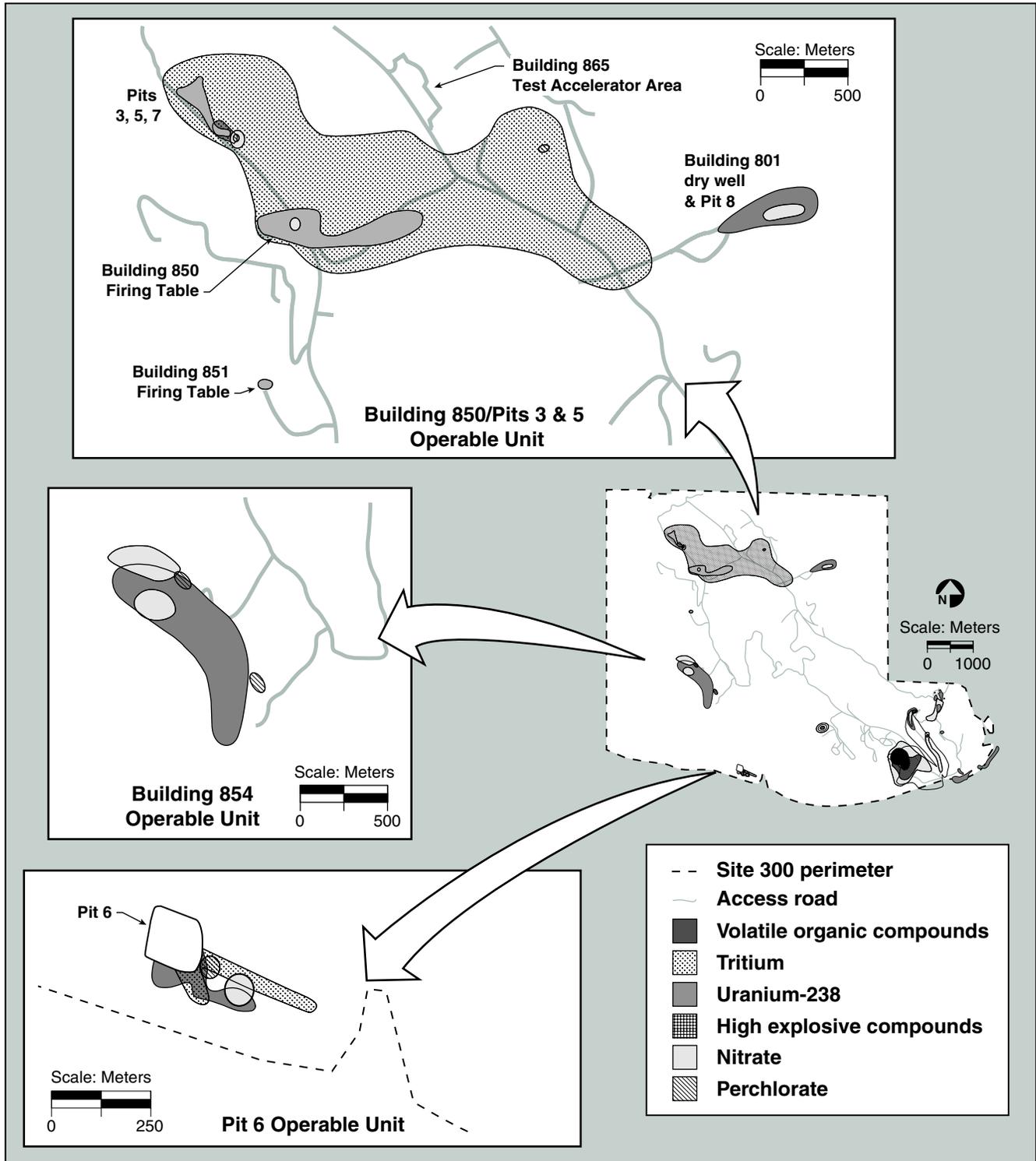
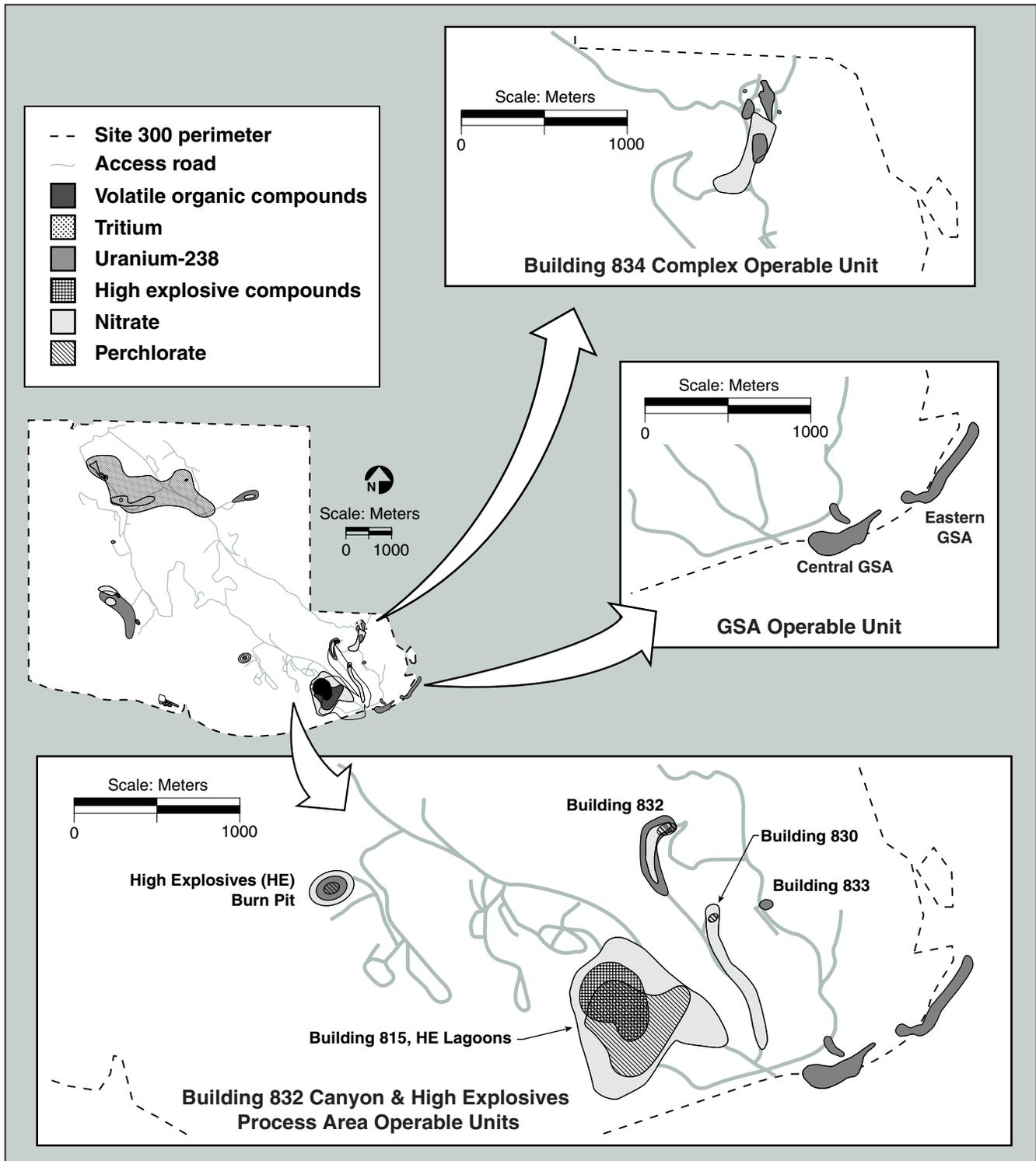


Figure 8-12. Extent of groundwater contamination at Site 300



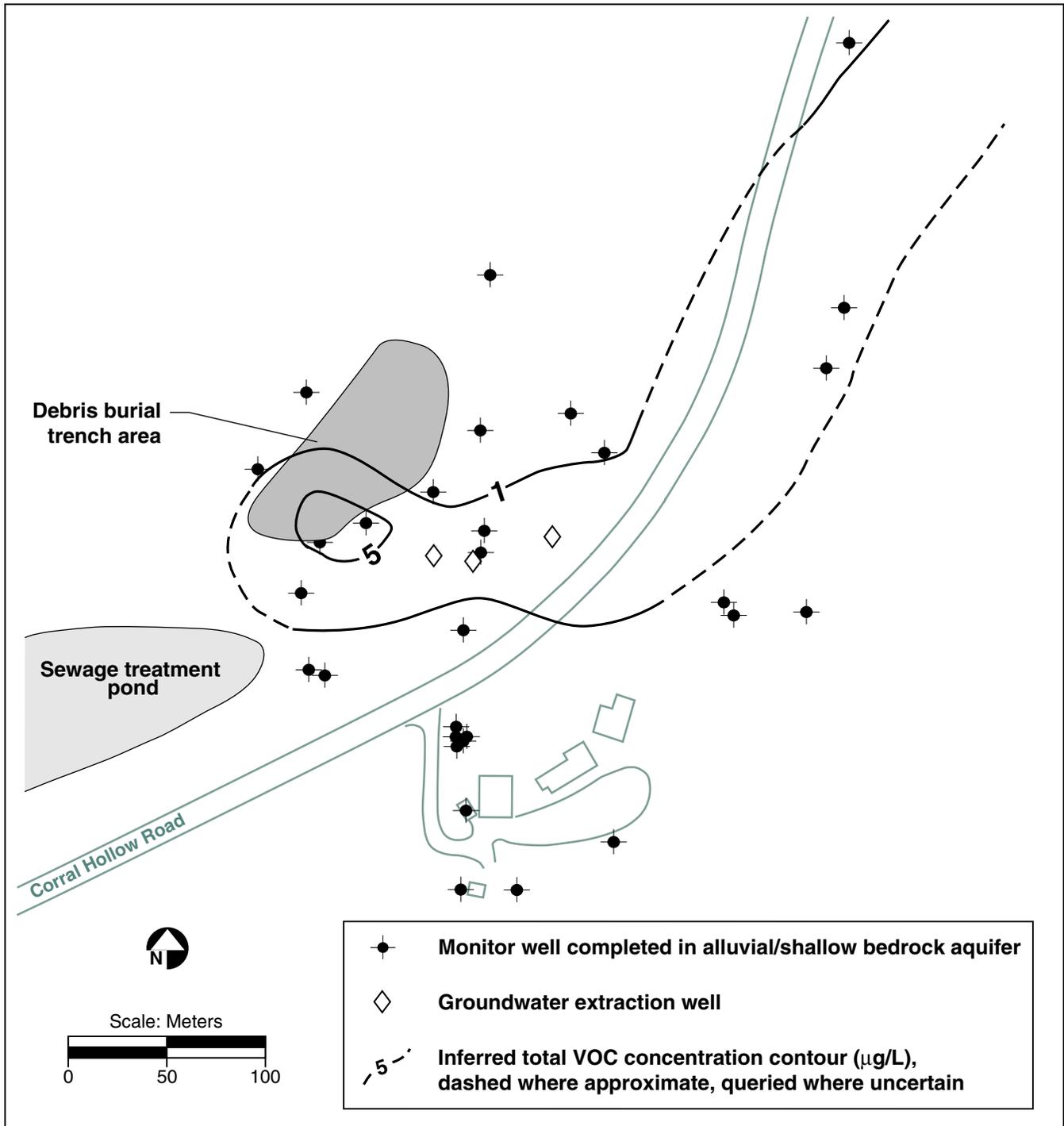


Figure 8-13. Total VOC concentrations in groundwater in the eastern GSA and vicinity (4th quarter, 2001)

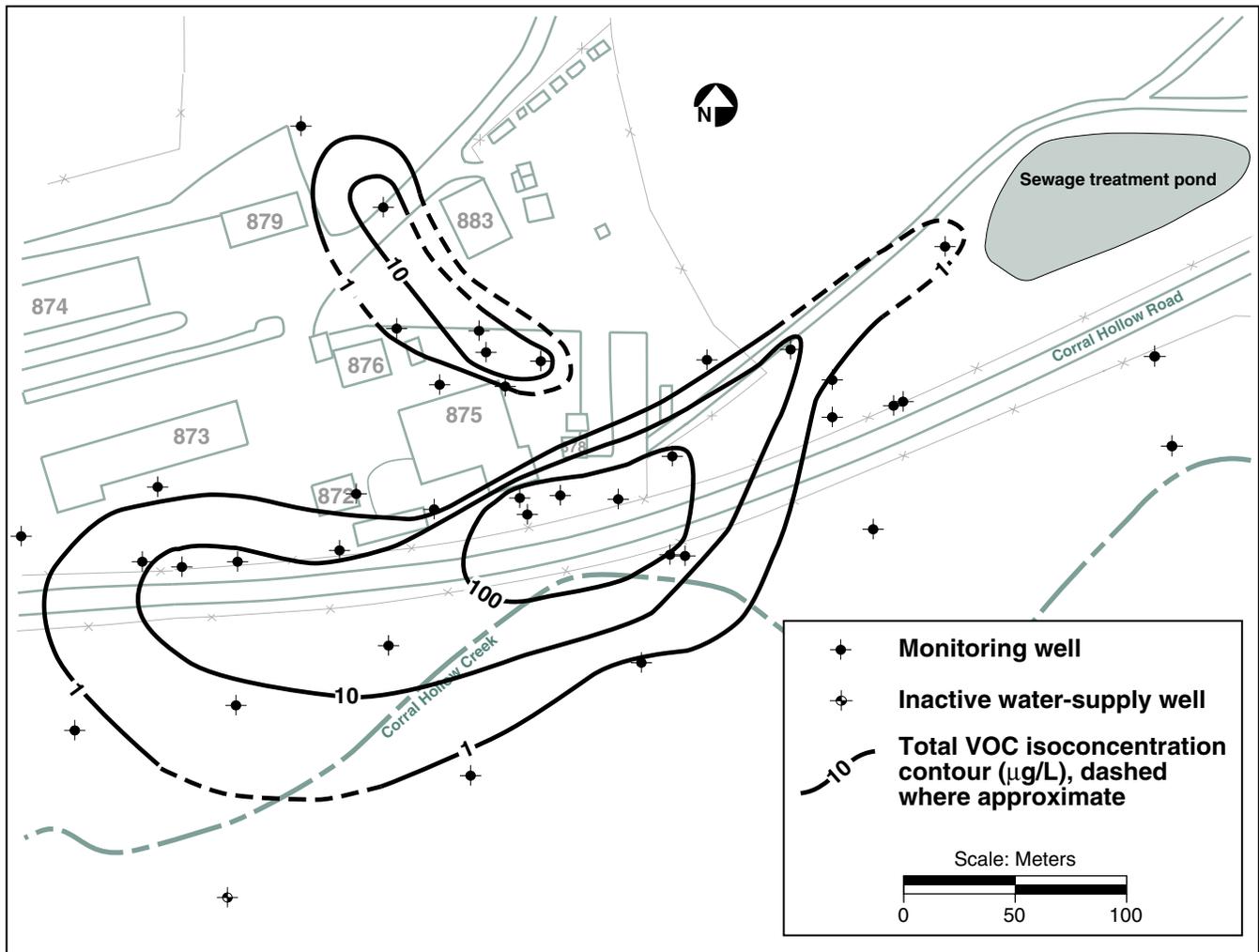


Figure 8-14. Total VOC concentrations in groundwater in the central GSA (4th quarter, 2001). Monitoring wells are completed in the Qt-Tnsc₁ hydrologic unit.

treatment system milestone can be delayed and that the need would be reevaluated during the GSA Five-Year Review.

The milestone to complete the *Draft Final Five-Year Review Report* was met on October 15, 2001. This purpose of this report is to determine whether the current pump-and-treat remedy for the GSA is protective of human health and the environment and to address all issues pertaining to the remediation efforts in progress

Building 834 Operable Unit

Since the late 1950s, the Building 834 complex, consisting of twelve separate buildings, has been used for weapons component testing. TCE was used as the primary heat transfer fluid in experiments involving thermal cycling of weapons components. TCE was pumped between buildings through aboveground pipelines. Occasionally, TCE was mixed with silicone oils, tetrabutyl orthosilicate (TBOS), and tetrakis (2-ethylbutyl) silane (TKEBS) to prevent degradation of pump seals and gaskets. Several large spills of TCE to the ground,



estimated at 550 gallons, and smaller releases of TBOS and TKEBS, resulted in contamination of a shallow perched water-bearing zone beneath the site. Natural biodegradation of the TCE, in the form of anaerobic dehalogenation, has been occurring in discrete zones resulting in the formation of appreciable amounts of cis-1,2-DCE. This intrinsic biodegradation is facilitated by fermentation of TBOS and TKEBS, which yields the hydrogen required for microbial dechlorination of VOCs.

An isolated, discontinuous, perched water-bearing zone occurs in Pliocene non-marine gravels (Tpsg) and occurs at a maximum depth of 9 m below the center of the complex. Within this Tpsg unit exist multiple thin water-bearing layers containing distinctive plumes that may be in hydraulic communication only following periods of heavy rainfall and the resulting higher groundwater elevations. The Tpsg is underlain by a clay perching horizon (Tps) which is nearly saturated. Tpsg and Tps strata crop out on all sides of the hill housing the Building 834 complex and are hydraulically isolated from the underlying regional aquifer by more than 90 m of unsaturated zone. Although the maximum total VOC groundwater concentration within the Tpsg during 2001 was 87,000 µg/L, the highest VOC concentrations in groundwater were found in the Tps perching horizon. This Tps has a very low hydraulic conductivity, but does yield some groundwater. The highest concentration of VOCs in groundwater samples obtained from the Tps during 2001 was 250,000 µg/L, which was predominantly TCE. The groundwater VOC distribution within the Tpsg is presented in **Figure 8-15**. The highest concentration of TBOS/TKEBS in groundwater during 2001 was 180,000 µg/L. High levels of nitrate (maximum 2001 concentration of 280 mg/L) also occur in the groundwater in the Building 834 OU, but the source is uncertain. Effluent from the septic system leach field has possibly contributed to elevated

nitrate concentrations in groundwater. Additional natural and/or anthropogenic nitrate sources may exist.

Groundwater treatment began during the 4th quarter of 1995. Soil vapor extraction and treatment commenced during the 3rd quarter of 1998.

Currently, groundwater and soil vapor extraction and treatment, using air-sparging and granular activated carbon, respectively, are in progress. Aqueous phase granular activated carbon is being tested as a possible replacement of air sparging for VOC removal from groundwater.

During 2001, LLNL submitted to the regulatory agencies, the *Draft Interim Remedial Design Report for the Building 834 Operable Unit Treatment Facility* (Gregory et al. 2002) and the *Draft Five-Year Review Report for the Building 834 Operable Unit* (Ferry et al. 2001a). One paper was presented in 2001 at the 97th Annual Meeting of the Geological Society of America (Madrid et al. 2001).

High Explosives Process Area Operable Unit

The High Explosives Process Area was established in the 1950s to chemically formulate, mechanically press, and machine high explosives (HE) compounds into detonation devices that are tested in explosives experiments in the East and West Firing Areas of Site 300. Process waste water from HE machining operations containing HMX, RDX, nitrate, and possibly perchlorate was discharged to nine former unlined lagoons at concentrations high enough to impact groundwater.

A concrete hardstand on which TCE was stored, located near the former Building 815 steam plant, is considered to be the primary source of TCE groundwater contamination. HMX and RDX are the most frequent and widespread HE compounds detected in soil and groundwater. TCE, nitrate,

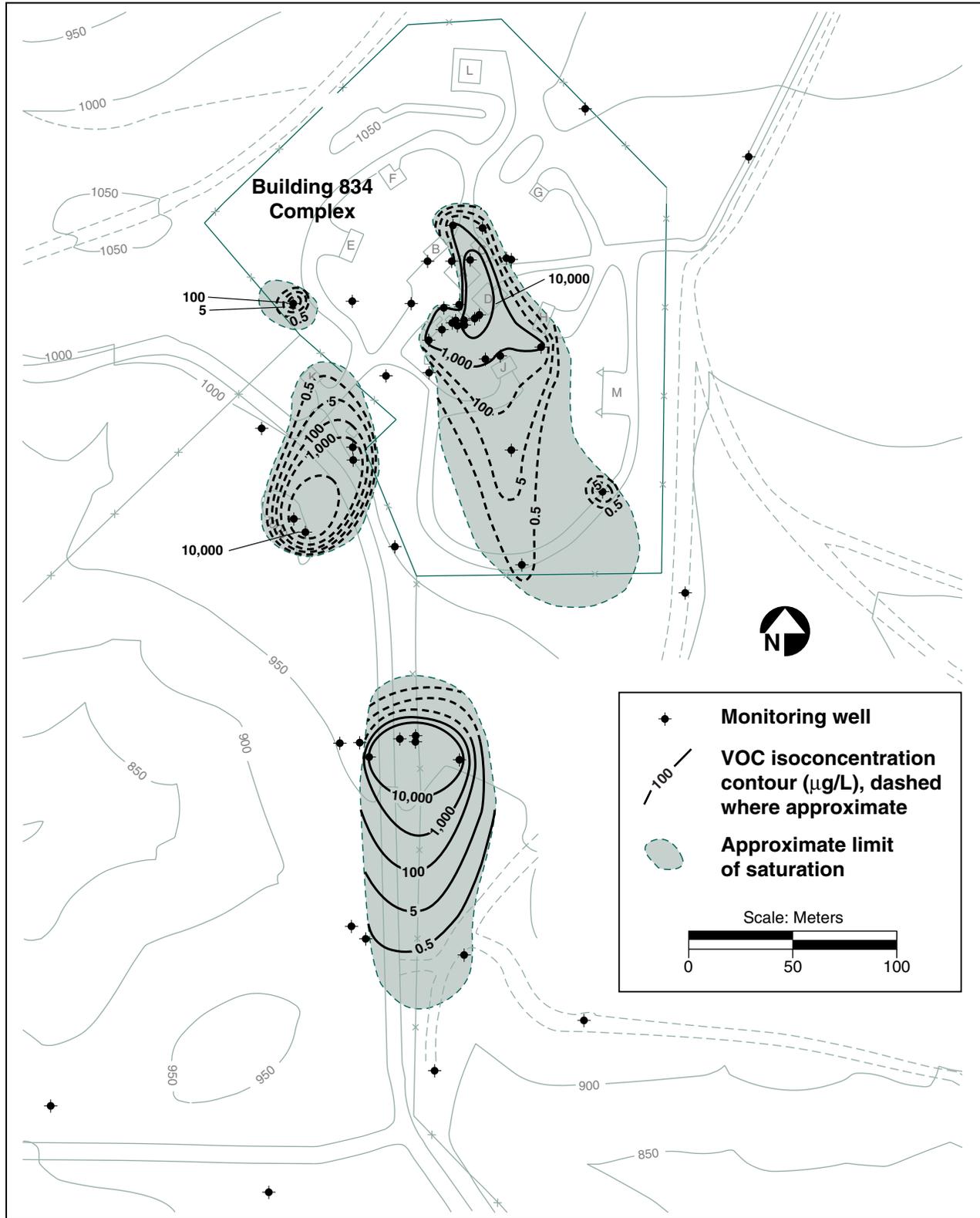


Figure 8-15. Isoconcentration contours for total VOCs in groundwater in the Qt-Tpsg hydrologic unit at the Building 834 complex (4th quarter, 2001)



perchlorate, and RDX occur in groundwater within two separate water-bearing zones. One of the water-bearing zones occurs in the Tps formation and the other occurs in the Tnbs₂ sandstone. Depth to groundwater ranges from 2 to 76 m. The VOC (principally TCE) plume in Tps strata is about 200 m long; the VOC plume in the Tnbs₂ aquifer is about 900 m long (Figure 8-16). The RDX plume is about 200 m long and the perchlorate plume is about 600 m long in the Tnbs₂ aquifer. The extent of nitrate above the MCL in the Tnbs₂ aquifer is about 700 m long. In 2001, maximum concentrations of TCE, RDX, nitrate, and perchlorate were 73 µg/L, 140 µg/L, 98 mg/L, and 33 µg/L, respectively.

Building 850/Pits 3 and 5 Operable Unit

Explosives experiments conducted at outdoor firing tables in the Building 850/Pits 3 and 5 area have generated wastes that in the past were disposed at several unlined land-fills. Tritium has been released to groundwater from landfill Pits 3 and 5 and the Building 850 firing table (Figure 8-17). Depleted uranium has been released to groundwater from landfill Pits 3, 5, and 7 and the Building 850 firing table. Release of tritium and uranium occurred from water-table rise and lateral flow of upgradient groundwater into the landfills and percolation of rainfall runoff water through the Building 850 firing table to underlying groundwater. The resulting plumes occur in a perched water-bearing zone within Qal alluvium and bedrock at the base of the Neroly Formation in the Tnbs₀. The water-bearing zone occurs at depths of 5–20 m below surface. There are three overlapping plumes of tritium in groundwater.

The maximum 2001 tritium activity was about 11,555 Bq/L (312,000 pCi/L). The total length of the co-mingling tritium plumes was about 3000 m. The perched water-bearing zone is connected to the regional Tnbs₁ aquifer at the Elk Ravine Fault. Maximum 2001 groundwater tritium

activities in this aquifer were about 563 Bq/L (15,200 pCi/L). There are two smaller plumes of depleted uranium (uranium-238), with maximum measured 2001 activities of about 7.4 Bq/L (199 pCi/L) and 0.2 Bq/L (5.4 pCi/L), respectively. The depleted uranium is confined to the perched water-bearing zone; the lengths of the two uranium plumes are about 380 m and 500 m, respectively. Computer modeling of contaminant fate and transport indicates that by the time the tritium and uranium in groundwater could reach the Site 300 boundary, these radionuclides will exist at near-background activities.

A remedial investigation/feasibility study (RI/FS) is in process for the Pits 3 and 5 area. The anticipated remedial technologies to be implemented at the landfill site include source isolation to prevent further release of tritium and uranium to groundwater. These technologies may include an upgradient interceptor trench and surface and shallow subsurface water diversion. LLNL is testing reactive media for possible deployment in a permeable reactive barrier for removal of depleted uranium from Pit 5 and 7 downgradient groundwater.

Although tritium continues to leach into groundwater from vadose zone sources at Building 850, the long-term trend in total groundwater tritium activity in this portion of the tritium plume is one of decreasing activity at approximately the radioactive decay rate of tritium. The extent of the 740 Bq/L (20,000 pCi/L) MCL contour for this portion of the plume is shrinking.

Nitrate and perchlorate in the Building 850/Pits 3 and 5 area occurred at maximum concentrations of 52 mg/L and 5.7 µg/L, respectively, in 2001. Trace amounts of TCE (less than 6.4 µg/L) are also present in groundwater near Pit 5.

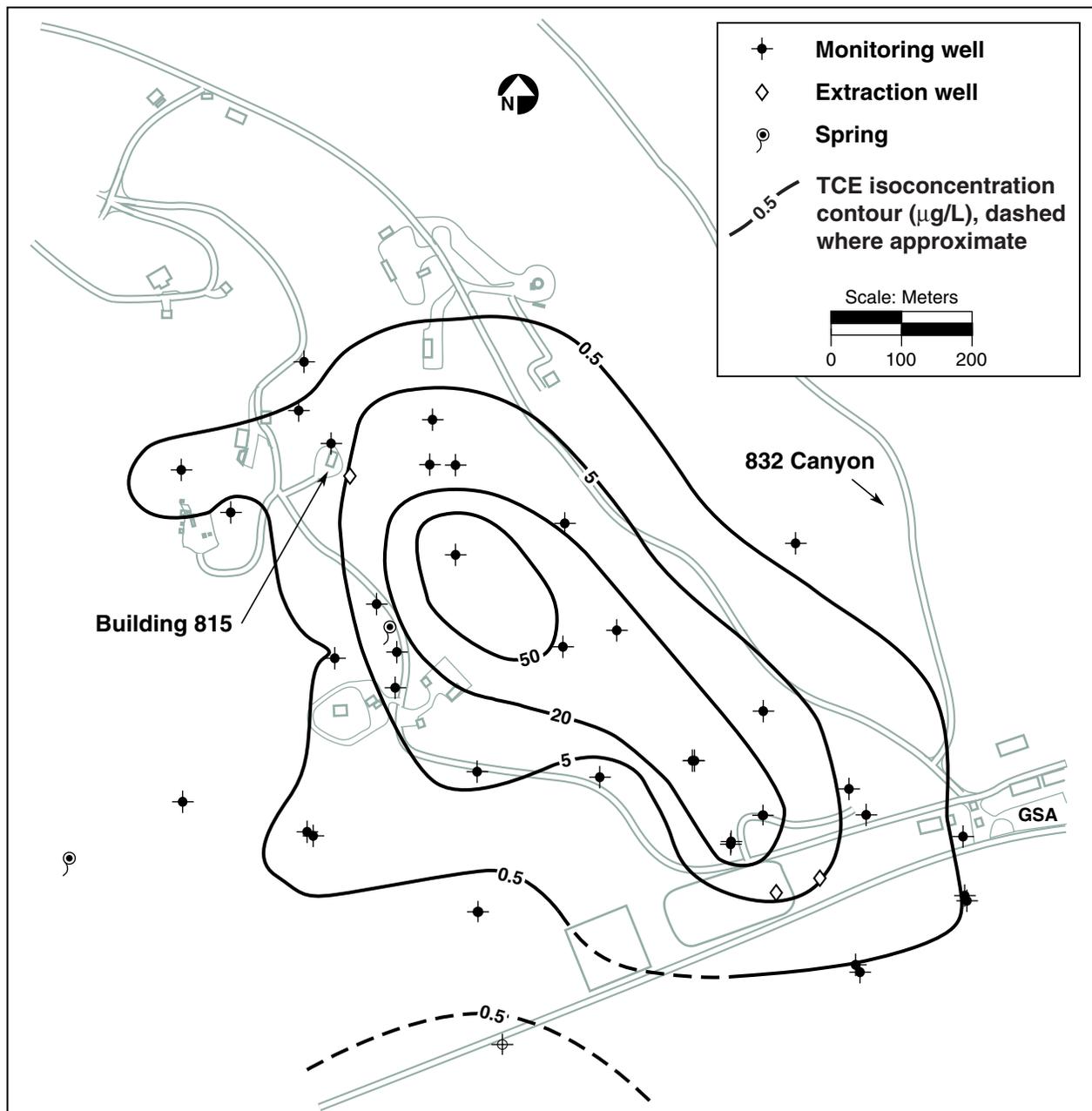


Figure 8-16. Isoconcentration contour map of trichloroethene (TCE) in groundwater in the Tnbs₂ aquifer in the HE Process Area (2nd quarter, 2001)

Building 854 Operable Unit

TCE in groundwater was previously found to arise principally from leaks in the former overhead TCE brine system at Buildings 854E and 854F. TCE,

nitrate, and perchlorate occur in groundwater in the Building 854 area in Neroly Formation Tnbs₁ strata at maximum 2001 concentrations of 290 µg/L, 160 mg/L, and 11 µg/L, respectively.

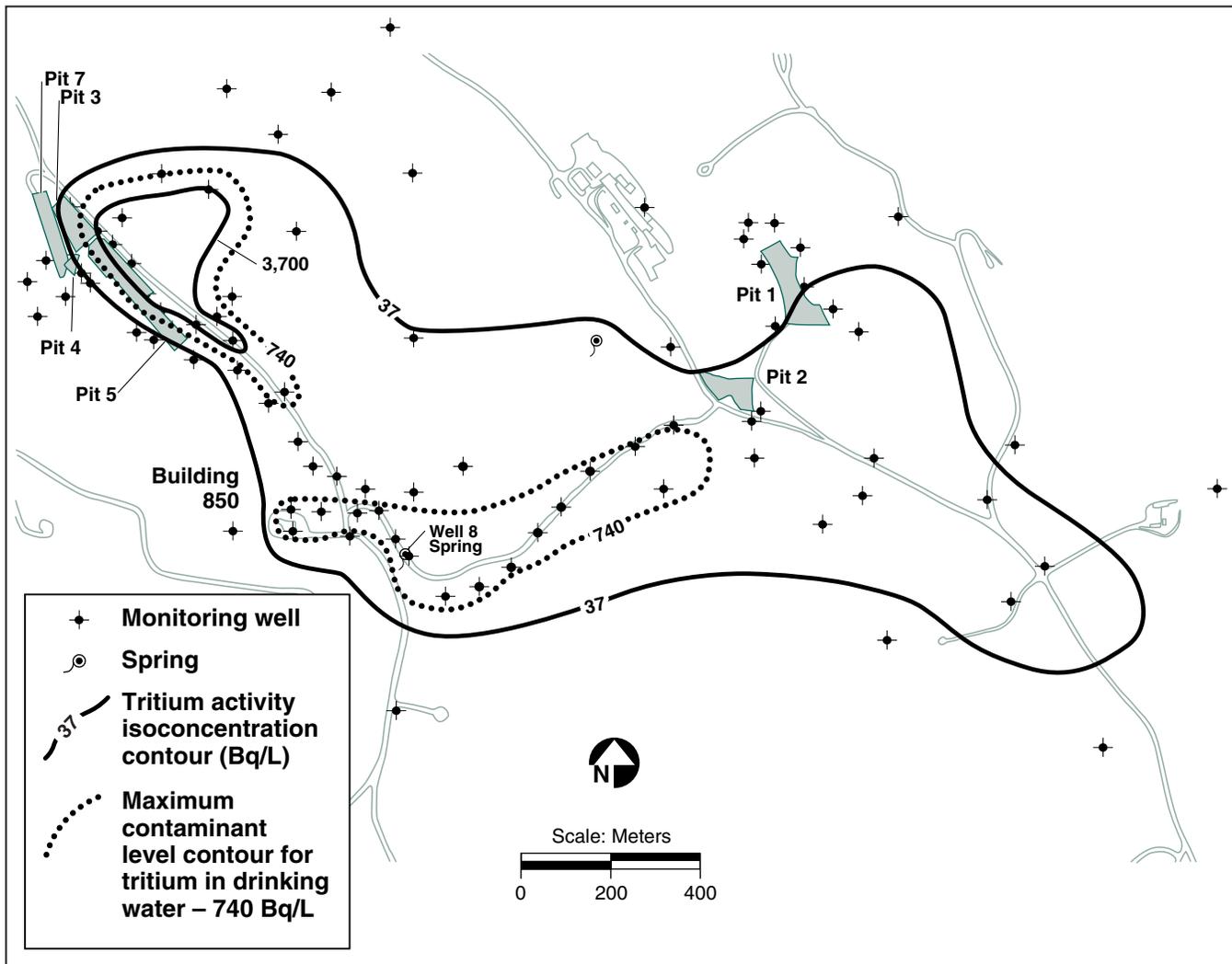


Figure 8-17. Distribution of tritium in groundwater in the first water-bearing zone in the Building 850/Pits 3 and 5 Operable Unit (2nd quarter, 2001)

The affected aquifer occurs at depths of 9–50 m below the surface. The TCE plume is about 1000 m long (Figure 8-18). TCE also occurs in underlying Tnsc₀ strata at maximum concentration 2.8 ppb.

During 2001, LLNL continued to define the extent of TCE in groundwater and the conceptual hydrogeological model. Four new monitor wells were installed along the downgradient and west sides of the groundwater TCE plume.

In 1999, LLNL installed and began operating a solar-powered portable treatment unit at Building 854 to treat extracted groundwater containing VOCs and nitrate. A second treatment unit was installed in 2000. This treatment unit uses activated carbon and a containerized wetlands, a modular, mobile unit that implements phytoremediation technology to treat VOCs, nitrate, and perchlorate.

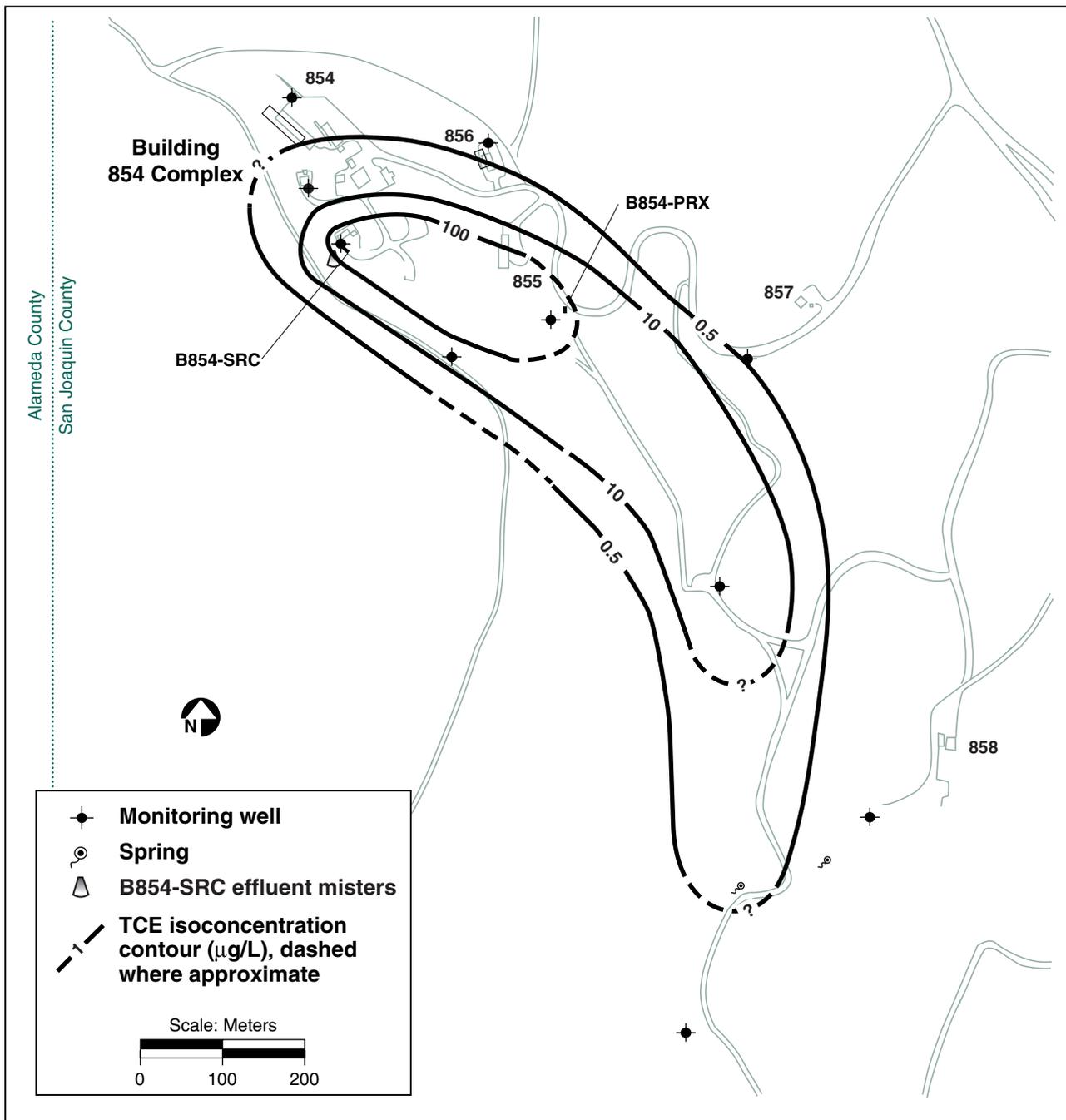


Figure 8-18. Distribution of TCE in groundwater in the Tnbs₁ aquifer in the Building 854 area (4th quarter, 2001)



Pit 6 Operable Unit

A low concentration groundwater TCE plume occurs in a perched water-bearing zone in terrace alluvium (Qt) and in the upper part of underlying Tnbs₁ sandstone (**Figure 8-19**). This perched water-bearing zone occurs at depths of 0–25 m below the surface. The source of the TCE plume,

which is about 200 m long, is likely the southeast portion of the capped Pit 6 landfill. Concentrations of TCE in the plume have declined fivefold since 1992. The 2001 maximum groundwater TCE concentration was 5.4 µg/L, which is similar to the previous two years. Tritium (**Figure 8-19**) at a maximum activity of 77 Bq/L (2080 pCi/L) and

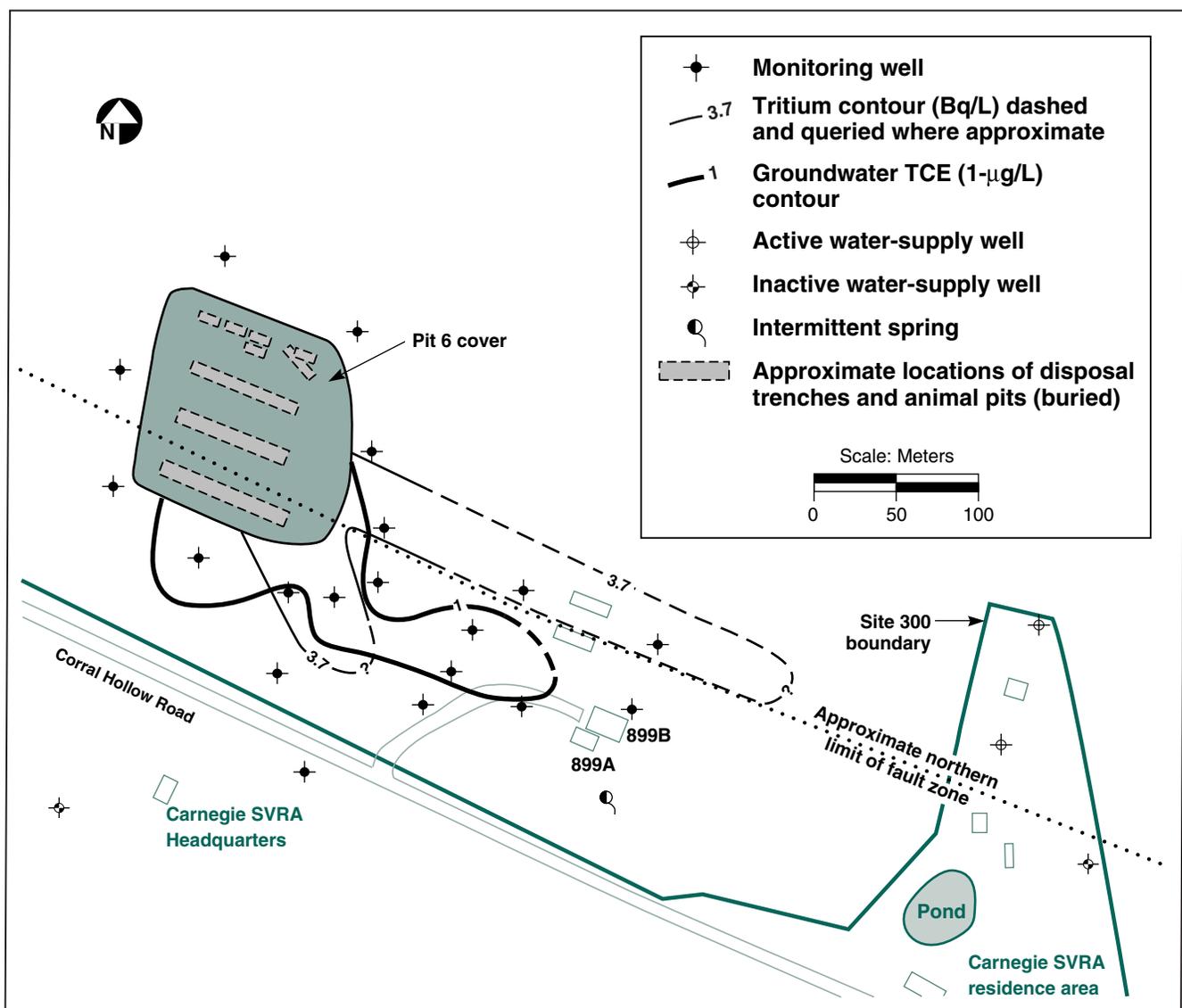


Figure 8-19. Distribution of TCE and tritium in groundwater in the Pit 6 area (4th quarter, 2001)



perchlorate at a maximum concentration of 19 $\mu\text{g}/\text{L}$ also occur in the perched water-bearing zone. The lengths of the tritium and perchlorate plumes are 275 and 200 m, respectively. While low in activity, this tritium plume appears to be influenced by heavy pumping from off-site Carnegie State Vehicular Recreation Area water-supply wells, and is being closely monitored. During 1997, a 2.4-acre engineered cap was constructed over the landfill as a CERCLA nontime-critical removal action.

Building 832 Canyon Operable Unit

At the Building 832 Canyon area (Buildings 830 and 832), solvents were released from weapons component test cells. TCE, perchlorate, and nitrate occur in groundwater primarily in Qal alluvium, and in Neroly Formation sandstone units within Tnsc₁ silty-claystone strata at a depth of 15–25 m. Groundwater TCE occurred at a maximum 2001 concentration of 9400 $\mu\text{g}/\text{L}$. The TCE plume emanates from both the Building 830 and 832 areas and is about 1400 m long (**Figure 8-20**). Perchlorate has also been detected at a maximum 2001 concentration of 26 $\mu\text{g}/\text{L}$. Nitrate concentrations in groundwater in 2001 reached a maximum of 194 mg/L (ppm). Well drilling conducted over the last three years indicates that the TCE contaminant plume emanating from the Building 832 complex is merging with the TCE in groundwater from the Building 830 area. A groundwater and soil vapor extraction and treatment system has been operating to remove contaminant mass at the Building 832 source area. Groundwater is also extracted and treated to remove VOCs, nitrate and perchlorate, at two remediation systems located downgradient of the Building 830 source area.

Site 300 Operable Unit

The Site 300 OU consists of several small release sites where active remediation is not required, as well as several sites where characterization has yet

to be completed. Sites in the OU include Building 801D dry well and Pit 8 Landfill, Building 833, Building 845 Firing Table and Pit 9 Landfill, Building 851 Firing Table, Building 812 Firing Table, Building 865 (Advanced Testing Accelerator), and Sandia Test Site.

VOCs have been detected in groundwater in the vicinity of the Building 801D dry well; however, concentrations are below drinking water standards (< 5 $\mu\text{g}/\text{L}$). Debris from the Building 801 firing table was buried in the Pit 8 Landfill. No contaminants have been detected in groundwater in the vicinity of the landfill. Groundwater monitoring will continue in this area to monitor the VOC concentrations and to detect any future releases from the landfill.

Contaminant releases, such as spills and leaching from a disposal lagoon adjacent to Building 833, resulted in VOC contamination of the ephemeral perched water-bearing zone. VOC concentrations have decreased over time and the monitoring of groundwater will continue in this area.

Leaching of contaminants from the Building 845 firing table resulted in the contamination of subsurface soil with uranium, tritium, and HMX. Firing table debris from Building 845 was disposed in the Pit 9 Landfill in the late 1950s and early 1960s. No contamination has been detected in groundwater in the vicinity of the landfill or firing table. Groundwater monitoring will continue in this area to detect any future releases of contaminants from soils under the firing table or the landfill.

Explosive experiments at the Building 851 firing table resulted in the release of low concentrations of metals, RDX, tritium, and uranium to soil. Although isotopic ratios indicative of depleted uranium have been found in groundwater samples from three wells, groundwater has not otherwise

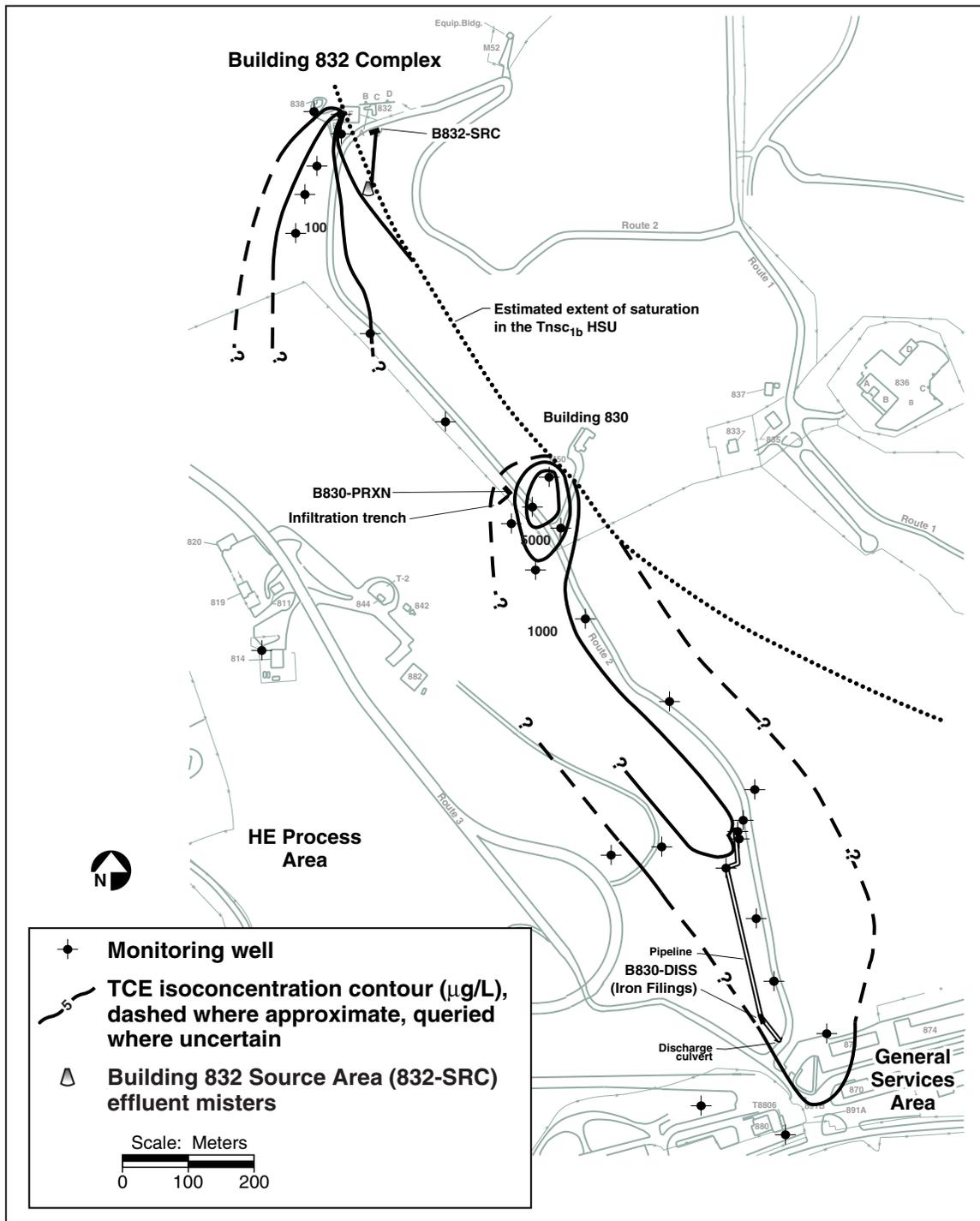


Figure 8-20. Distribution of TCE in groundwater in the Building 832 Canyon (4th quarter, 2001)



been impacted. The maximum 2001 total uranium groundwater activity was 0.015 Bq/L (0.4 pCi/L). Monitoring will continue to evaluate any future impacts to groundwater from soil contaminants.

LLNL continues to evaluate the nature and extent of Freon 113 at Building 865 (the closed Advanced Testing Accelerator). Freon 113 was used as a degreasing agent at the facility. Freon 113 was originally discovered in groundwater samples from wells in the Pit 1 monitoring network, downgradient and southeast of Building 865. Maximum Freon 113 concentrations in groundwater in this area are significantly less than the 1.2 ppm MCL for Freon 113.

There are eight monitor wells at Building 812, a firing table where depleted uranium and thorium were used in explosives experiments. The maximum total calendar year 2001 uranium activity found in groundwater sampled from these wells is 0.42 Bq/L (11.4 pCi/L). Further investigative work is planned.

From 1959 to 1960, Sandia National Laboratories/California, (Sandia/California), operated a small, temporary firing table in the East Firing Area of Site 300. Future characterization work is planned for this area.

Environmental Remediation at Site 300

Dedicated groundwater and soil vapor extraction and treatment facilities operate at the eastern GSA, central GSA, and Building 834 areas. Seven portable treatment facilities also are operating. Thus, in all, 10 treatment facilities that remove and treat VOCs operated throughout 2001. Nineteen wells that extract only groundwater, 7 wells that extract only soil vapor, and 24 wells that extract both groundwater and soil vapor, operated during 2001, treating about 94.7 million L of groundwater. The 24 wells that extract both vapor and

groundwater and the 7 wells that extract only vapor removed 922,000 m³ of vapor. In 2001, the Site 300 treatment facilities removed approximately 36.1 kg of VOCs. Since remediation efforts began in 1990, more than 772 million L of groundwater and approximately 3.13 million m³ of vapor have been treated, yielding about 198.3 kg of removed VOCs.

The central GSA, eastern GSA, and B830-Distal, South (B830-DISS) treatment facilities discharge to surface drainage courses. The B854-Proximal (B854-PRX) solar treatment unit/containerized wetland, B815-Distal (B815-DIS) aqueous phase granular activated carbon, and B830-Proximal, North (B830-PRXN) granular activated carbon treatment systems discharge to an infiltration trench. The other 4 treatment systems discharge to air by misting.

Table 8-5 summarizes calendar year 2001 and cumulative totals of volumes and masses of contaminants removed from groundwater and soil vapor at Site 300.

General Services Area

During 2001, the soil vapor extraction and treatment system in the central GSA dry-well source area was continuously operated and maintained to reduce VOC concentrations in soil vapors, remediate dense nonaqueous-phase liquids in the soil, and mitigate the VOC inhalation risk inside Building 875. The groundwater extraction and treatment systems in the central and eastern GSA areas were continuously operated and maintained to reduce VOC concentrations in the groundwater to drinking water MCLs, prevent further migration of the contaminant plume, and dewater the shallow water-bearing zone in the Building 875 dry-well area to enhance soil vapor extraction.



Table 8-5. Volatile organic compounds (VOCs) removed from groundwater and soil vapor at Site 300

Treatment area	Startup date	2001		Cumulative total	
		Water treated (ML) ^(a)	VOCs removed (kg)	Water treated (ML) ^(a)	VOCs removed (kg)
General Services Area					
Eastern GWTF ^(b)	1991	78.5	0.19	727.9	6.02 ^(c)
Central GWTF	1993	4.87	0.54	24.97	10.07
Building 834	1995	0.157	2.55	0.82 ^(c)	31.04 ^(c)
Building 815	1999	4.11	0.031	6.18	0.046
Building 832	1999	1.99	0.10	3.78	0.32
Building 854	1999	4.43	1.27	8.58	5.36
Pit 6	1998	— ^(d)	— ^(d)	0.268	0.0014
		Soil vapor treated (10 ³ m ³)	VOCs removed (kg)	Soil vapor treated (10 ³ m ³)	VOCs removed (kg)
General Services Area					
Central	1994	103.6	1.7	1693.6	41.28
Building 834	1998	740.3	29.41	1251.4 ^(c)	103.07 ^(c)
Building 832	1999	78.3	0.34	186.3	1.11

a ML = 1 million liters

b GWTF = Groundwater treatment facility

c Corrected from previous published values

d Groundwater treatment is not routine at Pit 6. A hydraulic pump test was conducted there in 1998.

Several monitoring wells are being considered for modification as extraction wells for the second phase of planned expansion to the groundwater extraction and treatment facility at central GSA. The addition of these extraction wells would enhance the system's ability to capture the contaminant plume and increase the mass removal.

Six new piezometers were installed in the shallow alluvium to better define the geometry and eastern GSA VOC plume. This information is to be used to guide the design of the second phase of the groundwater extraction and treatment facility expansion. It was determined that the plume is larger than previously thought, and it is anticipated

that continued monitoring of these piezometers will yield further information about the interaction of the various plumes in the GSA.

The eastern GSA treatment facility employs granular activated carbon canisters to remove VOCs from extracted groundwater. Extracted central GSA groundwater is run through an air-sparging PTU to remove VOCs. Extracted soil vapor at the central GSA is run through granular activated carbon canisters to remove VOCs.

Groundwater treated at the eastern GSA groundwater treatment facility was discharged off site to Corral Hollow Creek, in accordance with NPDES Permit No. CA0082651. During 2001, the

effluent line that conveys treated groundwater off site to the Corral Hollow Creek across private property was modified to protect the pipeline from damage due to cattle and to allow for re-use of the water by the private land owner for irrigation. The line now incorporates a diversion valve and buried or otherwise protected pipe. **Table 8-5** shows the volume of water treated and mass of VOCs removed at the eastern GSA. Influent TCE concentrations to the eastern GSA groundwater treatment system were reduced from 64 µg/L in January 1992 to 2.3 µg/L in December 2001. No longer do any off-site wells in the eastern GSA yield groundwater TCE concentrations in excess of the cleanup standard (MCL) of 5 µg/L. LLNL estimates that 2 more years of groundwater extraction and treatment will be required to achieve and maintain groundwater VOC concentrations below MCLs at the eastern GSA.

TCE concentrations in central GSA groundwater treatment system (GWTS) influent have been reduced from 9400 µg/L in 1993 to 50 µg/L in 2001. Volumes of water extracted and masses of VOCs removed from Central GSA groundwater are tabulated in **Table 8-5**. Treated groundwater continues to be discharged via misting towers, which disperse a fine mist over a large area in a remote canyon at Site 300.

Following dewatering of bedrock through groundwater extraction, soil vapor extraction and treatment of VOCs began in 1994. **Table 8-5** shows the amounts of soil vapor treated and VOCs removed at the central GSA. From 1994 through the end of 2001, total VOC concentrations in the central GSA soil vapor extraction influent stream were reduced from 450 parts per million by volume (ppmv) to 6.3 ppmv. VOC concentrations in individual central GSA soil vapor extraction wells have also been significantly reduced.

The central GSA groundwater treatment system is operating under substantive requirements for wastewater discharge issued by the Central Valley RWQCB. The eastern GSA groundwater treatment system operates under NPDES Permit No. CA0082651, issued by the Central Valley RWQCB for discharges into Corral Hollow Creek. The system operated under WDR91-052 until December 5, 1997, when WDR 97-242 was issued. Permit requirements for the central and eastern GSA groundwater treatment system are listed in **Table 8-6**. Both the central and eastern GSA treatment systems operated in compliance with regulatory requirements during 2001. LLNL submitted quarterly reports for the GSA treatment systems to the California EPA and the RWQCB in accordance with the National Pollutant Discharge Elimination System Order No. 97-242 for the eastern GSA and the Substantive Requirements for Waste Discharge for the Central GSA (Lamarre 2001i, d, k, l).

All four quarterly monitoring reports for the GSA were submitted to the EPA and RWQCB on schedule in 2001. These reports detail the performance of the treatment facilities (Lamarre 2001i, d, k, l).

Building 834 Complex

In 2001, the GWTS and soil vapor extraction (SVE) and treatment system were operated at full scale for the majority of the year. During the first and second quarters, various wellfield configurations were used to maximize VOC mass removal. Treatment facility performance under these various extraction well configurations is being evaluated to optimize cleanup operations. As mentioned previously, in situ bioremediation via reductive dechlorination of TCE occurs in areas within the Building 834 Core Area where sufficient amounts of silicon oils exist. However, it has been demonstrated that this intrinsic microbial degradation is inhibited during periods of active soil vapor



Table 8-6. General Services Area groundwater treatment system surface discharge permit requirements

Parameter	Treatment facility	
	Central General Services Area	Eastern General Services Area
VOCs	Halogenated and aromatic VOCs	Halogenated VOCs
Maximum daily	5.0 µg/L	5.0 µg/L
Monthly median	0.5 µg/L	0.5 µg/L
Dissolved oxygen	Discharges shall not cause the concentrations of dissolved oxygen in the surface water drainage course to fall below 5.0 mg/L.	Discharges shall not cause the concentrations of dissolved oxygen in the surface water drainage course to fall below 5.0 mg/L.
pH (pH units)	Between 6.5 and 8.5, no receiving water alteration greater than ±0.5 units	Between 6.5 and 8.5, no receiving water alteration greater than ±0.5 units
Temperature	No alteration of ambient receiving water conditions more than 3°C	No alteration of ambient receiving water conditions more than 3°C
Place of discharge	To groundwater during dry weather and to surface water drainage course in eastern GSA canyon during wet weather.	Corral Hollow Creek
Flow rate	272,500 L/day (30-day average daily dry weather maximum discharge limit)	272,500 L/day
Mineralization	Mineralization must be controlled to no more than a reasonable increment.	Mineralization must be controlled to no more than a reasonable increment.
Methods and detection limits for VOCs	EPA Method 601—detection limit of 0.5 µg/L EPA Method 602—method detection limit of 0.3 µg/L	EPA Method 601—detection limit of 0.5 µg/L

extraction because the soil vapor extraction system draws oxygen-rich vapors into the subsurface causing the microbes to become dormant.

Because of increased operation in 2001, overall mass removal was up 69% from the previous year. During 2000, the combined groundwater and soil vapor VOC mass removal at Building 834 was 22.0 kg. During 2001, the combined VOC mass removal at Building 834 was 31.96 kg. Additional VOC mass was destroyed through in situ bioremediation; this mass removal has not been quantified.

Table 8-5 shows the amounts of water and soil vapor treated and VOCs removed at Building 834. Quarterly reports for the Building 834 treatment facility were submitted to the California EPA and the RWQCB in accordance with the Substantive Requirements for Waste Discharge (Lamarre 2001e, f, g, h). Because treated groundwater is discharged to misters and is not discharged to the ground, there are no treatment system surface discharge permit requirements for Building 834.

High Explosives Process Area

The remedial strategy for groundwater cleanup in the HE Process Area was presented in the *Draft HE Process Area Remedial Design (RD)* report (Madrid et al. 2002). This report was prepared during 2001, and submitted to the regulatory agencies in February 2002.

The HE Process Area OU is divided into three treatment areas: (1) Source Area (SRC); (2) Proximal Area (PRX); and (3) Distal Site Boundary Area (DSB). The Source Area refers to the area around Buildings 806/807, 810, 815, and 817, where the majority of confirmed contaminant releases occurred. The Proximal Area is located immediately downgradient (south) of the Building 815 Source Area in the vicinity of Buildings 818 and 823.

Contaminants, mainly TCE and the HE compound cyclo-1,3,5-trimethylene-2,4,6-trinitramine (RDX), and perchlorate reside in groundwater beneath the Source and Proximal Areas. TCE and RDX have also been detected in soil and bedrock samples collected from the vadose zone beneath the Source Area. The bulk of TCE mass in the Tnbs₂ aquifer resides beneath the Proximal Area. The Distal Site Boundary Area is located in the southern part of the HE Process Area, where the Site 300 boundary is located. This area contains TCE at low concentrations, generally below 30 µg/L. However, RDX and perchlorate are not present in the Site Boundary Area at concentrations above EPA method detection limits for those chemicals.

The remediation strategy for the HE Process Area OU is a phased, risk-based approach consistent with the Remedial Design Work Plan (RDWP) for Site 300 (Ferry et al. 2001c). In accordance with the RDWP, groundwater cleanup in the HE Process Area will be implemented in the following four phases: (1) prevent off-site migration of

groundwater contaminants; (2) minimize influence of site boundary pumping on RDX plume; (3) maximize contaminant mass removal; and (4) clean up fine-grained source areas. Phase 1 began in 1999 with the installation of a treatment facility (B815-DSB) in the Distal Site Boundary area. The purpose of this facility is to prevent off-site migration of TCE. Phase 2 began with the installation of a second treatment facility (B815-SRC) in 2000 at the Building 815 Source Area. The purpose of this facility is to begin cleanup of the TCE and RDX plumes and to minimize influence of Site Boundary pumping on upgradient plume migration. Phase 3 will begin with the installation of a third facility (B815-PRX) scheduled for installation in 2002. The primary objective of this facility is TCE mass removal. Two additional facilities, B817-SRC and B817-PRX, are planned for 2004 and 2005, respectively, as part of this phase of the cleanup effort. Phase 4, which involves cleanup of fine-grained source areas, will begin using conventional pump-and-treat techniques. If these conventional methods prove impracticable, innovative techniques, such as enhanced bioremediation, will be considered.

The proposed extraction well field for cleanup of the Tnbs₂ aquifer consists of ten extraction wells. This well field was designed using a calibrated, finite element flow and transport model, FEFLOW (Diersch 1998). The calibrated model will be used to manage and optimize the extraction well field by simulating different pumping strategies. Additional extraction wells will be added, if necessary, to achieve cleanup goals to be specified in the Final Site 300 Record of Decision (ROD).

During the past several years, different groundwater treatment technologies, including aqueous-phase granular activated carbon and bioremediation using a bioreactor were tested to evaluate their efficiency for treating RDX, perchlorate, and nitrate. Aqueous-phase granular activated carbon



was found to be cost-effective for removing RDX from groundwater, and ex situ treatment using an anaerobic bioreactor was found to be cost-effective for nitrate destruction. However, granular activated carbon was not a cost effective removal technology for perchlorate, so ion exchange will be used as a “polishing” step to remove any perchlorate remaining after granular activated carbon treatment. Discharge of treated effluent is accomplished using one of two methods: 1) a misting system to discharge to the atmosphere, or 2) an infiltration trench to discharge to the subsurface.

To date, over six million liters of groundwater have been extracted and treated by the two existing facilities (B815-DSB and B815-SRC) in the HE Process Area. As presented in [Table 8-5](#), four million liters of groundwater were extracted and treated during 2001. In addition to the removal of 0.031 kg of VOCs, 0.127 kg of RDX and 0.023 kg of perchlorate have also been removed from extracted groundwater.

Building 854 Area

Treatability studies are being conducted at the Building 854 Complex to evaluate the effectiveness of groundwater remediation techniques to achieve source control, to remediate contaminant plumes, and to assess the effect of source control on down-gradient groundwater contaminant concentrations. Treatability tests are currently being conducted at facilities in two areas: (1) adjacent to the release site of TCE at Building 854F (B854-SRC), and (2) downgradient and in the middle of the groundwater TCE plume (B854-PRX).

The Building 854 groundwater extraction and treatment system (B854-SRC), located adjacent to Building 854F, began operation on December 13, 1999. Groundwater is extracted at a rate of approximately 11 L/min from one well (W-854-02) and treated using an ion exchange unit to remove

perchlorate, followed by a solar-powered aqueous-phase granular activated carbon treatment unit (STU) to remove VOCs. Treated water is discharged from misting nozzles that atomize the treated water. The discharge point for this system is located on the hillside west of the treatment facility. The B854-SRC discharge is regulated in accordance with the Draft RWQCB Substantive Requirements for the Building 832 Canyon and Building 854 OUs.

Analytical results from treatment system influent/effluent samples, monthly volumes of water treated and discharged, and total mass of contaminants removed for the two Building 854 OU treatment facilities and treatability tests are presented in quarterly Compliance Monitoring Reports for the Building 832 Canyon and the Building 854 OUs at LLNL Site 300 (Lamarre, 2001a, b, c, d).

During 2001, more than 4.4 million L of groundwater were treated and discharged. A mass of 1.2 kg of VOCs, primarily TCE, was removed by the groundwater treatment facility operations.

The Building 854 groundwater extraction and treatment system located southeast of Building 854F (B854-PRX) began operation on November 13, 2000. Groundwater is extracted at a rate of approximately 4 L/min from one well (W-854-03). The groundwater is treated using a solar-powered aqueous-phase granular activated carbon STU to remove VOCs, and a biotreatment unit (BTU) to remove nitrate and potentially perchlorate. An ion exchange unit follows the BTU to ensure perchlorate is removed prior to discharge. The treated water is discharged to the ground via an infiltration trench located immediately south of the treatment facility. The B854-PRX discharge is regulated in accordance with the Draft RWQCB Substantive Requirements for the Building 832

Canyon and Building 854 OUs. B854-PRX typically operates only a few hours per day based on solar power availability.

During 2001, more than 708,000 L of groundwater were treated and discharged. A mass of 70 g of VOCs, primarily TCE, was removed by the groundwater treatment facility operations.

Finalization of 854 field work was the only 2001 FFA milestone for Building 854. It was completed on time by May 31, 2001.

Building 832 Canyon

The Building 832 Canyon OU Treatability Study Workplan (Ziagos and Ko 1997) sets forth plans for groundwater and soil vapor TCE extraction and treatment, using portable treatment units, solar-powered water activated-carbon treatment units, and soil vapor extraction systems. Additionally, an aboveground iron filings treatment system is being employed in the lower canyon area to treat extracted TCE-laden groundwater, destroy the TCE and degradation products, and help control the migration of the TCE plume off site.

In 1999, the Building 832 Canyon groundwater and soil vapor treatment system, B832-SRC, began continuous operation. In June 2000, the Building 830 portable groundwater treatment system (B830-PRXN) began operation. This system uses granular activated carbon treatment. An iron filings treatment unit (B830-DISS), located near the mouth of the Building 832 Canyon, was completed and began operation in July 2000. This system also included a containerized wetland unit for the treatment and removal of nitrate. In March 2001, B830-DISS was converted to treat influent water with granular activated carbon and a bioreactor. The waste discharge requirements for these facilities were finalized during 2000. **Table 8-5** shows the volume of water treated and the mass of VOCs removed in

the treatment systems. The B830-DISS treatment facility discharges to surface drainage courses; the B830-PRXN systems discharges to an infiltration trench; the B830-SRC system discharges to air by misting. Progress of the pump-and-treat systems and groundwater monitoring results are published quarterly (Lamarre 2001 a, b, c, d).

Building 850/Pits 3 and 5 Operable Unit

To determine the appropriate remediation strategy for the Pits 3 and 5 landfills, LLNL is currently conducting an evaluation of tritium, depleted uranium, and metal sources within the landfills and is continuing to build and calibrate a three-dimensional geological structural model and a finite element model of groundwater flow and contaminant transport. Additionally, LLNL is evaluating several remediation strategies to keep water from entering the landfills. These techniques include subsurface groundwater interceptor trenches, landfill freezing, and other forms of permeability reduction, and geochemical techniques to immobilize uranium in groundwater. LLNL is also conducting a water budget and field studies to elucidate how water recharges the perched water-bearing zone and enters the landfills.



*Eric Christofferson
Richard A. Brown
Michael Revelli*

GROUNDWATER MONITORING

Introduction

Lawrence Livermore National Laboratory regularly samples and analyzes groundwaters in the Livermore Valley and in the Altamont Hills. LLNL maintains compliance and surveillance groundwater monitoring programs to comply fully with environmental regulations, applicable U.S. Department of Energy (DOE) orders, and the requirements of the Groundwater Protection Management Program (GWMP). The objectives of the groundwater monitoring programs described in this chapter are to measure compliance with waste discharge requirements and postclosure plans (compliance monitoring) and to assess the impact, if any, of LLNL operations on groundwater resources (surveillance monitoring).

DOE Order 5400.1 requires all DOE facilities to prepare a GWMP that describes the site's groundwater regime, areas of known contamination, remediation activities, programs to monitor groundwater, and the means to monitor and control potential sources of groundwater contamination. Considerable remediation monitoring of groundwater, discussed in [Chapter 8](#), is carried out under Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) restoration efforts. Surveillance monitoring of soil and sediment under the GWMP is described in [Chapter 10](#). Additional programs address potential contaminant sources such as the sanitary sewer system, building drains, and underground storage tanks.

Surveillance Monitoring

Groundwater monitoring at LLNL complies with DOE Order 5400.1, which affirms DOE's commitment to protect the environment. LLNL conducts surveillance monitoring of groundwater in the Livermore Valley and in the Altamont Hills through networks of wells and springs that include





private wells off site and DOE CERCLA wells on site. The two monitored areas are not connected hydrologically; they are separated by a major drainage divide and numerous faults.

The Livermore site in the Livermore Valley drains to San Francisco Bay via Alameda Creek. Most of Site 300 drains to the San Joaquin River Basin via Corral Hollow Creek, with a small undeveloped portion in the north draining to the north and east toward Tracy. To maintain a comprehensive, cost-effective monitoring program, LLNL determines the number and locations of surveillance wells, the analytes to be monitored, the frequency of sampling, and the analytical methods to be used.

A wide range of analytes is monitored to assess the impact, if any, of current LLNL operations on local groundwater resources. Because surveillance monitoring is geared to detecting substances at very low concentrations in groundwater, it can detect contamination before it significantly impacts groundwater resources. Wells at the Livermore site, in the Livermore Valley, and at Site 300 in the Altamont Hills are included in LLNL's surveillance monitoring plan. Historically, the surveillance and compliance monitoring programs have detected relatively elevated concentrations of various metals, nitrate, perchlorate, and depleted uranium (uranium-238) in groundwater at Site 300. Subsequent CERCLA studies have linked several of these contaminants, including uranium-238, to past operations, while other contaminants are the objects of continuing study. Present-day administrative, engineering, and maintenance controls at both LLNL sites are specifically tailored to prevent accidental releases of chemicals to the environment.

The Compliance Groundwater Monitoring Program at Site 300 complies with numerous federal and state controls. Compliance monitoring of groundwater is required at Site 300 in order to satisfy state-issued permits associated with closed

landfills containing solid wastes and with continuing discharges of liquid waste to surface impoundments, sewage ponds, and percolation pits. Compliance monitoring is specified in Waste Discharge Requirement (WDR) orders issued by the Central Valley Regional Water Quality Control Board (CVRWQCB) and in landfill closure and post-closure monitoring plans. (See [Table 2-5](#), for a summary of LLNL permits)

The WDRs and post-closure plans specify wells and effluents to be monitored, constituents of concern (COCs) and parameters to be measured, frequency of measurement, inspections to be conducted, and the frequency and form of required reports. These monitoring programs include quarterly and semi-annual monitoring of groundwater, monitoring of various influent waste streams, and visual inspections. LLNL performs the maintenance necessary to ensure the physical integrity of the closed facilities and their monitoring networks. LLNL conducts additional operational monitoring of wastewater effluents discharged to surface impoundments and sewage evaporation and percolation ponds to comply with WDRs issued under California's Porter-Cologne Water Quality Control Act. Quarterly and annual written reports of analytical results, inspection findings, and maintenance activities are required for each compliance monitoring network.

[Tables 9-1a](#) and [9-1b](#) in the Data Supplement list the analytical methods and reporting limits that are used to detect organic and inorganic constituents in groundwater (including specific radioisotopes analyzed by alpha spectroscopy and other sensitive methods). [Table 9-1c](#) in the Data Supplement shows the approximate analytical reporting limits for various radioactive gamma-ray emitters using the less-sensitive EPA Method 901.1.



Surveillance Monitoring of Livermore Site and Environs

Livermore Valley

LLNL has monitored tritium in water hydrologically downgradient of the Livermore site since 1988. Tritiated water (HTO) is potentially the most mobile groundwater contaminant emanating from LLNL. Rain and storm water runoff in the Livermore Valley, which recharges local aquifers, contains small amounts of tritium from natural sources, past worldwide atmospheric nuclear weapons tests, and atmospheric emissions from LLNL. (See [Chapters 4, 5, and 7](#) for further discussion of air emissions, rain, and storm water runoff.)

Groundwater is recharged at the Livermore site, primarily from arroyos by rainfall (see also [Chapter 7](#)). Groundwater flow at the Livermore site, which is generally westward, is discussed generally in [Chapter 1](#) and in detail in the *CERCLA Remedial Investigation Report for the LLNL Livermore Site* (Thorpe et al. 1990) and the annual *LLNL Ground Water Project* report (Dibley et al. 2002).

Groundwater samples were obtained during 2001 from 21 of 23 water wells in the Livermore Valley (see [Figure 9-1](#)) and measured for tritium activity. Two wells were either dry or could not be sampled during 2001.

Livermore Site Perimeter

LLNL designed a surveillance monitoring program to complement the Livermore Groundwater Project (discussed in [Chapter 8](#)). The intent of this network is to monitor for potential groundwater contamination from continuing LLNL operations. The perimeter portion of this surveillance groundwater monitoring network makes use of three background (upgradient) monitoring wells (wells W-008, W-221, and W-017) near the eastern

boundary of the site and seven (downgradient) monitoring wells located near the western boundary (wells 14B1, W-121, W-151, W-1012, W-571, W-556, and W-373) (see [Figure 9-2](#)). These seven wells, located in the regions of Treatment Facilities A, B, and C (see [Figure 8-1](#)), meet the requirements of DOE Order 5400.1. The western perimeter wells are screened in the uppermost aquifers near the areas where groundwater is being remediated.

The screened interval for each surveillance monitoring well is in the uppermost saturated aquifer (or aquifers) at that well location. As discussed in [Chapter 8](#), the alluvial sediments have been divided into seven hydrostratigraphic units (HSUs) dipping gently westward, which are shown in [Figure 8-1](#). Screened intervals for these monitoring wells range from the shallow HSU 1B, in which some of the western monitoring wells are screened, to the deeper HSU 5, in which background well W-017 and some wells around Buildings 514 and 612 are screened.

Two of the background wells, W-008 and W-221, are screened partially in HSU 3A; well W-017 is considered a background well for the deeper HSU 5. These background wells were sampled and analyzed twice in 2001 for pesticide and herbicide compounds that are used on site and off site, and for certain radioactive constituents. They were also sampled and analyzed once during 2001 for minerals, selected trace metals, and polychlorinated biphenyls (PCBs).

Except for well 14B1, the seven western downgradient wells are screened in shallower HSUs 1B and 2, the uppermost water-bearing HSUs at the western perimeter. (Because it was originally a production well, well 14B1 is screened over a depth range that includes HSUs 2, 3A, and 3B.) Like the background wells, these wells were

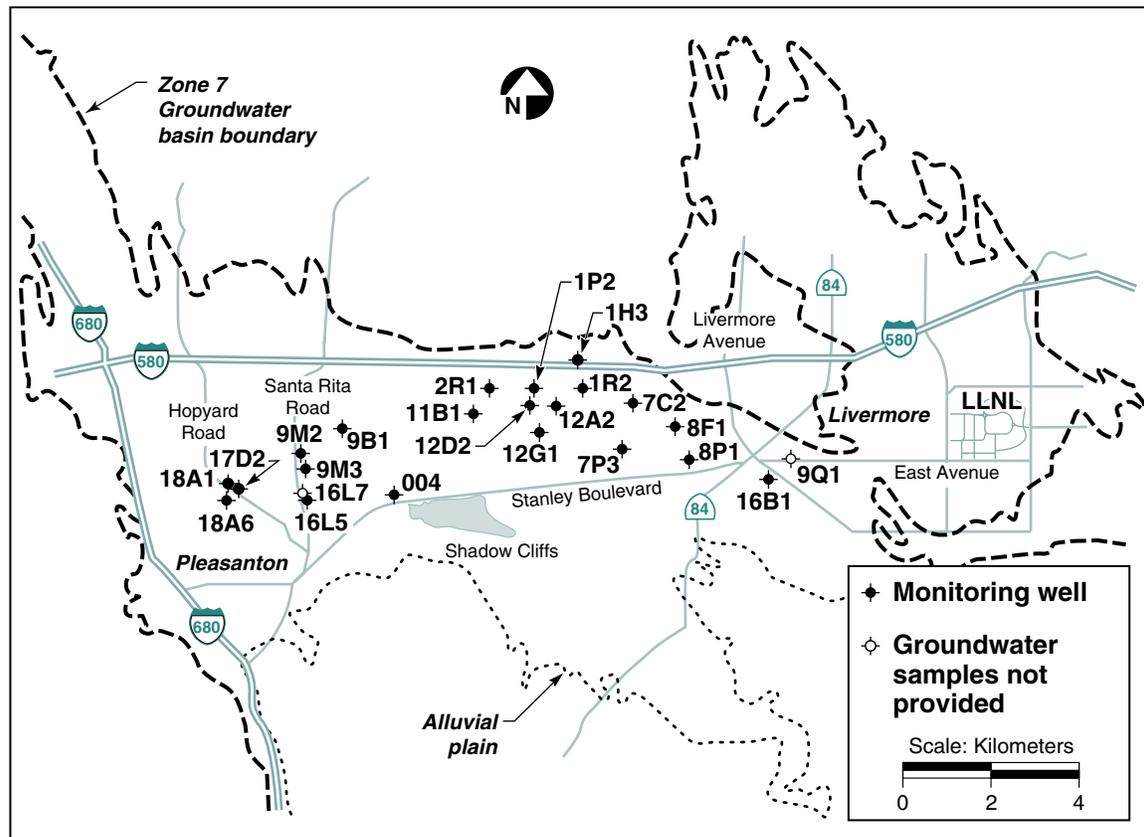


Figure 9-1. Locations of off-site tritium monitoring wells in the Livermore Valley

sampled and analyzed twice for pesticides, herbicides, and radioactive constituents, and sampled once for minerals, trace metals, and PCBs.

Tritium activities were not measured in western perimeter monitoring wells during 2001.

Livermore Site

Groundwater sampling locations within the Livermore site include areas where releases to the ground may have occurred in the recent past or where previously detected COCs have low concentrations that do not require CERCLA remedial action. Wells selected for monitoring are screened in the uppermost aquifers, and are situated down-gradient from and as near as possible to the potential release locations.

Within the Livermore Site, the Taxi Strip Area and the East Traffic Circle Landfill are two potential sources of groundwater contamination. Surveillance monitoring wells for these two sites were added to the surveillance monitoring network in 1997 (see Figure 9-2). Samples from monitoring wells screened in HSUs 2 (W-204) and 3A (W-363) downgradient from the Taxi Strip Area were analyzed in 2001 for copper, lead, zinc, americium-241, plutonium-238, plutonium-239, radium-226, radium-228, and tritium. Samples from monitoring wells screened at least partially in HSU 2 (W-119, W-906, W-1303, W-1306, and W-1308) within and downgradient from the East Traffic Circle Landfill were analyzed for the same

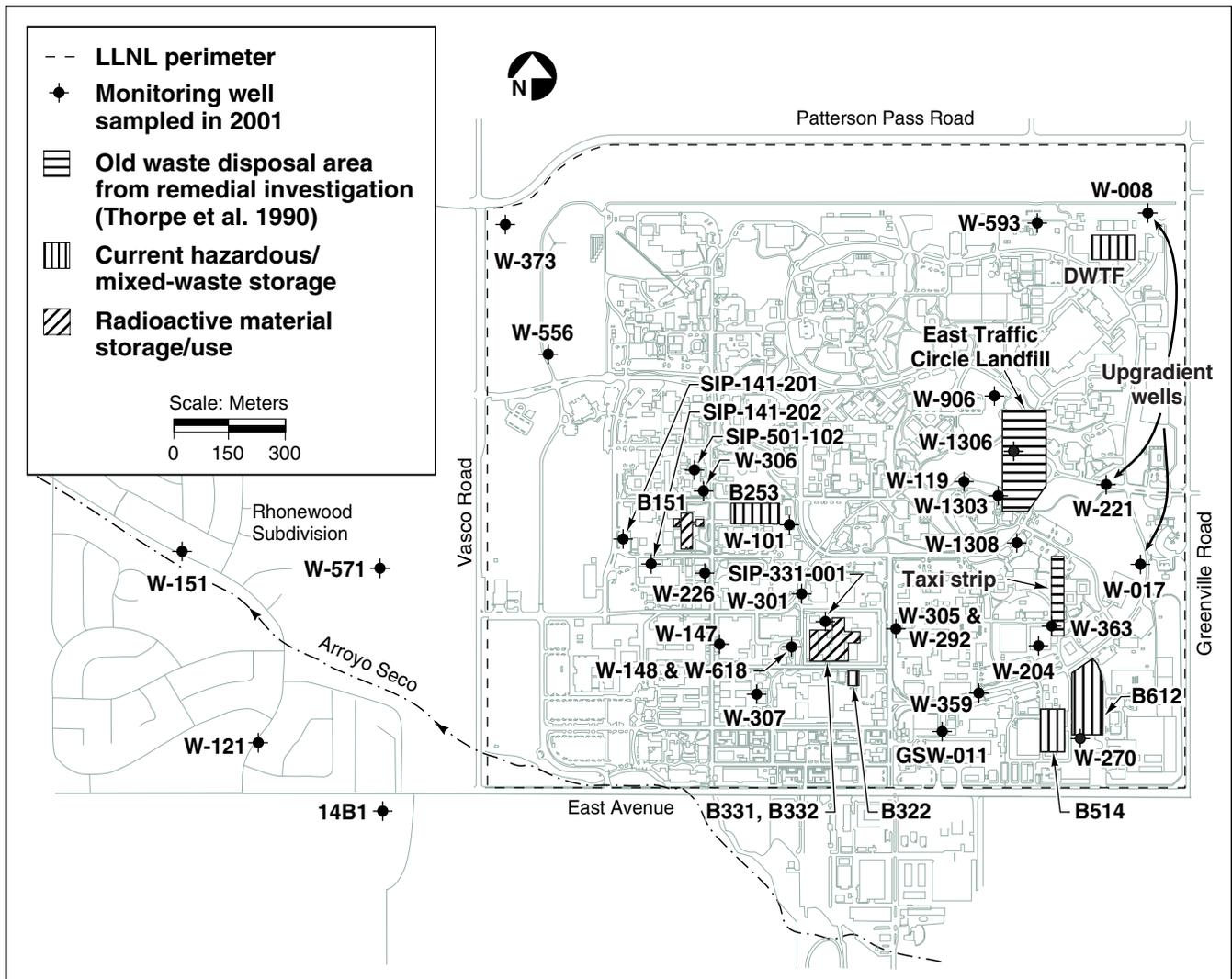


Figure 9-2. Locations of routine surveillance groundwater monitoring wells at the Livermore site

radioactive elements as in the Taxi Strip Area, minerals, selected metals, and PCBs. The locations of all of these wells are shown in [Figure 9-2](#).

Another potential source of groundwater contamination is the Decontamination and Waste Treatment Facility (DWTF) in the northeastern portion of LLNL. Samples were obtained downgradient from this facility from well W-593 during 2001 and were analyzed for minerals and selected metals.

The hazardous waste/mixed waste storage facilities around Buildings 514 and 612 are a potential source of contamination. They are monitored by wells W-270 and W-359 (screened in HSU 5) and well GSW-011 (screened in HSU 3B). These wells were sampled and analyzed for selected trace metals, general minerals, PCBs, and tritium in 2001.

Groundwater samples were obtained downgradient from areas where releases of metals to the ground have occurred. Samples were obtained from monitoring well W-307 (screened in HSU 1B),



downgradient from a fume hood vent on the roof of Building 322, a metal plating shop. Soil samples obtained from the area show elevated concentrations (in comparison with LLNL's site background levels) of chromium, copper, lead, nickel, zinc, and occasionally other metals. LLNL removed contaminated soils near Building 322 in 1999 and replaced them with clean fill. The area was then paved over, making it less likely that metals will migrate from the site.

Groundwater samples were obtained downgradient from a location where sediments containing metals (including cadmium, copper, lead, mercury, and zinc) had accumulated in a storm water catch basin near Building 253 (Jackson 1997). These samples were obtained from monitoring wells W-226 and W-306, which are screened in HSUs 1B and 2, respectively.

Additional surveillance groundwater sampling locations established in 1999 surround the area of the Plutonium Facility (Building 332) and the Tritium Facility (Building 331) (see [Figure 9-2](#)). Possible contaminants include plutonium-239 and americium-241 from the Plutonium Facility and tritium from the Tritium Facility. Both plutonium and americium are much more likely to bind to the soils than migrate into the groundwater. Tritium, as HTO, could migrate into groundwater if spilled in sufficient quantities. Upgradient of these facilities, well W-305 is screened in HSU 2, downgradient well W-148 is screened in HSU 1B, and SIP-331-001 is screened in HSU 2.

In 2001, a leaking pipe was discovered connected to a mixed-waste retention tank system of Building 151. It is unknown how long the pipe leaked, because the pipe was hidden underground. Liquid wastes in this tank have included various VOCs, trace metals, americium-241, tritium, and various gamma-emitting radioisotopes. Excavations were made around the pipe and the soils were

analyzed. (No soil contamination was discovered.) LLNL also determined groundwater sampling locations—one upgradient, SIP-501-102, and two downgradient from the building, SIP-141-201 and SIP-141-202. These Building 151 surveillance wells were sampled and analyzed in November for VOCs, trace metals, americium-241, tritium, gross alpha/beta radioactivity, and various gamma-emitting radioisotopes.

Surveillance and Compliance Monitoring of Site 300

For surveillance and compliance groundwater monitoring at Site 300, LLNL uses DOE CERCLA wells on site and private wells and springs off site. Representative groundwater samples are obtained at least once per year; they are routinely measured for various elements (primarily metals), a wide range of organic compounds, nitrate, general radioactivity (gross alpha and gross beta), uranium activity, and tritium activity.

[Figure 9-3](#) shows the locations of numerous wells, four Barcad devices, and three springs at Site 300 that are used for groundwater surveillance monitoring. Groundwater from the shallowest water-bearing zone is the target of most of the monitoring because it would be the first to show contamination from LLNL operations at Site 300. Multiple water-bearing zones are monitored at four locations (K1-02A, K2-01A, K2-02A, and K2-02B) by means of Barcad devices.

Twelve groundwater monitoring locations are off site. Two are springs, identified as MUL2 and VIE1, which are located near the northern boundary of Site 300. Off-site surveillance well VIE2 is located 6 km west of Site 300 in the upper reaches of the Livermore Valley watershed. Eight off-site surveillance locations are wells located near the southern boundary of Site 300 in or adjacent to the Corral Hollow Creek floodplain.

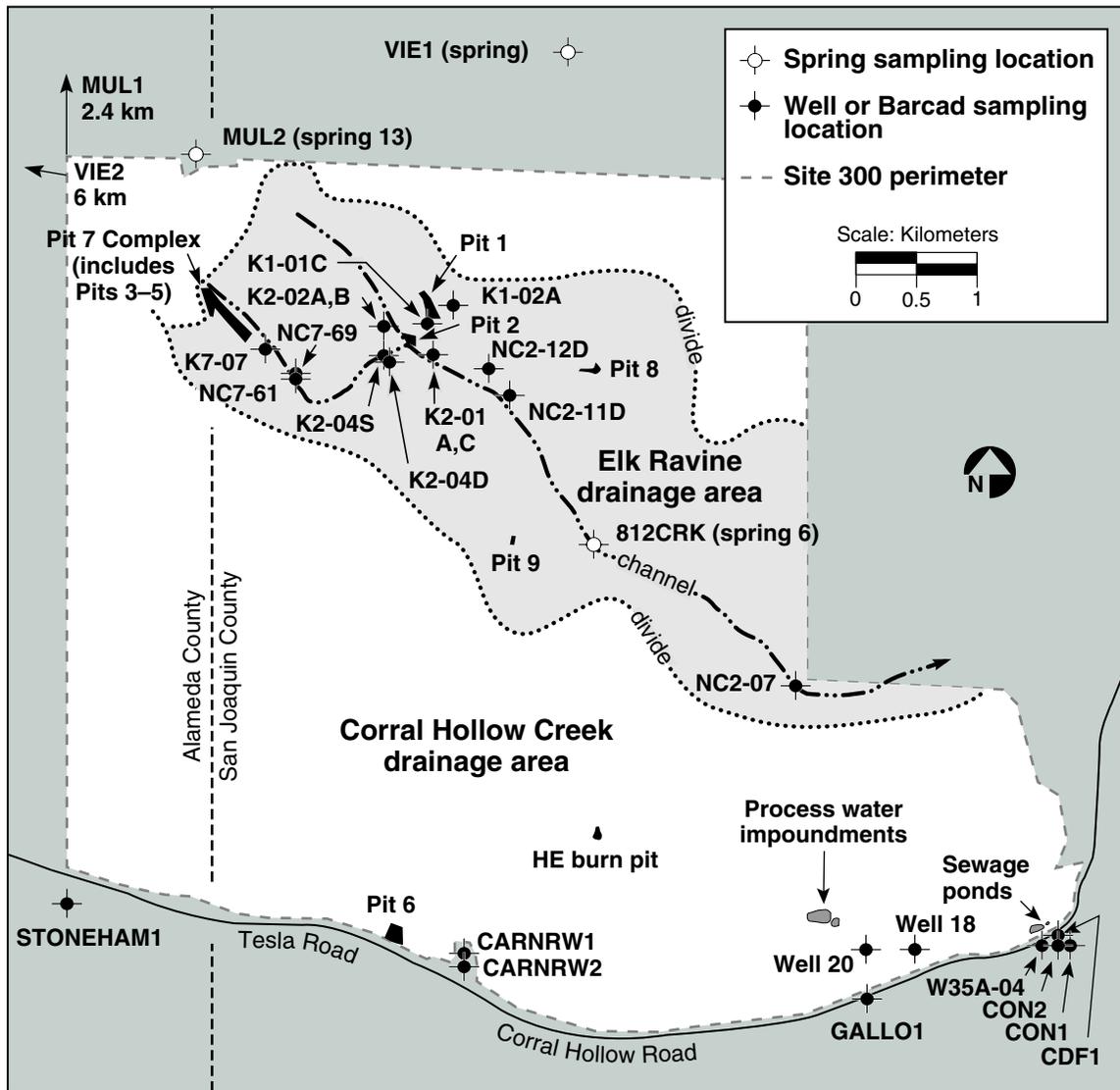


Figure 9-3. Locations of surveillance groundwater wells, Barcads, and springs at Site 300

On-site wells, installed for CERCLA site-characterization studies, continue to be used to monitor closed landfills, a former open-air high explosives (HE) burn pit, two connected surface water impoundments, and two connected sewer ponds (Figure 9-3). The closed landfills—identified as Pit 1, Pit 2, Pit 7 Complex, Pit 8, and Pit 9—are located in the northern portion of Site 300 in the Elk Ravine drainage area, while Pit 6, the former burn pit, the two surface impoundments, and the

sewage ponds are located in the southern portion of Site 300 in the Corral Hollow Creek drainage area. Two on-site water supply wells, identified as wells 18 and 20, are also used for surveillance monitoring purposes. Well 20 provides potable water to the site. Well 18 is maintained as a standby potable supply well.

Brief descriptions of the Site 300 groundwater monitoring networks are given below. Networks of



wells and Barcads within the Elk Ravine drainage area are described first, followed by the well networks in the Corral Hollow Creek drainage area. Subsets of CERCLA wells and Barcads, installed mainly for site characterization, have been selected for compliance and surveillance monitoring use based on their locations and our general understanding of local geologic and hydrogeologic conditions at Site 300 (see [Chapter 8](#) for a summary of Site 300 stratigraphy and hydrogeology).

Groundwater measurements made during 2001 for compliance purposes and published elsewhere are not contained in the Data Supplement accompanying this report. Instead, the compliance reports containing those data tables have been copied onto the compact disk with this Environmental Report, and clickable links to them are included in the “[Results](#)” section of this chapter.

Elk Ravine Drainage Area

The Elk Ravine drainage area, a branch of the Corral Hollow Creek drainage system, includes most of northern Site 300 (see [Figure 9-3](#)). Storm water runoff in the Elk Ravine drainage area collects in arroyos and quickly infiltrates into the ground. Groundwater from wells and Barcads in the Elk Ravine drainage area is monitored for COCs because of the system of surface and underground flows that connects the entire Elk Ravine drainage area. The area contains Pits 1–5 and 7–9 and firing tables where explosives tests are conducted. The following descriptions of monitoring networks within Elk Ravine begin with the headwaters area and proceed downstream. (See [Chapter 8](#) for a review of groundwater contamination in this drainage area as determined from numerous CERCLA investigations.)

Pit 7 Complex: Monitoring requirements for the Pit 7 landfill, which was closed under the Resource Conservation and Recovery Act (RCRA), are

specified in Waste Discharge Requirements Order 93-100 (WDR 93-100) administered by the CVRWQCB (1993 and 1998) and in *LLNL Site 300 RCRA Closure and Post-Closure Plans—Landfill Pits 1 and 7* (Rogers/Pacific Corporation 1990). The main objective of this monitoring is the early detection of any new release of COCs from Pit 7 to groundwater.

The Pit 7 Complex area is located at an elevation of about 400 m in the most elevated portion of the Elk Ravine drainage area. The complex consists of four adjacent landfills identified as Pits 3, 4, 5, and 7 (see [Figure 9-4](#)). From 1963 to 1988, the landfills received waste gravels and debris from hydrodynamic tests of explosive devices conducted on firing tables at Site 300. The gravels contained concrete, cable, plastic, wood, tritium, depleted uranium (uranium-238), beryllium, lead, and other metals in trace amounts. In 1988, 9440 m³ of gravel were removed from six firing tables at Site 300 and placed in Pit 7 (Lamarre and Taffet 1989). These were the last solid wastes to be placed in any landfill at Site 300.

As planned for compliance purposes, LLNL obtained groundwater samples quarterly during 2001 from the Pit 7 monitoring well network. Samples were analyzed for inorganic COCs (mostly metallic elements), general radioactivity (gross alpha and beta), activity of certain radioisotopes (tritium, radium, uranium, and thorium), explosive compounds (HMX and RDX), and volatile organic compounds (VOCs) (EPA method 601). Field measurements of groundwater depth, temperature, pH, and specific conductance were obtained at each well at the time of sample collection.

Elk Ravine: Groundwater samples were obtained twice during 2001 from the widespread Elk Ravine surveillance monitoring network. Samples were analyzed for inorganic constituents (mostly metallic elements), general radioactivity (gross alpha and

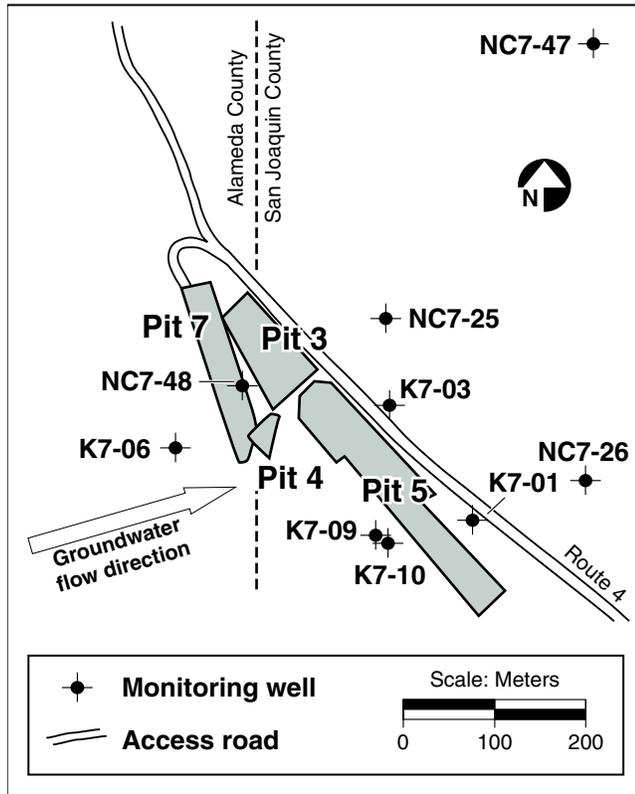


Figure 9-4. Locations of Pit 7 compliance groundwater monitoring wells

beta), tritium and uranium activity, and explosive compounds (HMX and RDX). Analyses for VOCs (EPA method 601) were done only on the set of samples obtained in November.

Pit 2: The closed Pit 2 landfill lies in the upper portion of Elk Ravine, about 320 m above sea level (Figure 9-3 and Figure 9-5). The landfill contains primarily gravels and debris from hydrodynamic tests of explosive devices conducted at the Building 801 and 802 firing tables. The buried waste material contains depleted uranium (uranium-238) and trace amounts of beryllium, thorium, and possibly tritium.

As planned for surveillance purposes, LLNL obtained groundwater samples twice during 2001 from the Pit 2 monitoring network (comprising

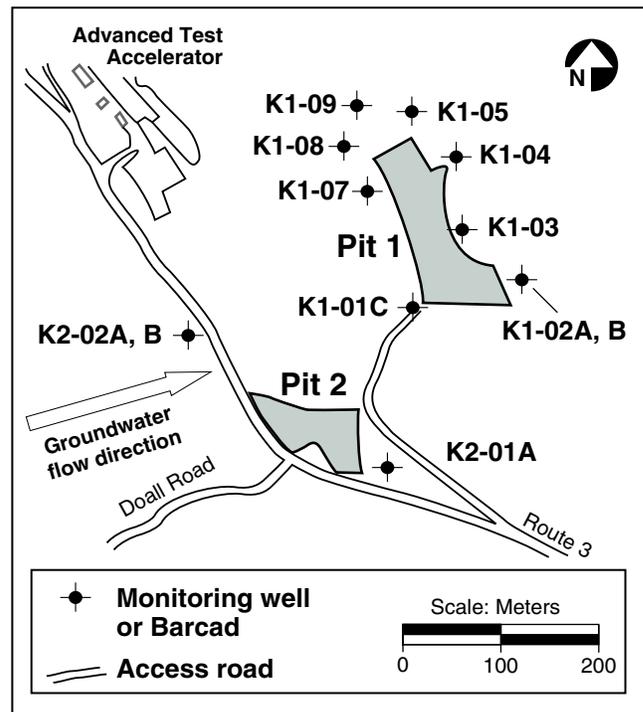


Figure 9-5. Locations of Pit 1 compliance and Pit 2 surveillance groundwater monitoring wells

four Barcads and one well) and analyzed them for inorganic COCs (mostly metallic elements), general radioactivity (gross alpha and beta), activity of certain radioisotopes (tritium and uranium), and explosive compounds (HMX and RDX). Well K1-01C serves double duty as a downgradient Pit 2 monitoring well and an upgradient Pit 1 monitoring well (Figure 9-5). Groundwater samples from this well were obtained quarterly during 2001 and were analyzed for a larger suite of COCs dictated by the compliance monitoring plans for Pits 1 and 7. Analyses for the presence of additional COCs were made on the groundwater samples obtained from well K1-01C. These analyses included pesticides (EPA method 608), PCBs (EPA method 8082), and extractable (semi-volatile) organic compounds (EPA method 625).



Pit 1: Monitoring requirements for the Pit 1 landfill, which was closed under the Resource Conservation and Recovery Act (RCRA), are specified in *Waste Discharge Requirements Order 93-100* (WDR 93-100) administered by the CVRWQCB (1993 and 1998) and in *LLNL Site 300 RCRA Closure and Post-Closure Plans—Landfill Pits 1 and 7* (Rogers/Pacific Corporation 1990). The main objective of this monitoring is the early detection of any release of COCs from Pit 1 to groundwater.

Pit 1 lies in the Elk Ravine drainage area about 330 m above sea level. The Pit 1 landfill and the positions of the eight groundwater wells used to monitor it are shown in [Figure 9-5](#). The eight wells are K1-01C, K1-02B, K1-03, K1-04, K1-05, K1-07, K1-08, and K1-09.

As planned for compliance purposes, LLNL obtained groundwater samples quarterly during 2001 from the Pit 1 monitoring well network. Samples were analyzed for inorganic COCs (mostly metallic elements), general radioactivity (gross alpha and beta), activity of certain radioisotopes (tritium, radium, uranium, and thorium), explosive compounds (HMX and RDX), and VOCs (EPA method 601). Every other quarter, analyses were conducted for an additional seven elements. Additional annual analyses were conducted on fourth-quarter samples for extractable organics (EPA method 625), pesticides and PCBs (EPA method 608), and herbicides (EPA method 615). Field measurements of groundwater depth, temperature, pH, and specific conductance were obtained at each well at the time of quarterly sample collection.

Pit 8: The closed Pit 8 landfill is located in the Elk Ravine drainage area adjacent to the Building 801 firing table. Explosives experiments were conducted there from 1958 to 1998, at which time construction of a new enclosed firing facility began. Construction continued through 2001.

Approximately 40 m³ of untreated debris from the firing table were placed in the pit until 1974 when the pit was closed. The debris buried there may contain trace amounts of tritium, depleted uranium (uranium-238), lead, and beryllium.

[Figure 9-6](#) shows the Building 801 and Pit 8 areas and the locations of the four monitoring wells. The pit is located in a narrow ravine within the Elk Ravine drainage area about 350 m above sea level. Chemical analysis of soil and rock samples obtained from this area during CERCLA remedial investigations detected no COCs above background level concentrations (Webster-Scholten 1994).

However, low concentrations of trichloroethylene (TCE) have been detected in groundwater samples from Pit 8 surveillance monitoring wells, including upgradient well K8-01, since 1987. Previous remedial investigation links the TCE to a dry well near Building 801 that was once used to dispose liquid wastes (Webster-Scholten 1994).

Because of construction activities in the vicinity of Pit 8, groundwater samples could be obtained only from surveillance monitoring wells K8-01 and K8-02B in June 2001. Groundwater samples were analyzed for inorganic COCs (mostly metallic elements), general radioactivity (gross alpha and beta), activity of certain radioisotopes (tritium and uranium), explosive compounds (HMX and RDX), pesticides (EPA method 608), PCBs (EPA method 8082A), and VOCs (EPA method 601).

Pit 9: The Pit 9 landfill is centrally located within Site 300 about 340 m above sea level. Similar to the other closed landfills in Elk Ravine, the closed Pit 9 landfill contains firing table gravels and debris from explosives experiments conducted on the Building 845 firing table nearby.

[Figure 9-7](#) shows the locations of the four surveillance wells used to monitor the groundwater in the vicinity of Pit 9. Groundwater flows

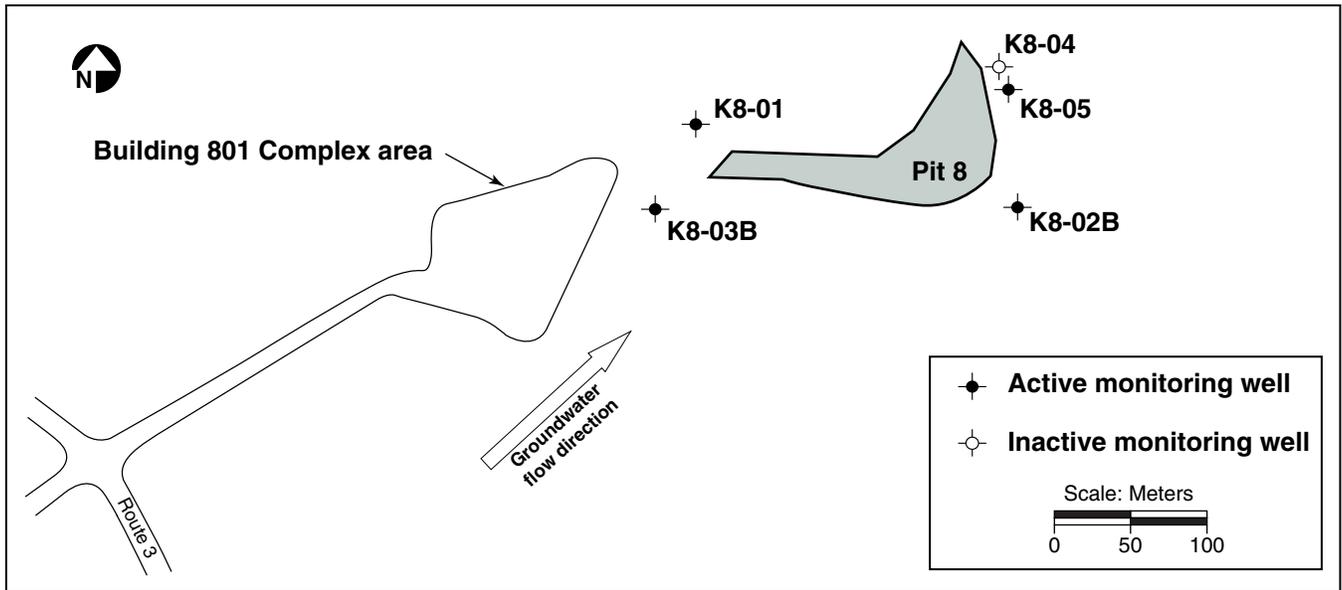


Figure 9-6. Locations of Pit 8 surveillance groundwater monitoring wells

east-northeasterly beneath Pit 9 in the Neroly lower blue sandstone unit (Tnbs₁). The water table lies about 40 m below the ground surface at Pit 9. Monitoring well K9-02 is hydrologically upgradient from Pit 9, and wells K9-01, K9-03, and K9-04 are downgradient.

As planned for surveillance purposes, LLNL obtained groundwater samples twice during 2001 from all four Pit 9 monitoring wells. Groundwater samples were analyzed for inorganic COCs (mostly metallic elements), general radioactivity (gross alpha and beta), activity of certain radioisotopes (tritium and uranium), explosive compounds (HMX and RDX), and VOCs (EPA method 601).

Corral Hollow Creek Drainage Area

This section describes the groundwater monitoring networks that are located in the southern half of Site 300 where runoff and groundwater flow south to Corral Hollow Creek. (See Chapter 8 for a review of groundwater contamination in this drainage area as determined from numerous CERCLA investigations.)

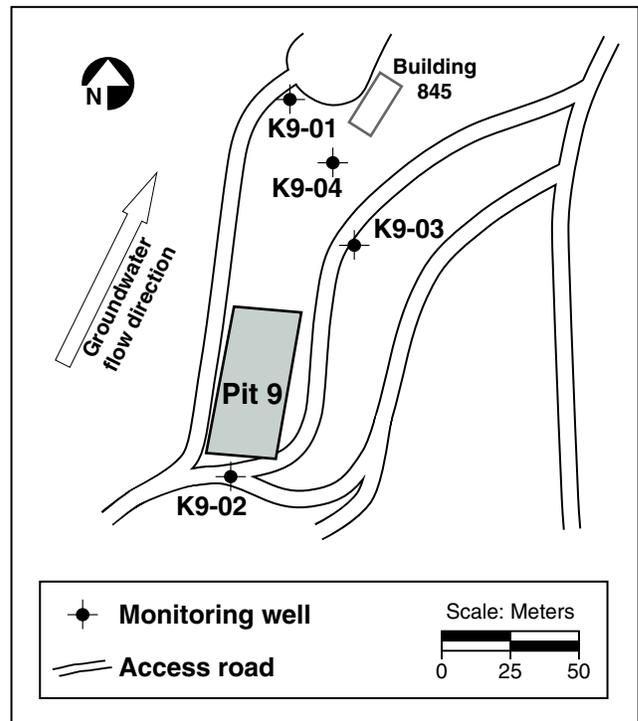


Figure 9-7. Locations of Pit 9 surveillance groundwater monitoring wells



Pit 6: Compliance monitoring requirements for the closed Pit 6 landfill in the Corral Hollow Creek drainage area are specified in the *Post-Closure Plan for the Pit 6 Landfill Operable Unit Lawrence Livermore National Laboratory Site 300* (Ferry et al. 1998). The closed Pit 6 landfill covers an area of about 1 hectare (2.5 acres), at an elevation of approximately 215 m above sea level. From 1964 to 1973, approximately 1500 m³ of solid wastes were buried there in nine separate trenches. The trenches were not lined, consistent with historical disposal practices. Three larger trenches contain 1300 m³ of solid waste that includes empty drums, glove boxes, lumber, ducting, and capacitors. Six smaller trenches contain 230 m³ of biomedical waste, including animal carcasses and animal waste. During 1997, a multilayered cap was constructed over all the trenches, and a drainage control system was installed around the cap. The cap and the drainage control system are engineered to keep rainwater from contacting the buried waste (Ferry et al. 1998).

The Pit 6 disposal trenches were constructed in Quaternary terrace deposits (Qt) north of the Corral Hollow Creek flood plain. Surface runoff from the pit area flows southward to Corral Hollow Creek. The Carnegie-Corral Hollow Fault zone extends beneath the southern third of Pit 6. The northern limit of the fault zone is shown in [Figure 9-8](#). Beneath the northern two-thirds of Pit 6, groundwater flows south-southeast, following the inclination of the underlying sedimentary rocks. Groundwater seepage velocities are less than 10 m/y. Depths to the water table range from 10 to 20 m. Beneath the southern third of Pit 6, a trough containing terrace gravel within the fault zone provides a channel for groundwater to flow southeast, parallel to the Site 300 boundary fence (Webster-Scholten 1994). (See [Chapter 8](#) for a review of the stratigraphy, hydrogeology, and groundwater contamination in the Pit 6 area.)

Two groundwater monitoring programs, which operate under CERCLA, were implemented at the Pit 6 landfill during 1998 to ensure compliance with all regulations: (1) the Detection Monitoring Program (DMP), designed to detect any new release of COCs to groundwater from wastes buried in the Pit 6 landfill, and (2) the Corrective Action Monitoring Program (CAMP), monitors the movement and fate of existing releases (see [Chapter 8](#) for a summary of CAMP monitoring results for Pit 6). [Figure 9-8](#) shows the locations of Pit 6 and the wells used to monitor groundwater there.

To comply with permit requirements, LLNL obtained groundwater samples quarterly during 2001 from the Pit 6 monitoring well network. Samples were analyzed for inorganic COCs (mostly metals), general radioactivity (gross alpha and beta), tritium activity, uranium activity, VOCs (EPA method 624), extractable organics (EPA method 625), pesticides (EPA method 608), and PCBs (EPA method 8082A). Field measurements of groundwater depth, temperature, pH, and specific conductance were obtained at each well at the time of sample collection.

HE Process Area Closed Burn Pits: Compliance monitoring requirements for the closed burn pits in the Corral Hollow Creek drainage area are specified in the *Final Closure Plan for the High-Explosives Open Burn Treatment Facility at Lawrence Livermore National Laboratory Experimental Test Site 300* (Mathews and Taffet 1997) and in the *Revisions to the Post-Closure Permit Application for the Building 829 HE Open Burn Facility – Volume 1* (LLNL 2000).

The former High-Explosives (HE) Open Burn Treatment Facility, part of the Building 829 Complex, is located on a ridge within the southeast portion of Site 300 at an elevation of about 320 m (see [Figure 9-9](#)). The facility included three

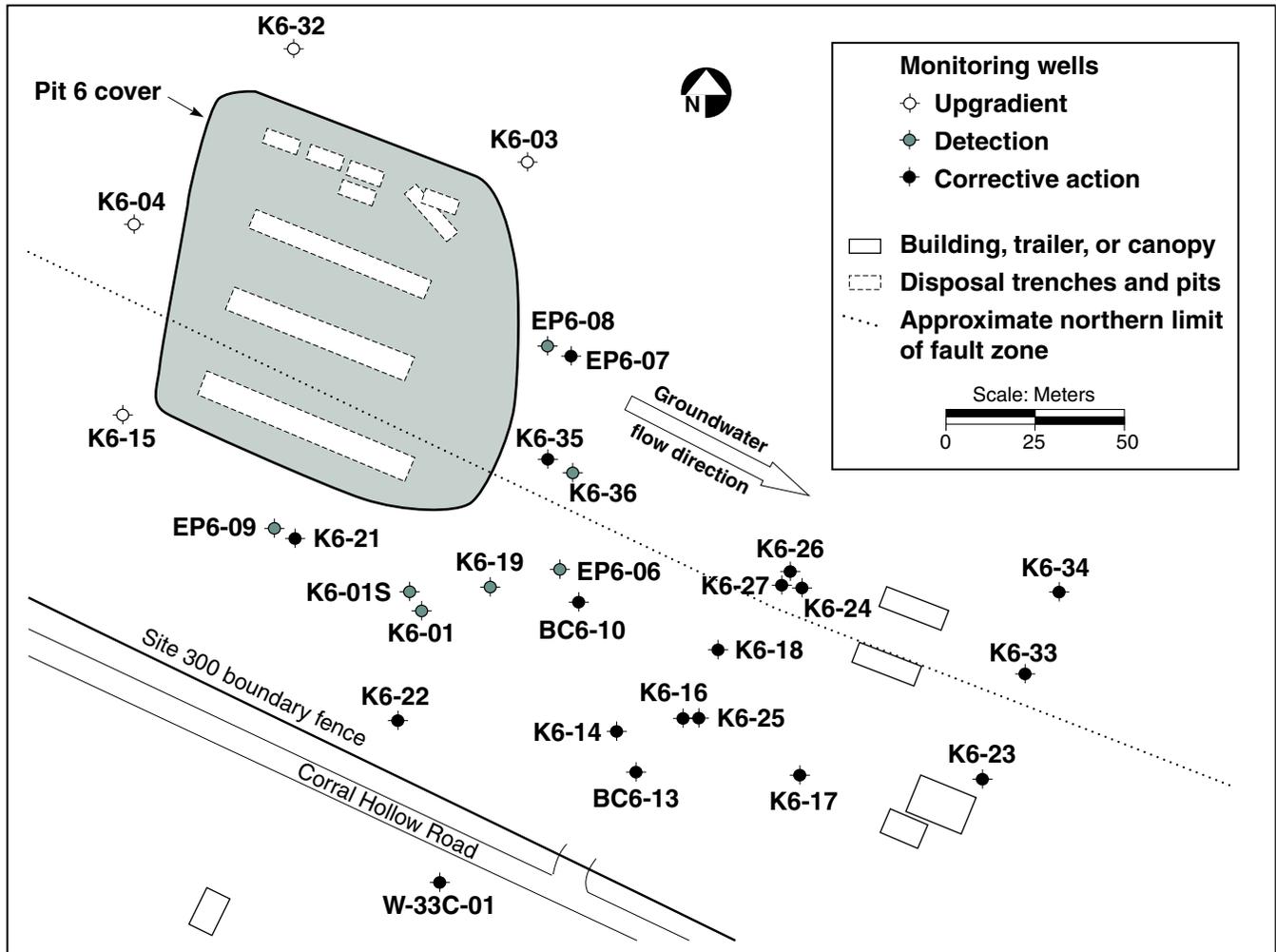


Figure 9-8. Locations of Pit 6 compliance groundwater monitoring wells

shallow unlined pits constructed in unconsolidated sediments that cap the ridge (Tps formation). The facility was used to burn explosives waste generated at Site 300. The facility was covered with an impervious cap in 1998 following RCRA guidance.

Surface water drains southward from the facility toward Corral Hollow Creek. The nearest site boundary lies about 1.6 km to the south at Corral Hollow Road. Stratified rocks of the Neroly (Tn) formation underlie the facility and dip southeasterly. Two water-bearing zones exist at different

depths beneath the facility. The shallower zone, at a depth of about 30 m, is perched within the Neroly upper siltstone/claystone aquitard (Tnsc₂). The deeper zone, at a depth of about 120 m, represents a regional aquifer within the Neroly upper sandstone member (Tnbs₂). (See Chapter 8 for a review of the stratigraphy, hydrogeology, and groundwater contamination in this area.)

Based on groundwater samples recovered from boreholes, previous CERCLA remedial investigations determined that the perched groundwater

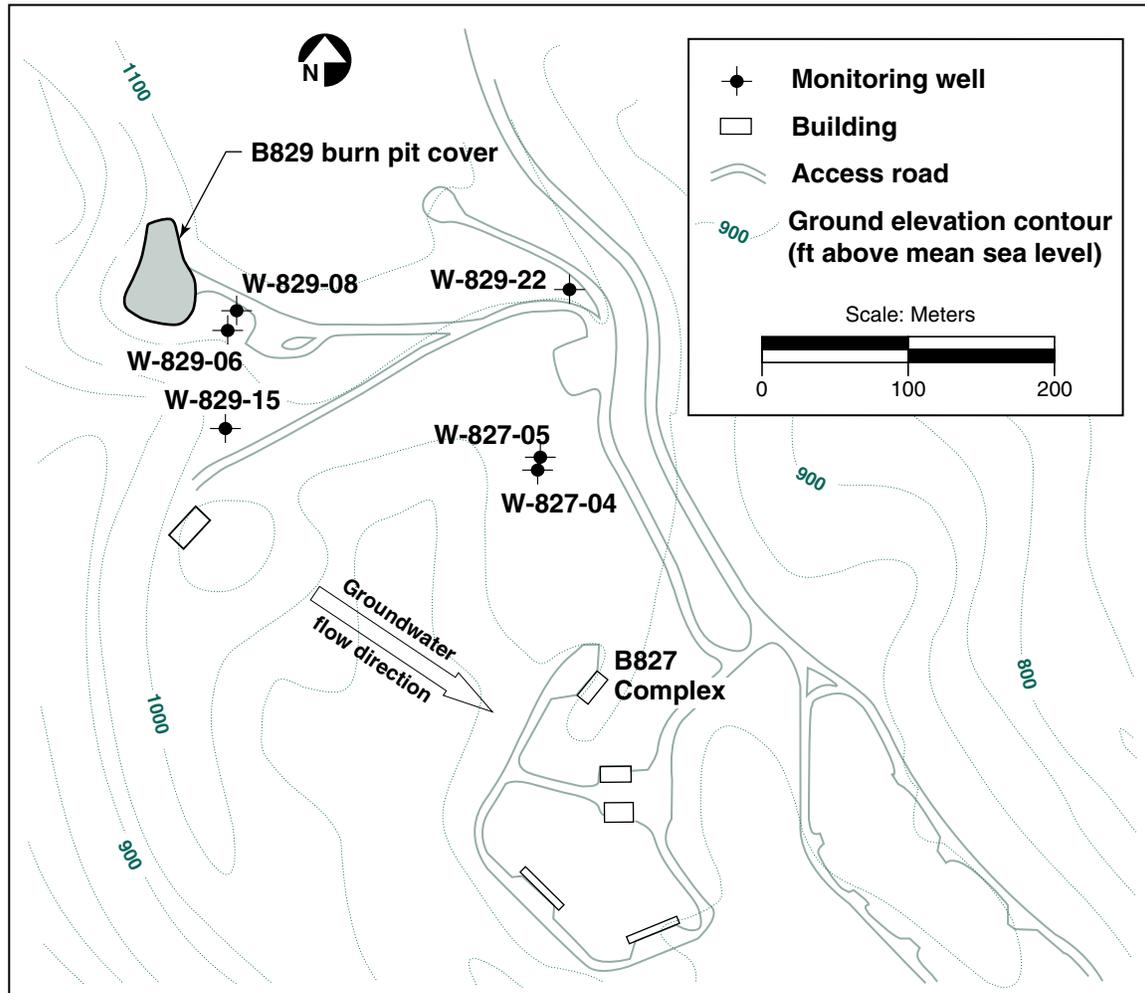


Figure 9-9. Locations of Building 829 closed burn pit compliance groundwater monitoring wells

beneath the burn facility was contaminated with VOCs, primarily TCE, but that the deeper regional aquifer was free of any contamination stemming from operation of the facility (Webster-Scholten 1994). Subsequent assays of soil samples obtained from shallow boreholes prior to closure revealed that low concentrations of HE compounds, VOCs, and metals exist beneath the burn pits (Mathews and Taffet 1997). Conservative transport modeling indicates that the shallow contamination will not adversely impact the regional aquifer primarily because its downward movement is blocked by a

100-m-thick intervening aquitard. However, beginning in 1999, LLNL implemented the intensive groundwater monitoring program for this area described in the post-closure plan (Mathews and Taffet 1997) to track the fate of contaminants in the perched water-bearing zone and to watch the deep regional aquifer for the appearance of any potential contaminants from the closed burn facility.

Figure 9-9 shows the locations of the closed burn treatment facility area and the six wells used to monitor the groundwater. Two wells, W-829-06

and W-829-08, are screened in the perched water-bearing zone beneath the former burn facility. The remaining four wells, W-827-04, W-827-05, W-829-15, and W-829-22, are screened in the deep regional aquifer downgradient of the closed facility.

As planned for compliance purposes, LLNL obtained groundwater samples quarterly during 2001 from the Building 829 monitoring well network. As in past years of this monitoring program, deep well W-827-04 remained dry throughout 2001. Groundwater samples from the three other wells screened in the deep regional aquifer were analyzed quarterly for inorganic COCs (mostly metals), general minerals, turbidity, explosive compounds (HMX, RDX, and TNT), VOCs (EPA method 624), extractable organics (EPA method 625), pesticides (EPA method 608), herbicides (EPA method 615), general radioactivity (gross alpha and beta), radium activity, total organic carbon (TOC), total organic halides (TOX), and coliform bacteria. Groundwater samples from the two wells screened in the shallow perched water-bearing zone were analyzed for explosive compounds and VOCs. However, well W-829-08 went dry after the first quarter sampling event and has remained dry since then.

Water Supply Wells: Water supply wells 18 and 20 are located in the southeastern part of Site 300 (Figure 9-3). Both are deep, high-production wells. Well 20 supplied potable water at the site during 2001, while well 18 was maintained as a standby water supply well. Both wells are screened in the $Tnbs_1$. The well 18 screen extends upward into the aquitard unit ($Tnsc_1$) that separates the upper ($Tnbs_2$) and lower blue sandstone units of the Neroly Formation. Each well can produce up to 1500 L/min of potable water.

Historically, well 18 groundwater samples have shown trace amounts of TCE. CERCLA studies have not yet determined the source of the TCE in well 18 (see Chapter 8 for the locations of TCE plumes at Site 300).

As planned for surveillance purposes, LLNL obtained groundwater samples quarterly during 2001 from these two on-site supply wells. Groundwater samples from well 20 were analyzed for inorganic COCs (mostly metals), VOCs (EPA method 502.2), explosive compounds (HMX, RDX), general radioactivity (gross alpha and gross beta), and tritium activity. Groundwater samples from standby well 18 were analyzed for VOCs, general radioactivity (gross alpha and gross beta), and tritium.

Explosives Process Area: WDR Order

No. 96-248 establishes the basis for compliance monitoring of the two adjacent surface impoundments at Site 300 (see Figure 9-10). This includes quarterly monitoring of the groundwater, monitoring of various influent waste streams to the surface impoundments, and visual observations of the leachate collection systems. Influent monitoring complements administrative control of chemicals that could degrade the polyethylene liners of the impoundments. A three-tiered monitoring program comprising weekly visual inspections of the leachate collection systems, quarterly inspections of lysimeters, and quarterly sampling of monitoring wells is in place to detect any release of chemicals from the surface impoundments.

LLNL is required to obtain groundwater samples quarterly from four monitoring wells (see Figure 9-10) and has established statistical concentration limits for COCs in groundwater beneath the surface impoundments. These requirements are part of the Monitoring and Reporting Program (MRP) for the surface impoundments detailed in WDR 96-248.

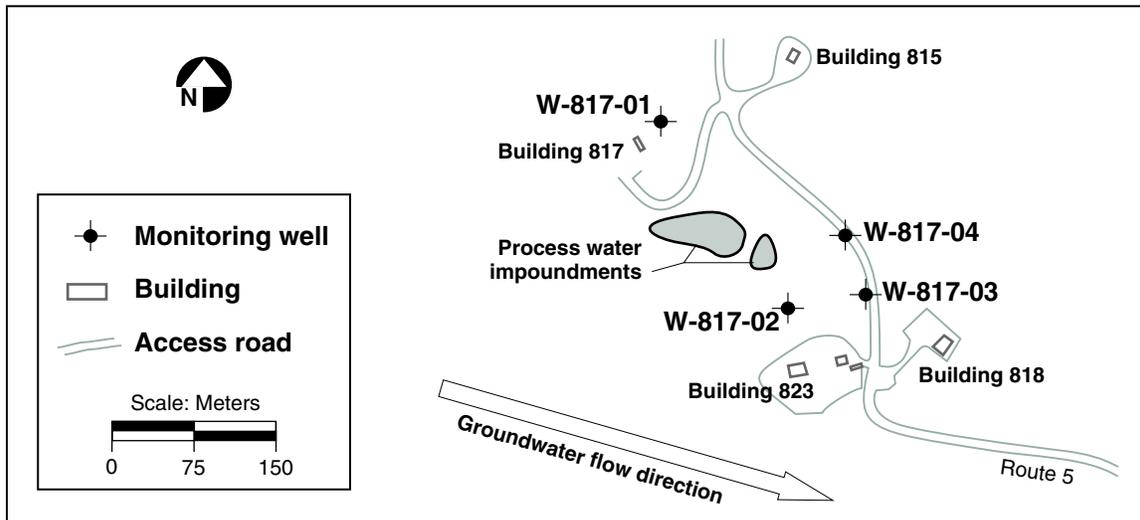


Figure 9-10. Locations of compliance groundwater monitoring wells in the Explosives Process Area

WDR 96-248 establishes limits for discharges of COCs into the surface impoundments and requires monitoring of the photographic process and chemistry area wastewater retention tanks that discharge to the surface impoundments as well as direct discharges to the surface impoundments from explosives processing. Influent streams are monitored at a prescribed frequency for area-specific COCs.

Retention tanks containing photographic process rinsewater from Buildings 801, 823, and 851 are regulated by effluent discharge limits specified in WDR 96-248. Discharges to the surface impoundments occur after samples are obtained, except for rinsewater from the Building 823 retention tanks, which is discharged automatically to the surface impoundments and sampled quarterly.

Samples of process wastewater from the Chemistry Area (Buildings 825, 826, and 827 Complex) are collected when the retention tanks are ready for discharge to the surface impoundments. The wastewater is held in retention tanks until analytical results indicate compliance with WDR 96-248.

Process water discharges to the surface impoundments are analyzed for COCs that have been found (or are likely to be found) in the process water from each specified building within the Explosives Process Area. This monitoring program includes process wastewater from Buildings 806/807, 809, and 817. WDR 96-248 requires annual analysis of this waste stream.

Percolation Pits: Percolation pits that are designed to accept discharges from mechanical equipment are located at Site 300 Buildings 806A, 827A, 827C, 827D, and 827E. In other remote Site 300 facilities, these types of waste streams are discharged to septic systems. These discharges are permitted by WDR 96-248, which specifies monthly observations and monitoring requirements for overflows. Overflows of the percolation pits, should they occur, are sampled and analyzed to determine the concentrations of any metals present.

Sewage Evaporation and Percolation Ponds:

Site 300 is not serviced by a publicly owned treatment works (POTW) as is the Livermore site; therefore, alternative methods of treating and disposing of sanitary waste are necessary. Sewage generated at buildings in the General Services Area is discharged into a lined evaporation pond. The wastewater is disposed of through evaporation from the pond. However, during rare periods of high rainfall, treated wastewater may overflow into an unlined percolation pond, where it enters the ground and the shallow groundwater.

The environmental monitoring requirements for the sewage evaporation and percolation ponds (hereafter sewage ponds) are specified in MRP 96-248. The monitoring requirements

include both wastewater monitoring and monitoring of the groundwater to detect potential impacts of the sewage on groundwater quality.

Wastewater is sampled quarterly at an influent location (ISWP) and within the pond (ESWP). Overflows are sampled as needed at discharge location DSWP. These sampling locations are shown in [Figure 9-11](#).

Nine groundwater monitoring wells are sampled semiannually to provide information on the groundwater quality in the vicinity of the sewage ponds ([Figure 9-11](#)). The wells are screened in three different geological formations: Qal, Tnbs₁, and Tnsc₁ (see [Chapter 8](#)). Tnbs₁ (Neroly Formation lower blue sandstone unit) is the regional aquifer.

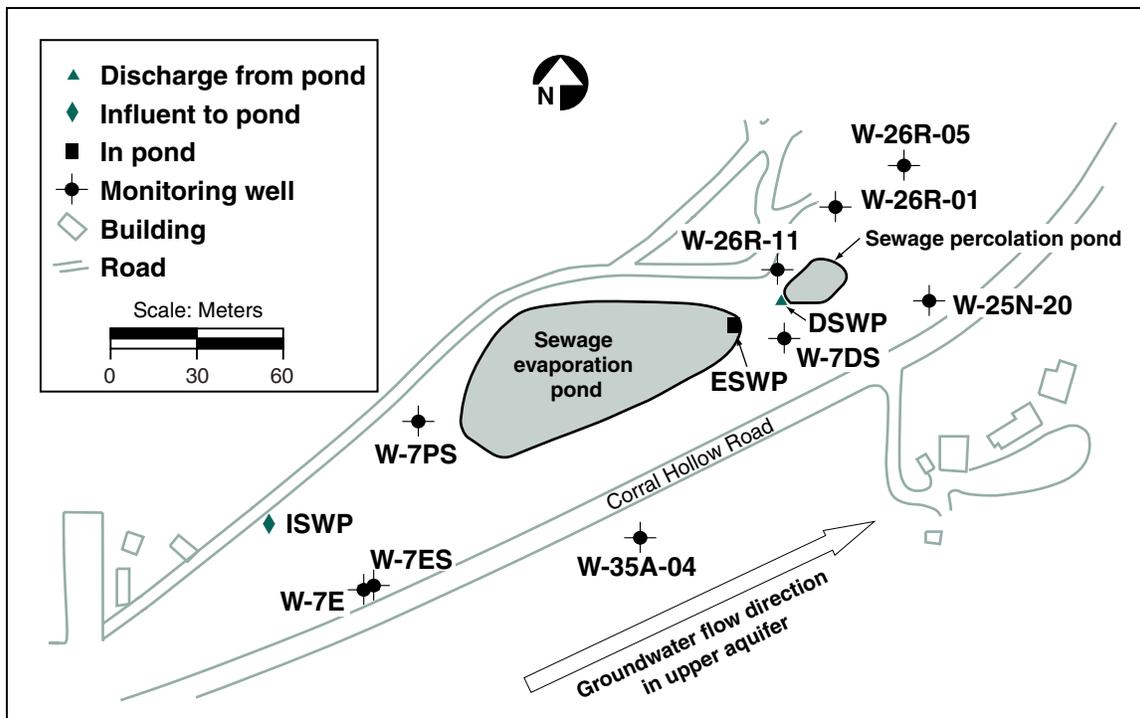


Figure 9-11. Sewage evaporation and percolation ponds, compliance groundwater monitoring wells, and wastewater monitoring locations



Off-site Surveillance Wells and Springs: As planned for surveillance purposes, LLNL obtained groundwater samples from two off-site springs and ten off-site wells during 2001. With the exception of one well, all off-site monitoring locations are near Site 300. The exception, well VIE2, is located at a private residence 6 km west of the site. It represents a typical potable water supply well in the Altamont Hills. One stock watering well, MUL1, and two stock watering springs, MUL2 and VIE1, are adjacent to Site 300 on the north. Eight wells, CARNRW1, CARNRW2, CDF1, CON1, CON2, GALLO1, STONEHAM1, and W35A-04, are adjacent to the site on the south (**Figure 9-3**). Seven of the wells to the south are privately owned and were constructed to supply water either for human consumption, stock watering, or fire suppression. The exception is well W35A-04, which is a DOE CERCLA well that was installed off site for monitoring purposes only.

Groundwater samples were obtained quarterly during 2001 at six off-site surveillance well locations south of Site 300. Of these, CARNRW1 and CON2 samples were analyzed for VOCs (EPA method 601) and tritium. Samples from CARNRW2, CDF1, CON1, and GALLO1 were analyzed quarterly for inorganic COCs (mostly metals), general radioactivity (gross alpha and beta), tritium activity, explosive compounds (HMX and RDX), and VOCs (EPA method 502.2). Additional analyses were conducted on third-quarter samples for uranium activity and extractable organics (EPA method 625).

Groundwater samples were obtained once (annually) during 2001 from six off-site surveillance monitoring locations—MUL1, MUL2, and VIE1 (north of Site 300); VIE2 (west of Site 300); and STONEHAM1 and W-35A-04 (south of Site 300). Samples were analyzed for inorganic COCs (mostly metals), general radioactivity (gross alpha and beta), tritium and uranium activity, explosive

compounds (HMX and RDX), VOCs (EPA method 502.2), extractable organics (EPA method 625), and pesticides (EPA method 608).

Sampling and Analytical Methods

Representative samples of groundwater were obtained from monitoring wells in accordance with the *LLNL Livermore Site and Site 300 Environmental Restoration Project Standard Operating Procedures (SOPs)* (Dibley and Depue 2000). These protocols cover sampling techniques and specific information concerning the chemicals that are routinely searched for in groundwater. Different sampling techniques were applied to different wells depending on whether they were fitted with submersible pumps, had to be bailed, or contained Barcad devices. Typically, analytical methods approved by the Environmental Protection Agency (EPA) are used to measure dissolved constituents in water because they are both accurate and sensitive. (See Data Supplement [Table 9-1](#) for the list of EPA or other standard analytical methods used to measure chemicals and radioactivity in groundwater.) All the analyses were performed by state-certified analytical laboratories.

At Site 300, wastewater samples from the photographic and explosives process areas, sewage evaporation pond influent and overflow, and water in the pond were obtained in accordance with the standardized procedures of the Operations and Regulatory Affairs Division (Tate et al. 1999). Standard sample handling and hygiene procedures were employed to prevent cross-contamination (e.g., wearing disposable gloves, decontaminating equipment between uses, and maintaining samples at $4 \pm 2^\circ\text{C}$). Duplicates, field blanks, and trip blanks were obtained for quality assurance/quality control purposes.

Technologists collected wastewater samples from retention tanks in the Chemistry Area associated with Buildings 825, 826, and 827 following Hazardous Waste Management Procedure 411. Wastewater was held in retention tanks until analytical results were reviewed for compliance with WDR 96-248. Some analyses were performed by LLNL, which is state-certified for these analyses. The remainder were done off-site by state-certified contract laboratories.

Results

This section presents the monitoring results for the Livermore site, Site 300, and adjacent areas.

Livermore Site and Environs

Livermore Valley

Tritium measurements of Livermore Valley groundwaters are contained in the Data Supplement, [Table 9-2](#). They continue to show very low and decreasing activities compared with the 740 Bq/L (20,000 pCi/L) maximum contaminant level (MCL) established for drinking water in California. As in past years, the maximum tritium activity measured off site was in the groundwater at well 11B1, located about 11 km west of LLNL (see [Figure 9-1](#)). The measured activity there was 2.7 Bq/L in 2001, which is equal to 0.4% of the MCL. [Figure 9-12](#) shows the history since 1988 of the maximum tritium activity measured in the Livermore Valley wells sampled.

Livermore Site Perimeter

Constituent measurements for the Livermore site perimeter wells are contained in the Data Supplement, [Tables 9-3](#) through [9-5](#). No pesticide or herbicide organic compounds were detected above analytical reporting limits in the groundwater during 2001. Likewise, no PCBs were detected in any groundwater samples analyzed for them in 2001.

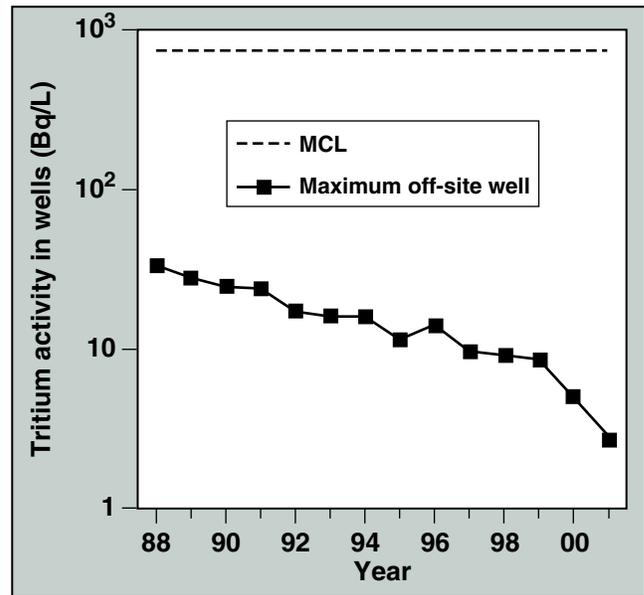


Figure 9-12. Trend of tritium activity in Livermore Valley wells, 1988 to 2001. The drinking water MCL of 740 Bq/L is also shown.

The inorganic compounds detected, include dissolved trace metals and minerals, which occur naturally in the groundwater at variable concentrations. [Table 9-1](#) shows the three anions with the highest concentrations in the two shallower (HSU) background wells, W-008 and W-221, and the seven western wells at LLNL. Concentrations of these major anions are higher in the background wells than in the western wells. Concentrations of chloride in all three background wells are higher than California's recommended secondary MCL of 250 mg/L, while chloride concentrations in none of the western wells exceed 250 mg/L. Likewise, sulfate concentrations in background well W-008 exceed California's recommended secondary MCL of 250 mg/L, while sulfate concentrations in none of the western wells exceed 250 mg/L. Poor groundwater quality in the upgradient (especially northeastern) portions of the site has been described previously in the remedial investigations (Thorpe et al. 1990).



Table 9-1. Concentration ranges for three major anions in shallow background and western perimeter monitoring wells

Anion	Concentration (mg/L)	
	Background	Western perimeter
Bicarbonate (HCO³⁻)		
Range	243–335	191–270
Median	289	241
Chloride (Cl⁻)		
Range	304–490	73–130
Median	397	89
Sulfate (SO₄²⁻)		
Range	101–328	26–63
Median	214	39

In March 1996, nitrate was first detected at a concentration level of 75 mg/L in a groundwater sample obtained from western perimeter monitoring well W-1012 (screened in HSU 2) (see [Figure 9-2](#)). This level is greater than the MCL of 45 mg/L. From a groundwater sample collected in February 2001, the concentration of nitrate for this well was 73.2 mg/L. This is the highest nitrate concentration measured in any surveillance monitoring well during 2001.

Because of the hydrologic influence of Treatment Facility B that pumps and treats groundwater from HSUs 1B and 2 (see [Chapter 8](#)), groundwater with high nitrate concentrations is restrained from moving off site to the west. The highest concentration measured in an off-site well was below the MCL at 37.6 mg/L, in downgradient monitoring well W-151 (see Data Supplement [Table 9-5](#)). Monitoring well W-151 is off site and downgradient to the southwest, along Arroyo Seco, and is screened in HSU 2. During 2001, concentrations of nitrate in on-site shallow background wells W-008 and W-221 ranged from 19.9 mg/L to

34 mg/L. Detected concentrations of nitrate in western perimeter wells, with the exception of well W-1012, ranged from 13 to 37.6 mg/L.

Nitrate was not detected at concentrations greater than the MCL in any other western perimeter surveillance monitoring well (besides on-site monitoring well W-1012) during 2001. Fluctuations in nitrate concentrations have occurred since regular surveillance monitoring began in 1996, but nitrate concentrations have not increased overall in groundwater from the western perimeter monitoring wells since 1996. The nitrate may originate as an agricultural residue (Thorpe et al. 1990).

Of the selected trace metal analytes, only hexavalent chromium (chromium(VI)) exceeded California's MCL of 50 µg/L in groundwater samples collected from western perimeter well W-373 in January. Groundwater samples collected from this well are from HSU 1B, and the nearby Treatment Facility C (see [Figure 8-1](#)) treats groundwater from HSU 1B for chromium. Consequently, concentrations of chromium (including hexavalent chromium) have been continually decreasing. The concentration of 51 µg/L for hexavalent chromium in the January 2001 sample is the lowest since monitoring began in that well in 1989.

Activities of naturally occurring total uranium (uranium-234+235+238) continued to be highest in the background wells during 2001. Activities of total uranium in those wells were measured as 0.20 ± 0.02 Bq/L to 0.25 ± 0.02 Bq/L (34% of California's MCL of 0.74 Bq/L, or 20 pCi/L). (See Data Supplement [Table 9-3](#)). Activities of total uranium are lower, from 0.02 ± 0.003 Bq/L (in well W-121) to 0.11 ± 0.01 Bq/L (15% of California's MCL in well W-1012), in groundwater from each of the western perimeter monitoring wells. Uranium-238 and its radioactive daughters, thorium-230, radium-226, and radon-222, occur



naturally in the sediments and rock layers beneath and surrounding LLNL. Uranium activities did not exceed drinking water limits.

Livermore Site

Constituent measurements for the Livermore site wells are contained in the Data Supplement, [Tables 9-6 through 9-13](#). Groundwater downgradient of potential sources showed possible impact from two releases of metals to the ground. Groundwater at well W-307 near Building 322 showed a maximum concentration of dissolved chromium of 19 µg/L, greater than 8 µg/L, the highest concentration of hexavalent chromium measured in any background well from 1996 through 2001.

Dissolved chromium was also detected at elevated concentrations in groundwater samples from wells W-226 and W-306, which are downgradient from the Building 253 catch basin. Concentrations were measured as 32 µg/L at well W-226 and 42 µg/L at well W-306. The accumulated sediment in the catch basin is a potential source of several metals (Jackson 1997). No concentrations of either dissolved chromium or hexavalent chromium exceeded the MCL of 50 µg/L for chromium in drinking water.

In the vicinity of the Plutonium Facility, concentrations of plutonium-238 or plutonium-239 were below detection limits in the groundwater samples collected during the first quarter of 2001. Thus, any existing concentration is far below EPA's Preliminary Remediation Goal of 0.006 Bq/L for plutonium in drinking water.

In August 2000, the tritium activity was 115 ± 5.0 Bq/L (about 15% of the MCL) in the groundwater sampled at well W-148, downgradient from the Tritium Facility (Building 331). Groundwater tritium activities had returned to near background level by December 2000 in all of the wells sampled downgradient of Building 331. The relatively elevated tritium activity in the ground-

water sampled at well W-148 in August 2000 was concluded to be most likely related to local infiltration of storm water containing elevated tritium activity. The highest tritium activity measured in any of these wells was 56 ± 6.3 Bq/L in a sample collected from well W-148 in October; this is about half the tritium concentration measured in 2000 in that well. LLNL continues to collect groundwater samples from these wells periodically for surveillance purposes, primarily to demonstrate that their tritium and plutonium contents remain below environmental levels of concern.

Near Building 151, there was in the past a minor unknown source of some VOCs, such as carbon tetrachloride, chloroform, Freon 113, tetrachloroethene (PCE), and TCE, to groundwater. These VOCs are being remediated under CERCLA (see [Chapter 8](#)). Concentrations of trace metals, americium-241, tritium, gross alpha/beta radioactivity, and various gamma-emitting radioisotopes showed no indications of being elevated downgradient from Building 151.

Site 300

The following are summaries of Site 300 groundwater surveillance and compliance monitoring results for 2001. Site 300 compliance monitoring results for 2001 have been published previously (Brown 2001a, b, c, and 2002; Christofferson and MacQueen 2001a, b, c, and 2002; Christofferson et al. 2000a, b, c, and 2002; Revelli 2002). Compliance monitoring results for Site 300 are discussed again in the following summaries. Surveillance monitoring results for 2001 have not been published elsewhere and are listed in the Data Supplement, [Tables 9-14 through 9-26](#).

Elk Ravine Drainage Area

Pit 7: No new release of COCs to groundwater from Pit 7 is evident in the chemical data obtained during 2001. The COCs detected in groundwater



include several metals, depleted uranium, tritium, and several volatile organic compounds (VOCs). These are associated with releases that occurred prior to 2001. The primary sources of COCs detected by the network of Pit 7 monitoring wells are the closed landfills known as Pits 3 and 5, which are adjacent to Pit 7 ([Figure 9-4](#)). Natural sources in the rocks and sediments surrounding Pit 7 also have contributed elements such as barium and uranium to the groundwater. In the past, especially during the El Niño winters of 1982–83 and 1997–98, excessive seasonal rainfall caused groundwater levels to rise into Pit 3 and Pit 5 from beneath, leading to the release of COCs, mainly tritium in the form of tritiated water molecules (HTO). Because of reduced rainfall since 1998, groundwater elevations have fallen generally at Site 300, thus reducing the potential for releases to occur by this mechanism. CERCLA modeling studies indicate that tritium and other COCs released in the past will not reach off-site aquifers at concentrations above MCLs. See Chapter 8 for a review of CERCLA concerns regarding groundwater contamination in the upper reaches of the Elk Ravine drainage area. For a detailed account of Pit 7 compliance monitoring during 2001, including tables and graphs of groundwater COC analytical data, see [Christofferson and MacQueen \(2002\)](#).

Elk Ravine: As in past years, no new release of COCs from LLNL operations in Elk Ravine to groundwater is indicated by the chemical and radioactivity data obtained during 2001. Constituent measurements for the Elk Ravine drainage area surveillance monitoring network are listed in the Data Supplement, [Table 9-14](#).

Tritium activity was above background level in many of the shallow groundwater surveillance samples obtained during 2001 from Elk Ravine. Tritium, as HTO, has been released in the past in the vicinity of Building 850 (see Chapter 8, [Figure 8-17](#), for a map showing the extent of

tritium plumes beneath the Elk Ravine drainage area). The largest HTO plume, which extends eastward more than a kilometer from a source beneath the Building 850 firing table area to the vicinity of Pits 1 and 2, is confined to shallow depths in the Neroly lower blue sandstone unit and overlying alluvium. This confinement is illustrated by comparing the tritium activity of 2100 Bq/L at well NC7-61, which samples the shallowest water-bearing zone, and the tritium activity of 0.1 Bq/L at well NC7-69, which samples the deeper water-bearing zone in this area.

The majority of the Elk Ravine surveillance network tritium measurements made during 2001 support earlier CERCLA studies that show that, despite additional releases, the tritium contents and extents of the plumes are generally diminishing over time because of natural decay and dispersion ([Ziagos and Reber-Cox 1998](#)). For example, tritium activity in groundwater at well NC7-61 decreased from 6500 Bq/L in 1996 to 2100 Bq/L in 2001. CERCLA modeling studies indicate that the tritium will decay to background levels before it can reach a site boundary.

Except in the immediate vicinity of Pit 7, groundwater surveillance measurements of gross alpha, gross beta, and uranium radioactivity in Elk Ravine are all low and are indistinguishable from background levels. (Note that gross beta measurements do not detect the low-energy beta emission from tritium decay.) Additional detections of nonradioactive elements including arsenic, barium, chromium, selenium, vanadium, and zinc are all within the ranges of concentrations typical of groundwater elsewhere in the Altamont Hills.

Pit 2: As in past years, no release of a COC from Pit 2 to groundwater is indicated by the surveillance monitoring data obtained during 2001.



Constituent measurements for the Pit 2 surveillance monitoring network are contained in Data Supplement [Tables 9-15a](#) and [9-15b](#).

Several metals were detected at low concentrations. Most were below analytical reporting limits, which are in the parts per billion (ppb) range. None exceeded an MCL. Arsenic and barium concentrations were within the range of background level concentrations in groundwaters at Site 300 (Webster-Scholten 1994). The radioactivity measurements show only low background-level activities for gross alpha, gross beta, and tritium. A distal lobe of the tritium plume extending from the Building 850 firing table is responsible for the tritium activity of 24 Bq/L measured downgradient of Pit 2 in the groundwater sampled at well K1-01C. Tritium activity was not detectable at Barcad K2-01A, which samples a deeper water-bearing zone in this area.

Pit 1: As in past years, no release of COCs to groundwater from Pit 1 is evident in the monitoring data collected during 2001. A detailed account of Pit 1 compliance monitoring during 2001, including tables and graphs of groundwater COC analytical data, appears in a separate report; see [Christofferson and MacQueen \(2002\)](#).

Tritium activity measured above background level (about 4 Bq/L) in the groundwater at Pit 1 monitoring wells K1-01C (24 Bq/L), K1-02B (190 Bq/L), K1-03 (36 Bq/L), and K1-08 (6 Bq/L) during 2001 (for well locations, see [Figure 9-5](#)). The tritium activity in the groundwater sampled at these wells represents a distal lobe of the Building 850 tritium plume (see [Figure 8-17](#) for a CERCLA map of the Building 850 tritium plume extending to Pit 1).

Measurements of radium, thorium, and uranium made during 2001 in groundwater samples from Pit 1 compliance monitoring wells showed low activities indistinguishable from background levels.

The VOC 1,1,2-trichloro-1,2,2-trifluoroethane (Freon 113) decreased from a maximum concentration of 140 µg/L measured in 1999 to 64 µg/L in 2001 in groundwater at Pit 1 monitoring wells K1-05 (23 µg/L), K1-08 (23 µg/L), and K1-09 (64 µg/L). The drinking water MCL for this VOC is 1200 µg/L. Previous CERCLA investigations have linked the Freon 113 detected in Pit 1 monitoring wells to past spills of Freon in the Advanced Test Accelerator area, about 200 m west and cross-gradient from the affected wells (Webster-Scholten 1994, Taffet et al. 1996).

Pit 8: As in past years, no release of a COC to groundwater from Pit 8 is indicated by the surveillance monitoring data obtained during 2001. Constituent measurements for the Pit 8 surveillance monitoring network are contained in Data Supplement [Table 9-16](#).

Two VOCs, TCE and 1,2-dichloroethane (1,2-DCA), were detected below their 5 µg/L MCLs. A relatively small VOC plume exists beneath this area (see [Figure 8-9](#) for a map showing the extent of the VOC plume), which originated prior to 1981 from waste discharged to a dry well upgradient of Pit 8, near Building 801 (Webster-Scholten 1994).

Arsenic, chromium, and vanadium were detected in concentrations similar to their natural levels in groundwater elsewhere in the Altamont Hills. Tritium activity, uranium activity, and gross alpha and beta radioactivity were measured at low background levels



Pit 9: As in past years, no evidence for a release from Pit 9 is indicated by the surveillance monitoring data obtained during 2001. Constituent measurements for the Pit 9 surveillance monitoring network are contained in the Data Supplement, [Table 9-17](#). COCs were either not detected or were indistinguishable from background level concentrations in the groundwater sampled at the Pit 9 monitoring wells.

Corral Hollow Creek Drainage Area

Pit 6: No new release of COCs from Pit 6 is indicated by the chemical analyses of groundwater samples obtained from Pit 6 monitoring wells during 2001. For a detailed account of Pit 6 compliance monitoring during 2001, including tables of groundwater analytical data and map figures showing the distribution of COC plumes, see [Christofferson et al. \(2002\)](#).

COCs that were released prior to constructing an impermeable cap over the closed landfill in 1997 continued to be detected in the groundwater at low concentrations. These COCs include tritium, perchlorate, TCE, PCE, and cis-1,2-dichloroethene (cis-1,2-DCE). As in the past, bis(2-ethylhexyl)phthalate (DEHP), which is not a designated COC, was detected in groundwater both upgradient and downgradient from Pit 6. All contaminant plumes associated with Pit 6 are relatively small and are confined to shallow depths. None extends beyond the Site 300 boundary.

Building 829 Closed HE Burn Facility: No new release of COCs to groundwater from the closed HE burn facility is indicated by the monitoring data obtained during 2001. For a detailed account of compliance monitoring of the closed HE burn pit during 2001, including tables and graphs of groundwater COC analytical data, see [Revelli \(2002\)](#).

Two zones containing groundwater beneath the capped facility are monitored: a shallow perched water-bearing zone and a much deeper regional aquifer. As in the past, analyses of groundwater samples obtained from the perched groundwater beneath the closed facility show evidence of past contamination.

Two wells, W-829-06 and W-829-08, are used to monitor the perched groundwater. Although well W-829-08 went dry after the first quarter of 2001, well W-829-06 provided a sufficient quantity of groundwater throughout 2001 for the required analyses. The primary contaminant in the perched groundwater is TCE. The maximum TCE concentration measured during 2001 was 330 µg/L. The maximum 1,2-DCE concentration measured during 2001 was 3.3 µg/L.

Both TCE and 1,2-DCE have decreased considerably by natural attenuation from maximum concentrations of 1000 µg/L and 13 µg/L, respectively, measured in 1993.

The analytical results from wells W-827-05, W-829-15, and W-829-22 in the deep regional aquifer represent background level concentrations of substances dissolved from natural sources in the underlying rocks. (A fourth deep well, W-827-04, was dry during 2001.)

Water Supply Wells: Quarterly measurements of groundwater at Site 300 water supply wells 18 and 20 do not differ significantly from previous years. Constituent measurements for these supply wells are in the Data Supplement, [Tables 9-18](#) and [9-19](#).

As in past years, TCE was detected during 2001 at low concentrations in the groundwater at standby well 18. The maximum concentration measured was 0.25 µg/L, which is equal to 5% of the MCL for TCE. The source of the TCE has not yet been identified.



As in past years, well 20, the main potable water supply well at Site 300, showed no evidence of contamination. Gross alpha, gross beta, and tritium activities in water samples from production wells 18 and 20 are very low and are indistinguishable from background level activities.

Explosives Process Area: No release of water to ground from the surface impoundments occurred during 2001. For a detailed account of compliance monitoring of the Site 300 surface impoundments, including tables of groundwater measurements, see [Brown \(2002\)](#).

The two leachate collection and removal systems were monitored weekly for the presence of liquids. None was observed during 2001. No water has been observed in the leachate collection and removal system since liner repairs were made in 1997. No water was found in any of the five lysimeters that are installed beneath the facility.

The explosive compounds (HMX, RDX, and TNT) and perchlorate are the compounds most indicative of discharges to groundwater from the Explosives Process Area surface impoundments. However, prior to 1985, explosives wastewater was discharged into unlined ponds in the vicinity of the surface impoundments, where it infiltrated the soil and some of it reached groundwater. Because of this past practice, it is necessary to discriminate between new releases from the surface impoundments and past releases from the unlined ponds.

As in the past, groundwater concentrations of nitrate continued to exceed the drinking water MCL in samples from all surface impoundment monitoring wells during 2001. Concentrations of arsenic continue to be detected at concentrations at or near its drinking water MCL in these same wells during 2001. Concentrations of both arsenic and nitrate in groundwater have historically exceeded their respective MCLs (0.050 mg/L for arsenic

and 45 mg/L for nitrate) in this area. Background level concentrations of arsenic in groundwater monitoring wells upgradient from the surface impoundments have been measured at concentrations above the drinking water MCL (Webster-Scholten 1994). Although the distribution of arsenic over time and throughout the area suggests a natural source, the occurrence and concentration of arsenic at Site 300 is the subject of a continuing CERCLA study. The remediation of these constituents (except for arsenic) is discussed in [Chapter 8](#) of this document.

During 2001, all discharges into the surface impoundments were in compliance with discharge concentration limits. Groundwater concentrations of some inorganic COCs were higher than the statistical limits during 2001. LLNL determined that concentrations of these COCs increased because of a change in geochemical conditions within the aquifer. LLNL continues to monitor and to track these concentrations. For details, see [Brown \(2002\)](#).

Percolation Pits: During 2001, the percolation pits at Buildings 806A, 827D, and 827E operated normally with no overflows. Standing water was regularly noted in the Building 827C percolation pit inspections ([Brown 2002](#)).

Sewage Evaporation and Percolation Ponds: All wastewater parameters for the sewage evaporation and percolation ponds complied with permit provisions and specifications throughout 2001. There was one overflow to the percolation pond during 2001. This was sampled and reported to the CVRWQCB. For details, see [Brown \(2002\)](#).

All of the groundwater monitored constituents were also in compliance with permitted limits. LLNL has not yet determined the origin of elevated nitrate concentrations, but a study of nitrate occurrence at Site 300 is continuing under



CERCLA auspices, and LLNL continues to monitor these wells and nearby off-site wells for nitrate concentrations (see also [Chapter 8](#)).

Off-Site Water Supply Wells: Generally, no COC attributable to LLNL operations at Site 300 was detected in the off-site groundwater samples. Constituent measurements for the off-site water supply wells are contained in the Data Supplement, [Tables 9-20](#) through [9-26](#).

Arsenic and barium were widely detected at the off-site locations, but their concentrations were below MCLs and their occurrence is consistent with natural sources in the rocks. Scattered detections of metals were all below MCLs and were probably related to metals used in pumps and supply piping.

As in past years, TCE was detected at concentrations up to 0.74 µg/L in the groundwater samples obtained from well GALLO1 (see [Figure 9-3](#)). Previous CERCLA remedial investigations concluded that the TCE in the GALLO1 well water was likely caused by a localized surface spill on the property, possibly solvents used to service the private well (Webster-Scholten 1994). (Surveillance monitoring of a similarly sited well, GALLO2, was terminated in 1991 because of contamination from chemicals leaking from the pumping apparatus.) Radioactivity measurements of off-site groundwater are all indistinguishable from background activities.

Environmental Impacts

The overall impact of Livermore site and Site 300 operations on off-site groundwaters is minimal. With the exception of VOCs being remediated under CERCLA at both sites, current LLNL operations have no measurable impact on groundwaters beyond the site boundaries.

Livermore Site and Environs

Groundwater monitoring at the Livermore site and in the Livermore Valley indicates that LLNL operations have minimal impact on groundwater beyond the site boundary. (See [Chapter 8](#) for CERCLA remediation activities with VOCs.)

During 2001, neither radioactivity nor concentrations of elements or compounds detected in groundwater from any off-site monitoring well were confirmed as exceeding primary drinking water MCLs. The maximum tritium activity measured off site in the Livermore Valley was 2.7 Bq/L (74 pCi/L), in well 11B1 (see Data Supplement [Table 9-16](#)).

Of the Livermore on-site monitoring wells, no inorganic data exceeded primary MCLs with the exceptions of chromium in monitoring well W-373 and nitrate in monitoring well W-1012 (see [Figure 9-2](#)). Hexavalent chromium in groundwater in the vicinity of monitoring well W-373 is being removed at Treatment Facilities B and C and concentrations are steadily decreasing.

The LLNL Ground Water Project reports on the treatment of groundwater in the vicinity of the treatment facilities (see [Chapter 8](#)). Concentrations of nitrate in groundwater samples collected from well W-1012 throughout 2001 exceeded California's MCL of 45 mg/L. Nitrate above the MCL has not migrated off site. LLNL continues to monitor nitrate concentrations at this well and monitoring well W-571, which is off-site and about 350 m downgradient from well W-1012.

Measurements of arroyo sediments made in 2001 indicate no potential for adverse impact of groundwater through the arroyos that cross the Livermore site (see [Chapter 10](#)).



Site 300

Groundwater monitoring at Site 300 and adjacent properties in the Altamont Hills shows minimal impact of LLNL operations on groundwater beyond the site boundaries.

Within Site 300, the chemicals detected in groundwater beneath the Explosives Process Area will not migrate off site. Plans to remediate TCE, explosive compounds such as RDX, perchlorates, and nitrate are being implemented under CERCLA auspices (see [Chapter 8](#)). Additionally, LLNL is investigating the distribution and origins of arsenic and zinc in this area.

VOCs, primarily the solvent TCE, have been released historically to shallow groundwater at numerous locations at Site 300 (see [Chapter 8](#) and references cited therein). With the exception of a small plume in the General Services Area that extends minimally off site along Corral Hollow Road, all of the TCE-bearing groundwater is onsite. The plume extending off site from the Eastern GSA area is being drawn back to the site by pumping, and the TCE is being removed from the groundwater.

LLNL is investigating various remedial methods to remove depleted uranium from the groundwater adjacent to several source areas within Site 300 (see [Chapter 8](#) for locations).

Tritiated water (HTO) has been released to groundwater from several landfills and a firing table in the northwestern part of Site 300. The boundaries of the slowly moving HTO plumes lie entirely within the site. CERCLA modeling studies indicate that, given tritium's short half-life of 12.3 years, and the relatively slow rate of groundwater flow (5–15 m/yr), the activity of the released HTO will decrease to several orders of magnitude below the MCL of 740 Bq/L (20,000 pCi/L) before it can reach a site boundary and migrate off site (Taffet et al. 1996).

SOIL AND SEDIMENT MONITORING

*Gretchen M. Gallegos
Richard A. Brown*

Introduction

The soil and sediment surveillance monitoring that Lawrence Livermore National Laboratory performed in 2001 included work in three areas: surface soil in the Livermore Valley and at Site 300, sediment at the Livermore site, and vadose zone soils at the Livermore site.

Soil is weathered material, mainly composed of disintegrated rock and organic material that sustains growing plants. Soil can contain pollutants originally released directly to the ground, to the air, or through liquid effluents. Department of Energy (DOE) guidance for environmental monitoring states that soil should be sampled to determine if there is a measurable, long-term buildup of radionuclides in the terrestrial environment and to estimate environmental radionuclide inventories (U.S. DOE 1991). The guidance recommends monitoring for radionuclides specific to a particular operation or facility as well as those that occur naturally. Particulate radionuclides are of major interest in the LLNL soil monitoring program because airborne particulate releases are the most likely pathway for LLNL-induced soil contamination.

Sediments are defined for the purposes of this chapter as finely divided, solid materials that have settled out of a liquid stream or standing water. The accumulation of radioactive materials in sediment could lead to exposure of humans

through their ingestion of aquatic species, sediment resuspension into drinking water supplies, inhalation of dust particles, or as an external radiation source (U.S. DOE 1991). However, the Livermore site and Site 300 do not have habitats for aquatic species that are consumed by people, nor do they have surface drainage that directly feeds drinking water supplies.





Soils in the vadose zone—the region below the land surface where the soil pores are only partially filled with water—are collected in arroyo channels at the Livermore site as part of the Ground Water Protection Management Program (GWMP). Infiltration of natural runoff through arroyo channels is a significant source of groundwater recharge, accounting for an estimated 42% of resupply for the entire Livermore Valley groundwater basin (Thorpe et al. 1990). Soils in the shallow vadose zone are collected and analyzed to provide information about possible constituents that may be dissolved as runoff water infiltrates through the arroyo to the groundwater.

Sampling Locations

Since 1971, surface soil sampling near the LLNL Livermore site and Site 300 has been part of a continuing LLNL monitoring program designed to measure any changes in environmental levels of radioactivity and evaluate any increase in radioactivity that might have resulted from LLNL operations. These samples have been analyzed for plutonium and gamma-emitting radionuclides, such as depleted uranium used in some explosive tests at Site 300. The inclusion of other gamma-emitting, naturally occurring nuclides (potassium-40 and thorium-232) and the long-lived fission product, cesium-137, provides background information and baseline data on global fallout from historical above-ground nuclear weapons testing. In addition, LLNL analyzes Site 300 soils for beryllium, a potentially toxic metal used at this site. Soils in the Livermore vicinity were analyzed for beryllium from 1991 to 1994. However, analysis for beryllium was discontinued at the Livermore site in 1995, because it was never measured above background values.

Surface soil samples are collected at 19 locations in the Livermore Valley, including 6 sampling locations at the LWRP, an area of known plutonium

contamination (**Figure 10-1**) and 14 locations at or near Site 300 (**Figure 10-2**). The locations were selected to represent background concentrations (distant locations unlikely to be affected by LLNL operations) as well as areas where there is the potential to be affected by LLNL operations. Areas with known contaminants, such as the Livermore Water Reclamation Plant (LWRP), are also sampled.

Site 300 soil sampling locations are established around firing tables and other areas of potential soil contamination.

Sediment samples have been collected from selected arroyos and other drainage areas at and around the Livermore site since 1988; these locations (**Figure 10-3**) largely coincide with selected storm water sampling locations (see **Chapter 7**).

Sediment sampling locations have not been established at Site 300. The drainage courses at Site 300 are steep, causing flowing water to scour the drainages, which prevents the accumulation of sediment. Because of these conditions, sediment sampling at Site 300 is not warranted.

Vadose zone soil sampling has been conducted since 1996. These sampling locations correspond to the same selected storm water sampling locations as the sediment sampling locations (see **Figure 10-3**). Vadose zone samples were not collected in the Drainage Retention Basin because the liner for the basin prevents migration of materials to the groundwater. The collocation of sampling for these three media facilitates comparison of analytical results. As with sediment samples, vadose zone samples are not collected at Site 300.

Approximately 10% of locations are sampled in duplicate; two samples are collected at each location chosen for this sampling. All soil and sediment sampling locations have permanent location markers for reference.

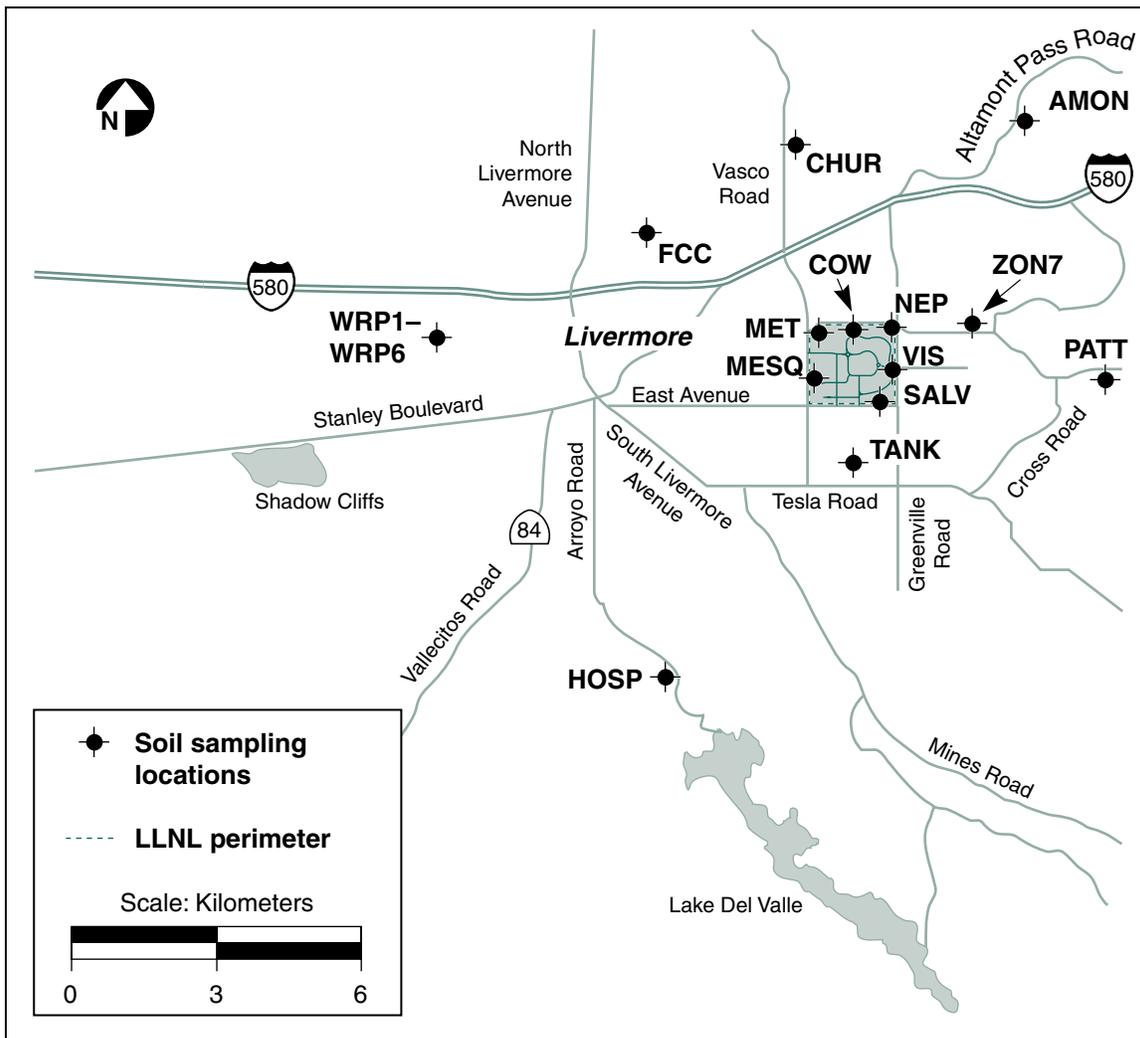


Figure 10-1. Surface soil sampling locations, Livermore Valley, 2001

Methods

Surface soil, sediment, and vadose zone soil sampling is conducted annually according to written, standardized procedures (Tate et al. 1999). Soil samples are collected from undisturbed areas near permanent location markers. These areas are generally level, free of rocks, and unsheltered by trees or buildings. Surface soil samples are collected from the top 5 cm of soil because aerial deposition is the primary pathway for potential contamination, and resuspension of materials from the surface into

the air is the primary exposure pathway to nearby human populations.

Sediments are collected annually from drainages at and around the Livermore site after the cessation of spring runoff. Samples to be analyzed for particulate radionuclides are collected from the top 5 cm of soil. Samples to be analyzed for tritium are collected 5–15 cm deep to obtain sufficient water in the sample for analysis. Vadose zone soil samples are collected at 30–45 cm deep for metals analysis

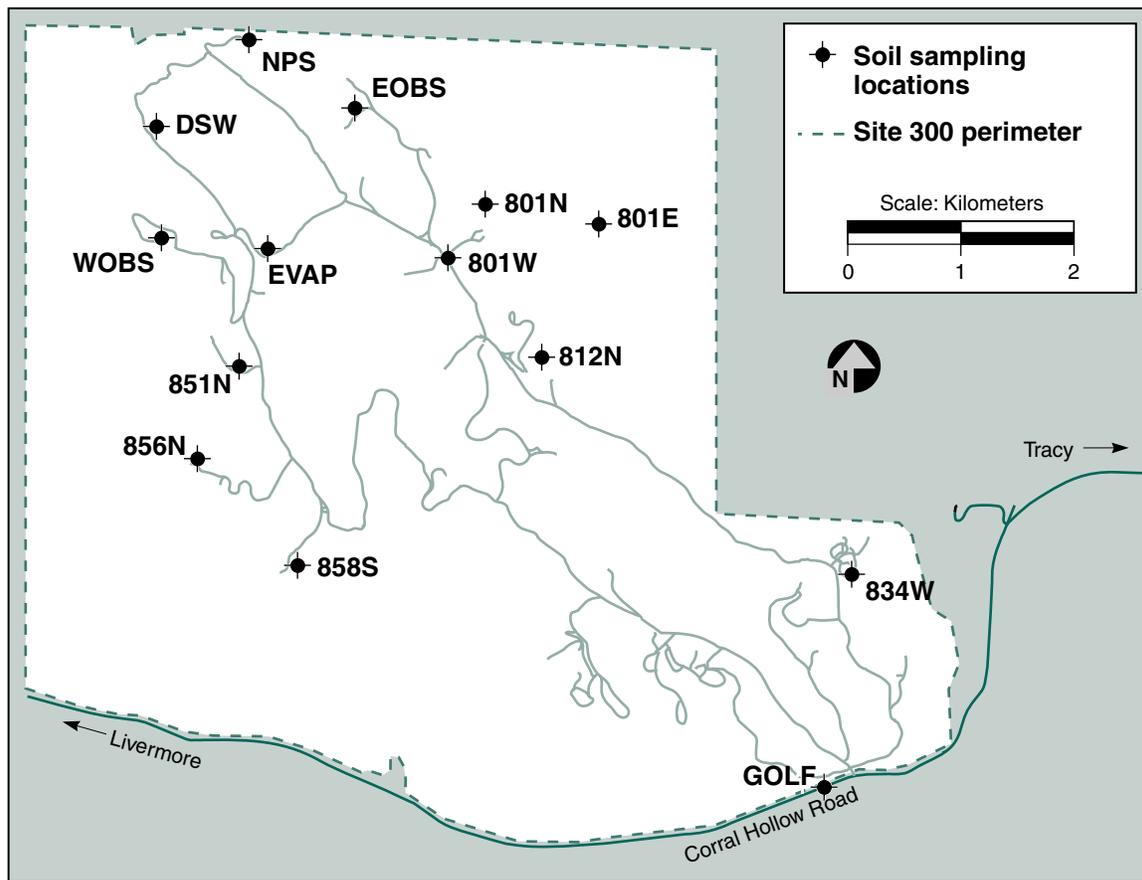


Figure 10-2. Site 300 surface soil sampling locations, 2001

and at 45–65 cm deep for analysis of soluble volatile organic compounds and for polychlorinated biphenyls (PCBs).

In 2001, surface soil samples in the Livermore Valley were analyzed for plutonium and gamma-emitting radionuclides. Samples from Site 300 were analyzed for gamma-emitting radionuclides and beryllium. Analysis of Site 300 soil samples for plutonium was discontinued in 1997 because plutonium has not been used at the site, and sample results have continuously been at background levels since sampling began in 1972. Annual sediment samples collected at the Livermore site were analyzed for plutonium, gamma-emitting radionuclides, and tritium. Vadose zone samples were

analyzed for total and soluble metals, and for soluble volatile organic compounds; one vadose zone location was analyzed for PCBs.

Prior to radiochemical analysis, surface soil and sediment samples are dried, ground, sieved, and homogenized. The samples are analyzed by LLNL's Chemistry and Materials Science Environmental Services (CES) laboratory. The plutonium content of a 100-g sample aliquot is determined by alpha spectroscopy. Other sample aliquots (300-g) are analyzed for more than 150 radionuclides by gamma spectroscopy using a high-purity germanium (HPGe) detector (Hall and Edwards 1994a, b, c). The 10-g subsamples for beryllium analyses are sent to a contract analytical laboratory and are

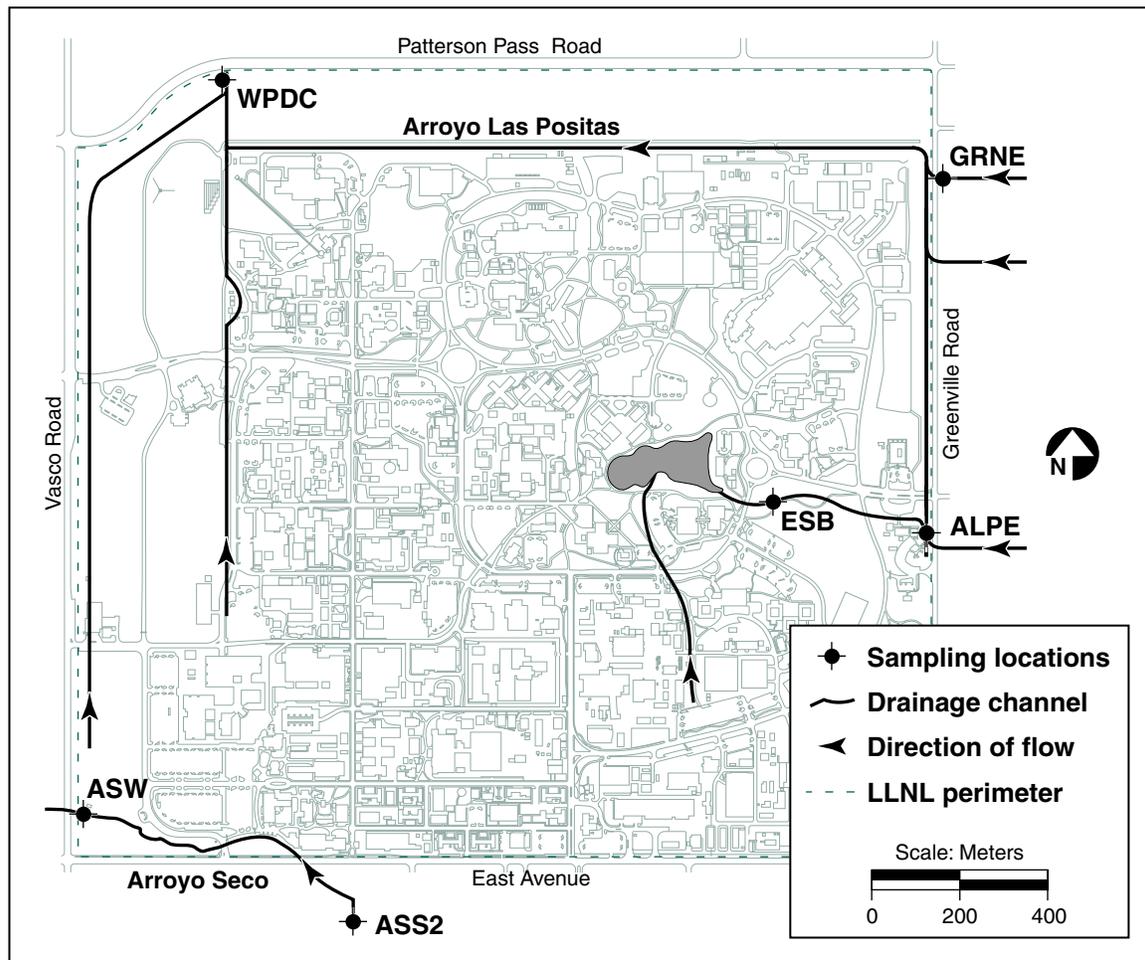


Figure 10-3. Sediment and vadose zone sampling locations on or near the Livermore site, 2001

analyzed by atomic absorption spectroscopy (EPA Method 7091). For sediment samples collected for tritium analyses, CES uses freeze-drying techniques to recover water from the samples and determines the tritium content of the water by liquid-scintillation counting.

Vadose zone soil samples are analyzed by a contract analytical laboratory. The analytical methods include the toxicity characteristic leaching procedure (TCLP, EPA Method 1311) followed by EPA Method 8260 for volatile organic compounds, and total metals by EPA Methods 200.7, 245.2, 7471A, and 6010B. The procedure for deter-

mining soluble metals includes the California Waste Extraction Test, followed by the same analytical methods for metals applied to the leachates. In 2001, a vadose zone soil sample from location ESB (Figure 10-3) was also analyzed for PCBs by EPA Method 8082. Chain-of-custody procedures are followed throughout the sampling, delivery, and analytical processes.

Livermore Valley Surface Soil Results

Table 10-1 presents data on the concentrations of plutonium-238 and plutonium-239+240 in the Livermore Valley surface soils. Data for

**Table 10-1. Plutonium activity concentrations in Livermore Valley soil, 2001**

Location identifier	Plutonium-238 mBq/dry g	Plutonium-239+240 mBq/dry g
L-AMON-SO	0.0019 ± 0.0010	0.073 ± 0.0063
L-CHUR-SO	0.0051 ± 0.0016	0.13 ± 0.0092
L-COW-SO	0.00084 ± 0.00081	0.021 ± 0.0031
L-FCC-SO	0.0016 ± 0.0012	0.066 ± 0.0069
L-HOSP-SO	0.0069 ± 0.0020	0.19 ± 0.012
L-MESQ-SO	0.00084 ± 0.0011	0.033 ± 0.0045
L-MET-SO	0.0017 ± 0.0015	0.047 ± 0.0067
L-NEP-SO	0.0013 ± 0.0010	0.055 ± 0.0054
L-PATT-SO	0.00074 ± 0.0010	0.022 ± 0.0039
L-SALV-SO	0.0063 ± 0.0017	0.066 ± 0.0057
L-TANK-SO	0.0056 ± 0.0019	0.13 ± 0.0097
L-VIS-SO	0.017 ± 0.0032	0.37 ± 0.020
L-ZON7-SO	0.0085 ± 0.0022	0.16 ± 0.011
Median	0.0019	0.066
IQR ^(a)	0.0050	0.083
Maximum	0.017	0.37

Note: Radioactivities are reported as the measured concentration and either an uncertainty ($\pm 2\sigma$ counting error) or as being less than or equal to the detection limit. If the concentration is less than or equal to the uncertainty or the detection limit, the result is considered to be a nondetection. See [Chapter 14](#).

^a IQR = interquartile range

cesium-137, potassium-40, thorium-232, uranium-235, and uranium-238 in surface soils from the Livermore Valley sampling locations are presented in [Table 10-1](#) of the Data Supplement.

The concentrations and distributions of all observed radionuclides in soil for 2001 are within the ranges reported in previous years and generally reflect worldwide fallout and naturally occurring concentrations.

Plutonium has, in the past, been detected at levels above background at VIS, a perimeter sampling location near the east boundary of the Livermore site. Since 1980, soil samples at this location have

generally shown plutonium-239+240 values higher than background. However, in 2001, the measured plutonium-239+240 value for VIS at 370 $\mu\text{Bq/dry g}$ (9.93×10^{-3} pCi/dry g) was within the range of background. The slightly higher values at and near the Livermore site have been attributed to historic operations, including the operation of solar evaporators for plutonium-containing liquid waste in the southeast quadrant (Silver et al. 1974). LLNL no longer operates the solar evaporators or engages in any other open-air treatment of plutonium-containing waste. Nonetheless, plutonium-239+240, from historic operations, can be carried off site by resuspension of soil by wind.

Similarly, elevated levels of plutonium-239+240 (resulting from an estimated 1.2×10^9 Bq [32 mCi] plutonium release to the sanitary sewer in 1967 and earlier releases) were first observed in soils near LWRP during the early 1970s, and were again detected at LWRP sampling locations.

As in 1997 through 1999, americium-241 was detected in LWRP samples; it is most likely caused by the natural decay of the trace concentrations of plutonium-241 that were present in the releases to the sewer. Plutonium and americium concentrations for the LWRP are presented in [Table 10-2](#). Data for cesium-137, potassium-40, thorium-232, uranium-235, and uranium-238 for LWRP sampling locations are presented in [Table 10-1](#) of the Data Supplement.

Historical plots of median plutonium-239+240 concentrations in soil in the Livermore Valley

upwind and downwind of the center of the LLNL Livermore site and at LWRP are shown in [Figure 10-4](#). Livermore Valley upwind concentrations have remained relatively constant since monitoring began and generally are indicative of worldwide fallout. Greater variation can be noted in the downwind concentration data, which in 2001 included sampling locations VIS, PATT, NEP, COW, AMON, and ZON7, compared with the upwind data. The concentrations of plutonium at the downwind locations reflect resuspension of low-level plutonium contamination from soils in the southeast quadrant of the Livermore site. Greater variability in plutonium-239+240 is seen in samples from LWRP. Because the plutonium-239+240 is likely to be present in discrete particles, the random presence or absence of the particles dominates the measured plutonium-239+240 in any given sample.

Table 10-2. Plutonium and americium activity concentrations in LWRP soil, 2001

Location identifier	Plutonium-238 mBq/dry g	Plutonium-239+240 mBq/dry g	Americium-241 mBq/dry g
L-WRP1-SO	0.34 ± 0.017	6.5 ± 0.23	4.0 ± 2.8
L-WRP2-SO	0.20 ± 0.013	3.4 ± 0.13	1.5 ± 0.83
L-WRP3-SO	0.054 ± 0.055	1.0 ± 0.043	<0.68
L-WRP4-SO	0.017 ± 0.0030	0.32 ± 0.017	<0.54
L-WRP5-SO	0.085 ± 0.0078	1.9 ± 0.078	<0.53
L-WRP6-SO	0.061 ± 0.0063	1.1 ± 0.047	<0.51
Median	0.073	1.5	<0.61
IQR ^(a)	0.12	2.0	Not calculated ^(b)
Maximum	0.34	6.5	4

Note: Radioactivities are reported as the measured concentration and either an uncertainty ($\pm 2\sigma$ counting error) or as being less than or equal to the detection limit. If the concentration is less than or equal to the uncertainty or the detection limit, the result is considered to be a nondetection. See [Chapter 14](#).

a IQR = interquartile range

b Interquartile range not calculated because of high incidence of nondetections.

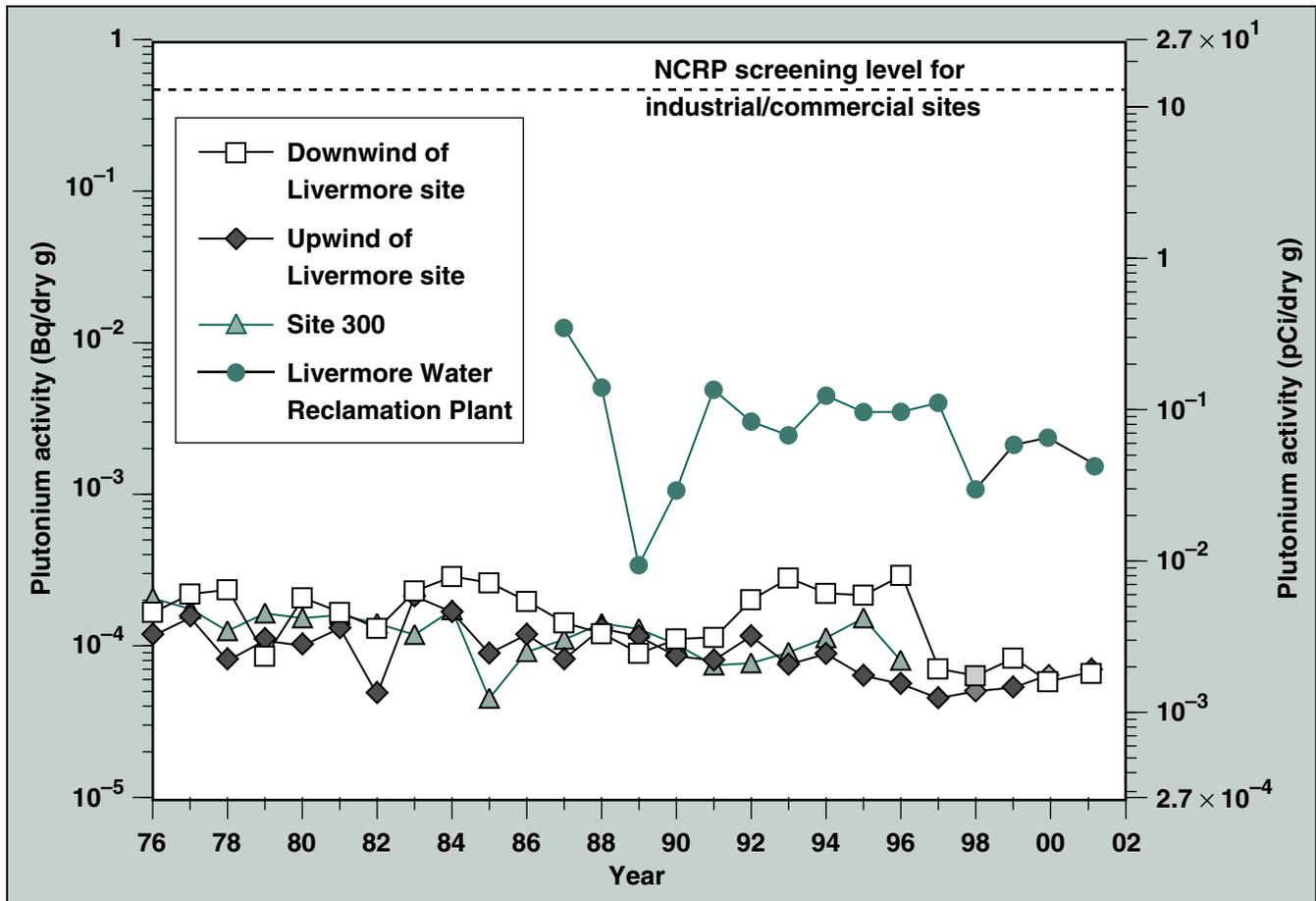


Figure 10-4. Median plutonium-239+240 activities in surface soils, 1976–2001. Upwind and downwind designations are relative to the center of the Livermore site.

Livermore Site Sediment Results

Table 10-3 presents data for plutonium-238, plutonium-239+240, and tritium in sediment samples. Data for cesium-137, potassium-40, thorium-232, uranium-235, and uranium-238 for surface sediment sampling locations are presented in Table 10-1 of the Data Supplement. The levels of plutonium-239+240 were generally at background concentrations, reflective of worldwide fallout. Sampling location ESB (see Figure 10-3) shows a moderately higher value for plutonium than values at other locations. The value may be attributed to historic actions because this location is in a drainage area for the southeast quadrant at

LLNL. Tritium concentrations were within the range of previous data. The highest detected value, 19 Bq/L (520 pCi/L), was also at location ESB. Location ESB is not only located in a settling basin that serves to remove particles from the surface water drainage of the southeast quadrant before the water enters the Drainage Retention Basin (DRB), but is also located very near the DRB. The DRB contains water with similar concentrations of tritium (see Chapter 7). The detection at ESB is 3% of the drinking water standard of 740 Bq/L (20,000 pCi/L) for tritium. Tritium in sediments will continue to be evaluated as long as the measured values remain above the detection limits of the liquid scintillation analytical method. As for

Table 10-3. Plutonium and tritium activity concentrations in surface sediment, 2001

Location identifier	Plutonium-238 mBq/dry g	Plutonium-239+240 mBq/dry g	Tritium Bq/L
L-ALPE-SD	0.0015 ± 0.00097	0.021 ± 0.0033	1.4 ± 2.0
L-ASS2-SD	0.00094 ± 0.0013	0.0094 ± 0.0031	0.71 ± 1.9
L-ASW-SD	0.00092 ± 0.0011	0.013 ± 0.0028	0.2 ± 2.0
L-ESB-SD	0.22 ± 0.014	1.9 ± 0.079	19 ± 2.7
L-GRNE-SD	0.003 ± 0.0014	0.035 ± 0.0046	1.2 ± 2.0
L-WPDC-SD	-0.000058 ± 0.00058	0.0091 ± 0.0023	2.5 ± 2.0
Median	0.0012	0.017	1.3
IQR ^(a)	0.0017	0.021	1.4
Maximum	0.22	1.9	19

Note: Radioactivities are reported as the measured concentration and either an uncertainty ($\pm 2\sigma$ counting error) or as being less than or equal to the detection limit. If the concentration is less than or equal to the uncertainty or the detection limit, the result is considered to be a nondetection. See [Chapter 14](#).

a IQR = interquartile range

surface soil, the concentrations and distributions of all observed radionuclides in surface sediment for 2001 are within the ranges reported in previous years and generally reflect worldwide fallout and naturally occurring concentrations.

Livermore Site Vadose Zone Soil Results

Analytical results for vadose zone soil samples are compared with soil reuse standards developed by LLNL and approved by the San Francisco Bay Regional Water Quality Control Board (SFBRWQCB) (Folks 1997; Marshack 2000). Metals background concentrations are based on naturally occurring levels in the soil, considering first the results for total metals and then the soluble metals test. Natural background levels for organic compounds and tritium at this depth are zero, or below detectable levels. Soils containing materials at levels above background still may not adversely affect the groundwater. If there are any detected organic compounds or tritium, the designated level methodology (DLM) (i.e., application of a simple

attenuation factor and specific water quality objectives) is used to determine the soluble levels of contaminants that would not adversely impact groundwater beyond its beneficial uses. (Background and DLM de minimis values are presented in [Tables 10-3](#) and [10-4](#) in the Data Supplement.)

All analytical results for soluble VOCs were below detection limits. Unfortunately, detection limits were elevated for all compounds due to matrix interferences. All total metals concentrations were within site background. See [Tables 10-5](#) to [10-7](#) in the Data Supplement for analytical results for VOCs and metals. A PCB, Arochlor 1260, was detected at 2.1 mg/kg at location ESB. The presence of PCBs suggests that this sample represents residual low-level contamination from the 1984 excavation of the former East Traffic Circle landfill (see [Chapter 9](#)). The detected concentrations are below the federal and state hazardous waste limits. Tritium results from the sediment sampling were evaluated by the DLM method and were all below de minimis levels (see [Table 10-3](#)).



Site 300 Results

Table 10-4 presents data on the concentrations of uranium-235, uranium-238, and beryllium in soil from the Site 300 sampling locations; 2001 soils data for Site 300 for cesium-137, potassium-40, and thorium-232 are found in **Table 10-2** of the Data Supplement. The concentrations and the distributions of all observed radionuclides in Site 300 soil for 2001 lie within the ranges reported in all years since monitoring began. The

ratio of uranium-235 to uranium-238 generally reflects the natural ratio of 0.7%. There is significant uncertainty in calculating the ratio, however, due to the difficulty of measuring low activities of uranium-238 by gamma spectrometry. Historical trends of uranium-238 concentrations from both the Livermore Valley and Site 300 are shown in **Figure 10-5**. Median values have remained relatively constant for both places. The highest values at Site 300 result from the use of depleted uranium in explosive experiments.

Table 10-4. Uranium and beryllium concentration in Site 300 soil, 2001

Location identifier	Uranium-235 ^(a) μg/dry g	Uranium-238 ^(b) μg/dry g	Uranium-235 and Uranium 238 ratio	Beryllium mg/kg
3-801E-SO	0.020 ± 0.0092	1.5 ± 1.1	0.013 ± 0.011	0.8
3-801N-SO	0.036 ± 0.012	9.2 ± 0.22	0.0039 ± 0.0013	1.4
3-801W-SO	0.020 ± 0.0090	4.0 ± 0.79	0.0050 ± 0.0025	0.9
3-812N-SO	0.042 ± 0.0084	18 ± 2.0	0.0023 ± 0.00053	1.0
3-834W-SO	0.022 ± 0.012	1.7 ± 1.3	0.013 ± 0.012	1.4
3-851N-SO	0.029 ± 0.0092	2.6 ± 0.78	0.011 ± 0.0048	1.1
3-856N-SO	0.016 ± 0.0081	1.8 ± 1.1	0.0089 ± 0.0071	1.1
3-858S-SO	0.024 ± 0.012	2.0 ± 1.2	0.012 ± 0.0094	0.8
3-DSW-SO	0.019 ± 0.0074	2.3 ± 0.74	0.0083 ± 0.0042	0.8
3-EOBS-SO	0.019 ± 0.011	1.7 ± 0.99	0.011 ± 0.0090	1.1
3-EVAP-SO	0.024 ± 0.0095	4.0 ± 0.79	0.0060 ± 0.0027	0.7
3-GOLF-SO	0.020 ± 0.0089	1.6 ± 0.78	0.013 ± 0.0086	0.8
3-NPS-SO	0.023 ± 0.0092	2.0 ± 0.79	0.012 ± 0.0067	0.7
3-WOBS-SO	0.017 ± 0.01	1.8 ± 0.99	0.0094 ± 0.0076	0.8
Median	0.021	2.0	0.010	0.85
IQR ^(c)	0.0048	1.9	0.0054	0.3
Maximum	0.042	18	0.013	1.4

Note: Radioactivities are reported as the measured concentration and either an uncertainty ($\pm 2\sigma$ counting error) or as being less than or equal to the detection limit. If the concentration is less than or equal to the uncertainty or the detection limit, the result is considered to be a nondetection. See **Chapter 14**.

- a Uranium-235 activities can be determined by multiplying the mass concentration provided in the table in $\mu\text{g/dry g}$ by specific activity of uranium-235, i.e., 0.080 Bq/ μg , or 2.16 pCi/ μg .
- b Uranium-238 activities can be determined by multiplying the mass concentration provided in the table in $\mu\text{g/dry g}$ by specific activity of uranium-238, i.e., 0.01245 Bq/ μg , or 0.3367 pCi/ μg .
- c IQR = interquartile range

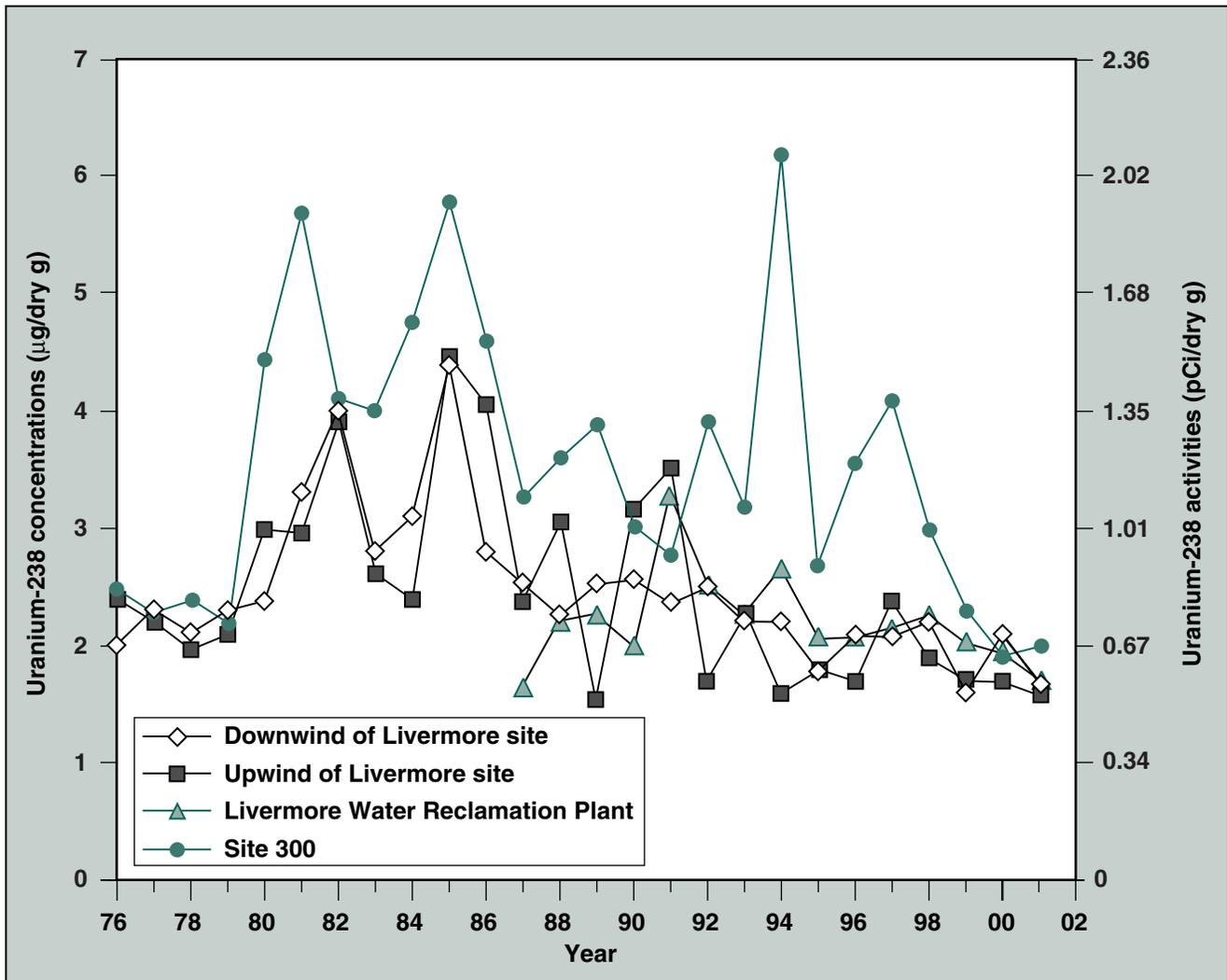


Figure 10-5. Median uranium-238 concentrations in surface soils, 1976–2001. Upwind and downwind designations are relative to the center of the Livermore site.

Environmental Impact

This section discusses the environmental impact of operations at the LLNL Livermore site and Site 300 inferred from soil, sediment, and vadose zone soil monitoring.

Livermore Site

Routine surface soil, sediment, and vadose zone soil sample analyses indicate that the impact of LLNL operations on these media in 2001 has not changed from previous years and remains insignificant. Most analytes of interest or concern were detected at background concentrations or in trace amounts, or could not be measured above detection limits.



The highest value of 6.5 mBq/dry g (0.18 pCi/dry g) for plutonium-239+240 measured at LWRP is 1.4% of the National Council on Radiation Protection (NCRP) recommended screening limit of 470 mBq/g (12.7 pCi/g) for property used for commercial purposes (NCRP 1999). Statistical analysis shows no general increase or decrease in plutonium-239+240 values with time.

Over the years, LLNL has frequently investigated the presence of radionuclides in local soils. Several of the studies are listed in [Table 10-5](#). LLNL sampling of surface soil, sediment, and vadose zone soil will continue on an annual basis.

Site 300

The concentrations of radionuclides and beryllium observed in soil samples collected at Site 300 are within the range of previous data and are generally

representative of background or naturally occurring levels. The uranium-235/uranium-238 ratios that are indicative of depleted uranium occur near active and inactive firing tables at Buildings 801 and 812. They represent a small fraction of the firing table operations that disperse depleted uranium. The uranium-238 concentrations are below the NCRP recommended screening level for commercial sites of 313 µg/g (3.9 Bq/g or 105 pCi/g).

Historically, some measured concentrations of uranium-238 near Building 812 have been greater than the screening level. The investigation and characterization planned for the area surrounding Building 812 will clarify the nature and extent of the contamination in the area. An investigation of the groundwater near Building 812 is in progress. The groundwater has been found to contain depleted uranium. For a further discussion of this investigation, see [Chapter 8](#).

Table 10-5. Special soil studies

Year	Subject	Reference
1971-1972	Radionuclides in Livermore Valley soil	Gudiksen et al. 1972; Gudiksen et al. 1973
1973	Radionuclides in San Joaquin Valley soil	Silver et al. 1974
1974	Soil study of southeast quadrant of Livermore site	Silver et al. 1975
1977	Sediments from LLNL to the San Francisco Bay	Silver et al. 1978
1980	Plutonium in soils downwind of the Livermore site	Toy et al. 1981
1990	195 samples taken in southeast quadrant for study	Gallegos et al. 1992
1991	Drainage channels and storm drains studied	Gallegos 1991
1993	EPA studies southeast quadrant	Gallegos et al. 1994
1993	Historic data reviewed	Gallegos 1993
1995	LLNL, EPA, and DHS sample soils at Big Trees Park	MacQueen 1995
1999	Summary of results of 1998 sampling at Big Trees Park	Gallegos et al. 1999
2000	Health Consultation, Lawrence Livermore National Laboratory, Big Trees Park 1998 Sampling	Agency for Toxic Substances Disease Registry 2000
2002	Livermore Big Trees Park:1998 Results	MacQueen et al. 2002

VEGETATION AND FOODSTUFF MONITORING

Introduction

Lawrence Livermore National Laboratory has a vegetation and foodstuff monitoring program to comply with U.S. Department of Energy (DOE) guidance. This guidance (U.S. DOE 1991) states that periodic sampling and analysis of vegetation should be performed to determine if there is measurable, long-term buildup of radionuclides in the terrestrial environment.

LLNL has historically released tritium to the air during routine operations and, occasionally, by accident. Tritium is the only nuclide of interest in the LLNL vegetation and foodstuff monitoring program because tritium is the only radionuclide released from LLNL activities that occurs in detectable concentrations in vegetation and foodstuff. Tritium moves through the food chain as tritiated water (HTO) and can be rapidly assimilated into plant water and then incorporated into the organic matter of plants through photosynthesis. It can contribute to human radiation dose if it is inhaled, absorbed through the skin, or ingested via vegetables or via milk and meat from animals that have eaten tritiated vegetation.

LLNL has been monitoring tritium in vegetation to some extent since 1966 and has performed vegetation sampling in the vicinity of the Livermore site and Site 300 as part of a continuing monitoring program since 1971. The monitoring program is designed to measure changes in the environmental levels of radioactivity, to evaluate

the environmental effect of LLNL operations, and to calculate potential human doses from tritium in the food chain.

In 1977, LLNL added wine to the LLNL monitoring program. Wine is the most important agricultural product in the Livermore Valley, with a retail value estimated conservatively at \$140 million. Although the tritium concentrations in all wines are very low, the sampling data indicate that Livermore Valley wines contain statistically more tritium than do wines from other California wine-producing regions.





In the past, other foodstuffs (cow milk, goat milk, and honey) leading to potential dose were also monitored for tritium. At present, however, only tritium concentrations in vegetation and wine are used to assess potential ingestion dose from tritium emitted during LLNL operations.

During 2001, LLNL collected and analyzed samples of herbaceous vegetation and wine. Potential human doses from these foodstuffs were calculated using the monitoring data, and the dose models are presented in Appendix A. In addition, as part of a continuing study, LLNL determined the potential tritium dose to the maximally exposed individual from a pine tree at the Livermore site. This tree serves as a diffuse source of tritium because it loses tritium to the air through evapotranspiration of tritium-contaminated water in the root zone. The dose was calculated using the U.S. Environmental Protection Agency (EPA) model CAP88-PC.

Methods

The methods used for monitoring vegetation and wine are presented in the following sections. All vegetation and wine sampling was conducted according to written and approved standardized procedures in the *Environmental Monitoring Plan* (Tate et al. 1999).

Vegetation

In 2001, LLNL staff collected vegetation samples, usually annual grasses or small herbaceous plants, quarterly from 18 fixed locations in the Livermore Valley, San Joaquin County, and Site 300. LLNL collected approximately 100 to 200 g of vegetation with relatively high water content for each analysis; a sample of equal size from the same location was also collected for archiving. Samples, delivered to LLNL's Chemistry and Materials Science Environmental Services Laboratory, were kept frozen prior

to processing. Water from the vegetation was collected using freeze-drying techniques (lyophilization), and the tritium concentration of the extracted water was determined by liquid scintillation counting.

Approximately 10% of the sites were sampled in duplicate to comply with quality assurance protocols. Duplicate samples were preserved, stored, processed, and analyzed with methods identical to those employed for all other samples.

Location maps are provided in [Figure 11-1](#) and [Figure 11-2](#). Sample locations were selected to represent vegetation from locations near LLNL that could be affected by LLNL operations, background locations where vegetation is unlikely to be affected by LLNL operations, and areas of known or suspected LLNL-induced contamination.

Prior to the start of 2001, sampling at locations PARK in the Livermore Valley and CARN, GEO, and GOLF at Site 300 was discontinued as unnecessary, given changes in LLNL operations over the past few years; all other sampling locations were the same as those in 2000.

The routine vegetation sampling locations are designated with permanent location markers. Consistent use of the same general sampling locations allows LLNL to determine trends in data and to monitor areas of concern more closely. Vegetation sampling locations chosen by LLNL are places where ample living vegetation is most likely found. Sampling locations are distant from buildings or other obstructions that can cause unusual patterns of airflow. Irrigated or shaded areas are also avoided. Practical considerations, such as ease of access and personnel safety, also affected selection of sampling locations.

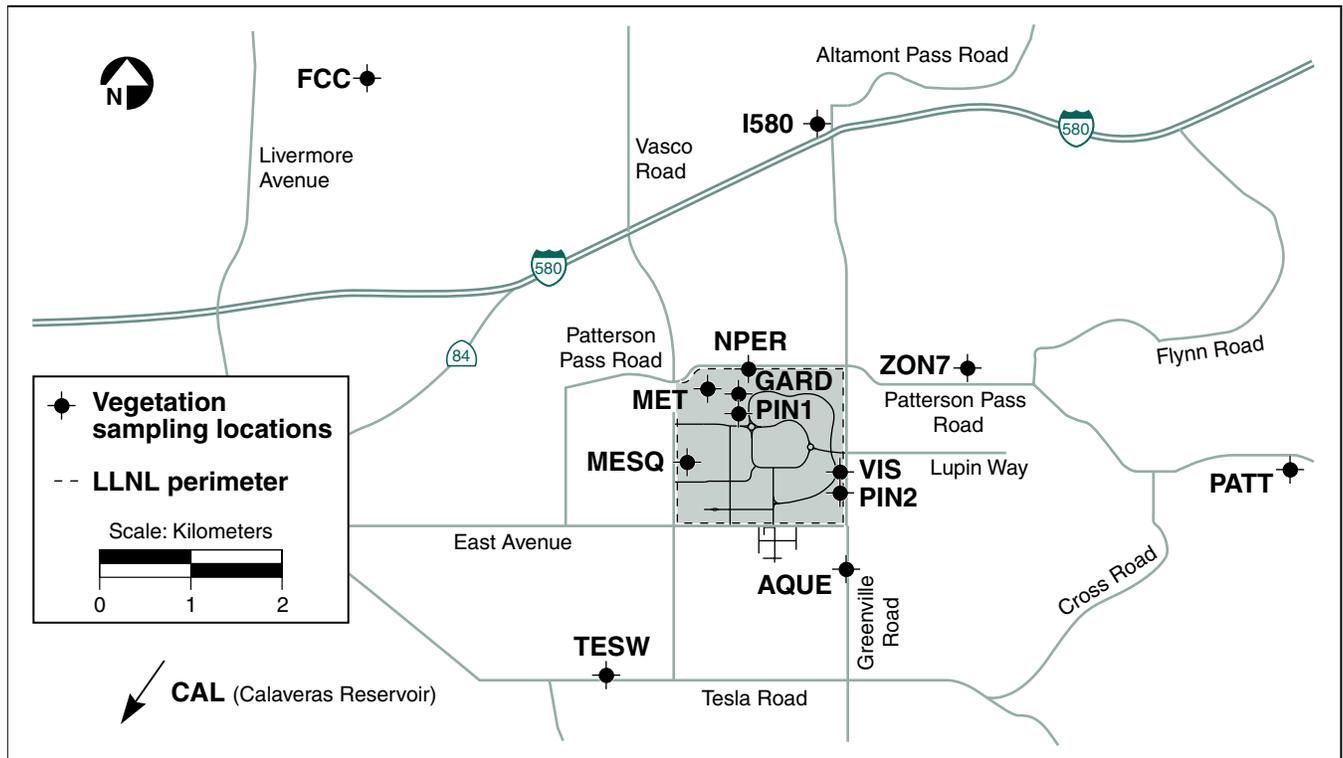


Figure 11-1. Livermore site and Livermore Valley vegetation sampling locations, 2001

Wine

In 2001, twelve bottles of wine from the Livermore Valley, six bottles of wine from different wine-growing regions of California (excluding Livermore), and four wines from different regions of Italy, France, and Germany were collected and analyzed for tritium. An equal mix of red and white wines was selected to represent each area. Any estate-bottled wine from a designated area was considered representative of that area.

Selection of wines from a particular wine-growing region was based primarily on availability in local stores. The wines were purchased from local retailers to represent what the general public could buy and drink during 2001. Approximately 10% of

the total complement of wines was sampled in duplicate to comply with quality assurance protocols.

LLNL analyzed wines for tritium using ^3He mass spectrometry in the Analytical and Nuclear Chemistry Division's Noble Gas Mass Spectrometry Laboratory, which is in the newly formed Environmental Radiochemistry Group. Using this highly sensitive method (Surano et al. 1992), the minimum detectable tritium concentration is about 0.056 Bq/L (1.5 pCi/L), well below measured concentrations in wine. With great care, a conventional scintillation detection system's sensitivity can reach about 1 Bq/L (27 pCi/L); this detection level, however, is not sensitive enough to detect small differences in wine samples.

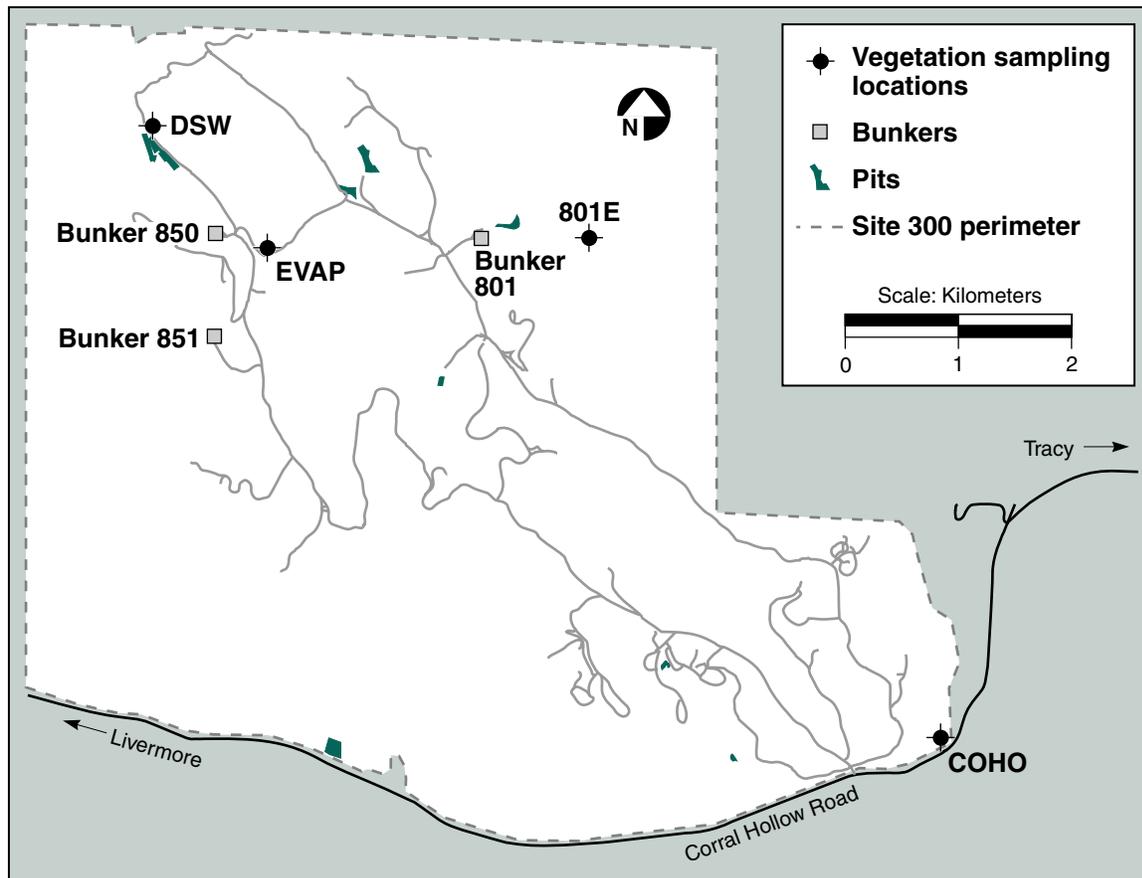


Figure 11-2. Site 300 vegetation sampling locations, 2001

Results

The results of vegetation monitoring for the Livermore site and Site 300 and the results of wine monitoring are presented in the following sections.

Livermore Site

Vegetation

The Livermore site and Livermore Valley vegetation locations are put into four groups for statistical evaluation:

- **Near:** locations within 1 km of the Livermore site perimeter. Near locations are AQUE, GARD, MESQ, NPER, MET, PIN2, and VIS.
- **Intermediate:** locations in the Livermore Valley 1–5 km from the Livermore site perimeter that are often downwind and, thus, potentially under the influence of tritium releases at the site. The Intermediate locations are I580, PATT, TESW, and ZON7.
- **Far:** locations unlikely to be affected by LLNL operations. One background location (CAL) is more than 25 km away. The other (FCC), although in the Livermore Valley, is unlikely to be affected by LLNL operations because it is more than 5 km from the Livermore site and generally upwind.

- **PIN1:** location of a pine tree rooted in an area of known tritium contamination on the Livermore site.

Table 11-2 shows tritium for all vegetation collected for the LLNL vegetation monitoring program in 2001. **Figure 11-3** shows the 2001 medians of the tritium concentrations for PIN1, Near, Intermediate, and Far Livermore locations as a continuation of historic median concentrations from 1971 to 2000.

For 1998 through 2000, the medians for the Far locations were negative. In the SAER figures for 1999 and 2000, the lowest positive value reported was used for plotting. This year it was decided that values far below the detection limit that vary considerably are meaningless and therefore will be arbitrarily given values of 1 Bq/L for plotting. This 1 Bq/L value is well below the lower limit of detection for tritium in vegetation.

For 2001, the data for tritium in vegetation were compared using Scheffé's *F* and Games/Howell multiple comparisons (Scheffé 1953; Games and Howell 1976). These tests are the most appropriate tests for these distributions of data. The Near group was found to be significantly different at the 5% level from the Far group, but not from the Intermediate group. The Intermediate group was also statistically different from the Far group.

There was significant overlap in the ranges of values for some of the Near and Intermediate locations. The highest tritium results for individual vegetation sampling locations were found at the Near location AQUE and at the Intermediate location I580. The small upturn in median values for the Near and Intermediate groups (**Figure 11-3**) is most likely caused by variability due to frequency of sampling.

In 1997, PIN1, a pine tree growing in a known area of tritium contamination at the Livermore site, was monitored on a monthly basis to estimate emissions for compliance with National Emissions Standards for Hazardous Air Pollutants (NESHAPs). In 1998, the tree sampling was coordinated with the quarterly vegetation sampling. NESHAPs dose calculations to the maximally exposed individual (MEI), now based on quarterly observations, assume the tree to be a diffuse source of tritium.

To assess the contribution of soil water tritium to PIN1, LLNL also sampled a second tree (PIN2), which is not growing in tritium-contaminated soil. Concentrations of tritium in PIN2, like in all other vegetation sampled near the Livermore site, are from air and soil water in quasi-equilibrium with air. When samples from PIN1 were compared with samples from each Near location for 2001 using Scheffé's *F* procedure, concentrations of tritium in PIN1 were found to be significantly higher than concentrations at all other locations, including PIN2, at the 5% significance level.

Wine

Data from the analysis of tritium in wine can be used to estimate the potential tritium dose received by consumers during the year of purchase. However, because wines purchased in 2001 represent vintage years 1997, 1998, 1999, and 2000, the 2001 sampling data cannot be used to indicate how LLNL's operations affected concentrations of tritium in wines produced from grapes grown in 2001. To analyze trends and help determine the impact of LLNL operations on tritium in wine for the year of harvest, LLNL corrects the wine concentrations for radiological decay that has occurred between the approximate date of the grape harvest and the date when the wine was analyzed in the laboratory. Comparisons can then be made of wine concentrations that represent the year when the grapes were exposed to the tritium.



Table 11-1. Concentrations of tritium in plant water (Bq/L) collected quarterly from various sampling locations, 2001

	First Quarter	Second Quarter	Third Quarter	Fourth Quarter	Median	IQR ^(a)	Dose (nSv/y) ^(b)	
							Median	Maximum
Sampling locations within 1 km of the Livermore site perimeter								
AQUE	2.3 ± 2.0	-1.6 ± 2.0	9.9 ± 2.4	3.0 ± 2.1	2.7	3.4	13	49
GARD	1.3 ± 1.9	-0.73 ± 2.1	-1.0 ± 2.0	4.1 ± 2.2	0.29	2.8	1.4	20
MESQ	0.60 ± 1.9	-1.7 ± 2.0	-1.5 ± 1.9	3.0 ± 1.5	-0.45	2.8	— ^(c)	15
MET	3.8 ± 2.0	3.2 ± 2.2	-0.42 ± 2.0	4.9 ± 2.2	3.5	1.8	17	24
NPER	3.3 ± 2.0	1.5 ± 2.2	2.1 ± 2.1	2.9 ± 2.1	2.5	1.1	12	16
PIN2	5.2 ± 2.1	4.9 ± 2.3	6.8 ± 2.3	5.0 ± 2.2	5.1	0.63	— ^(d)	— ^(d)
VIS	4.3 ± 2.0	5.7 ± 2.3	0.77 ± 2.0	5.3 ± 2.2	4.8	2.0	24	28
PIN1 ^(e)	61 ± 3.7	13 ± 2.6	170 ± 5.8	70 ± 4.0	66	46	0.0042 ^(f)	0.011 ^(f)
Sampling locations 1–5 km from the Livermore site perimeter								
I580	3.4 ± 2.0	-3.9 ± 1.9	14 ± 2.6	1.9 ± 2.1	2.6	5.6	13	69
PATT	1.4 ± 1.9	-0.64 ± 2.1	1.1 ± 2.1	-0.90 ± 2.0	0.23	1.9	1.1	6.9
TESW	3.2 ± 2.0	0.51 ± 2.1	1.0 ± 2.0	1.3 ± 2.0	1.1	0.89	5.4	16
ZON7	3.7 ± 2.0	0.045 ± 2.1	4.6 ± 2.2	2.4 ± 2.1	3	2.1	15	23
Sampling locations more than 5 km of the Livermore site perimeter								
CAL	1.3 ± 1.9	-0.66 ± 2.1	0.10 ± 2.0	0.0021 ± 2.0	0.051	0.56	0.25	6.4
FCC	1.0 ± 1.9	-1.7 ± 2.0	-0.37 ± 2.0	-0.80 ± 2.0	-0.59	1.0	— ^(c)	4.9
Sampling locations at Site 300								
COHO	1.5 ± 1.6	-2.1 ± 2.0	-0.076 ± 2.0	-1.2 ± 1.9	-0.64	1.7	— ^(c)	7.4
801E	0.78 ± 1.5	-2.3 ± 2.0	-1.0 ± 2.0	-0.30 ± 2.0	-0.65	1.3	— ^(c)	3.8
DSW ^(e)	120 ± 4.8	2700 ± 22	190 ± 6.1	0.85 ± 2.0	160	730	780	13000
EVAP ^(e)	3.2 ± 1.7	190 ± 6.2	460 ± 9.3	0.64 ± 2.0	97	250	480	2300

Note: Radioactivities are reported as the measured concentration and an uncertainty ($\pm 2\sigma$ counting error). If the concentration is less than or equal to the uncertainty, the result is considered to be a nondetection. See [Chapter 14](#).

a IQR = Interquartile range

b Ingestion dose is based on conservative assumptions that an adult's diet is exclusively vegetables with this tritium concentration, and that meat and milk are derived from livestock fed on grasses with the same concentration of tritium. See [Appendix A](#).

c Dose is not calculated when the median concentration is negative.

d Doses were not calculated because pine trees are not ingested by human beings. Concentrations from PIN2 are included with NEAR vegetation ([Figure 11-3](#)) because plant water tritium concentrations are similar among plant types.

e Plant(s) rooted in area of known subsurface contamination

f For this dose calculation, PIN1 is treated as a diffuse source of tritium (since pine needles are not eaten by human beings). Dose, calculated using CAP88-PC (see [Chapter 13](#)), is to the maximally exposed individual.

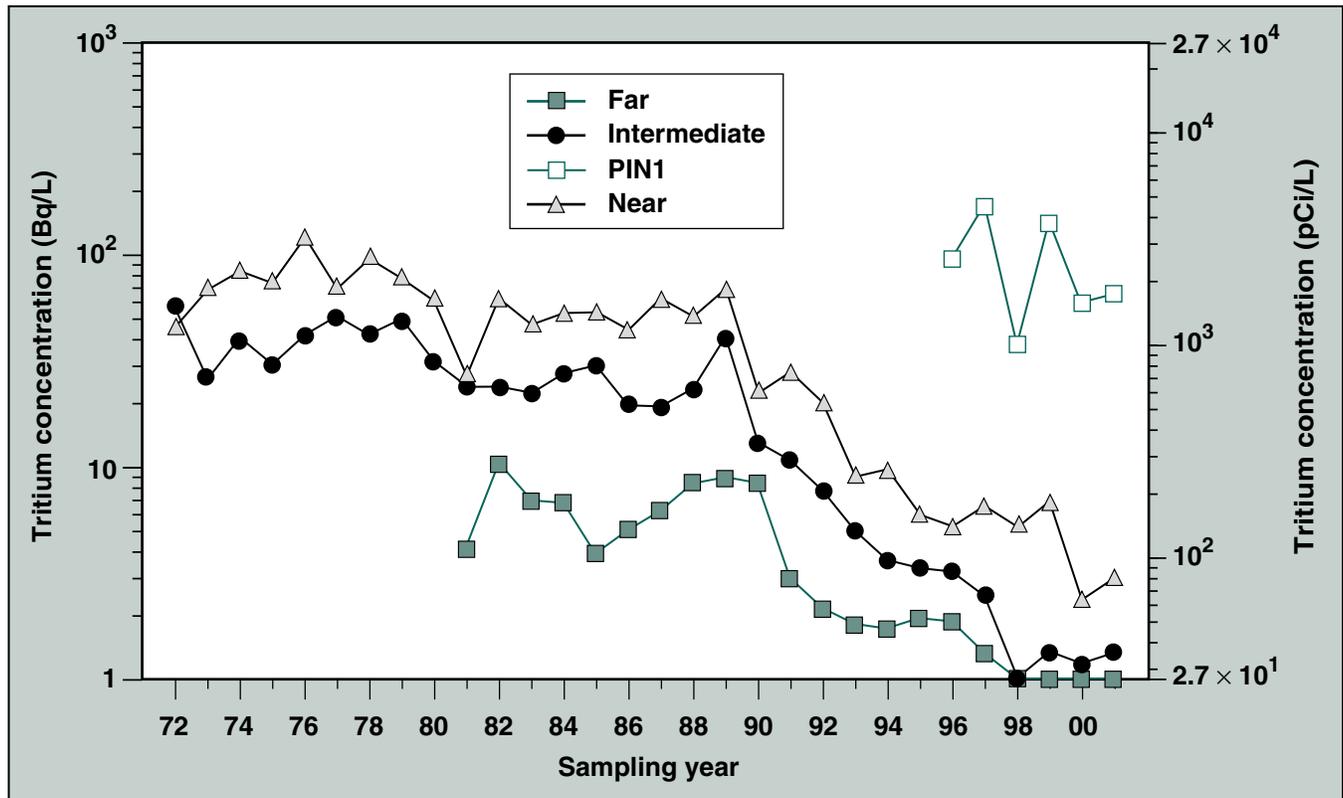


Figure 11-3. Median tritium concentrations in Livermore site and Livermore Valley plant water samples, 1971–2001. When median values are below detection limits, values are plotted arbitrarily as 1 Bq/L.

The results from the 2001 wine tritium analyses are shown in [Table 11-2](#). Tritium concentrations are within the range of those reported in previous years and remain low in wines from all areas. The data for the 2001 sampling year were analyzed using Scheffé's *F* and Games/Howell multiple comparisons. The results of the comparisons are the same as in previous years. Both analyses show that the tritium concentrations of Livermore Valley wines are higher than those of the six California wines at the 5% significance level. The Scheffé's *F* test, which can be used when the number of samples is fewer than six, also demonstrated that the California wines sampled have significantly lower tritium concentrations than the European

wines sampled and that tritium concentrations in European wine are statistically indistinguishable from tritium concentrations in Livermore Valley wines.

There is remarkably little variability in Livermore Valley wines collected for 2001, although the vintage years represented are 1997, 1998, 1999 and 2000.

Concentrations of tritium in wine corrected to vintage year are plotted in [Figure 11-4](#). The downward trend for Livermore Valley and California wines continues. Two peaks of concentration stand out in [Figure 11-4](#), one in 1989 and one in 1996.


Table 11-2. Tritium in retail wine (Bq/L), 2001^(a)

Sample	Area of production		
	Livermore Valley	California	Europe
1	0.95 ± 0.21	0.35 ± 0.19	0.76 ± 0.2
2	0.99 ± 0.21	0.40 ± 0.19	1.2 ± 0.22
3	1.0 ± 0.21	0.40 ± 0.19	1.2 ± 0.22
4	1.0 ± 0.21	0.42 ± 0.19	3.9 ± 0.44
5	1.4 ± 0.23	0.52 ± 0.19	
6	1.4 ± 0.23	0.53 ± 0.19	
7	1.6 ± 0.25		
8	1.7 ± 0.25		
9	1.9 ± 0.26		
10	2.4 ± 0.31		
11	2.6 ± 0.32		
12	2.6 ± 0.32		
Median	1.5	0.41	1.2
Interquartile range	1.0	0.095	0.79
Dose (nSv/y)^(b)			
Median concentration	1.3	0.37	1.1
Maximum concentration	2.3	0.48	3.5

Note: Radioactivities are reported here as the measured concentration and an uncertainty ($\pm 2\sigma$ counting error). If the concentration is less than or equal to the uncertainty, the result is considered to be a nondetection. See [Chapter 14](#).

a Wines from a variety of vintages were purchased and analyzed in 2001. The concentrations reported are those at the time the bottle was opened.

b This dose is calculated based on consumption of 52 L wine per year (see [Appendix A](#)).

Statistically, the concentrations in wines from 1989 are indistinguishable from those from 1988 and 1990. Concentrations of tritium in 1996 Livermore Valley wines are significantly higher than those from 1997, 1998, and 2000 but are indistinguishable from those of 1995 and 1999. As mentioned, wines are sampled randomly. Quite by chance, the 1996 wines unequally represent vineyards close to LLNL and therefore exhibited higher values.

Site 300

Vegetation

There are four monitoring locations for vegetation at Site 300 ([Figure 11-2](#)). Of these, 801E and COHO show changes in atmospheric tritium concentrations. Vegetation from locations DSW and EVAP grows in areas of known groundwater contamination.

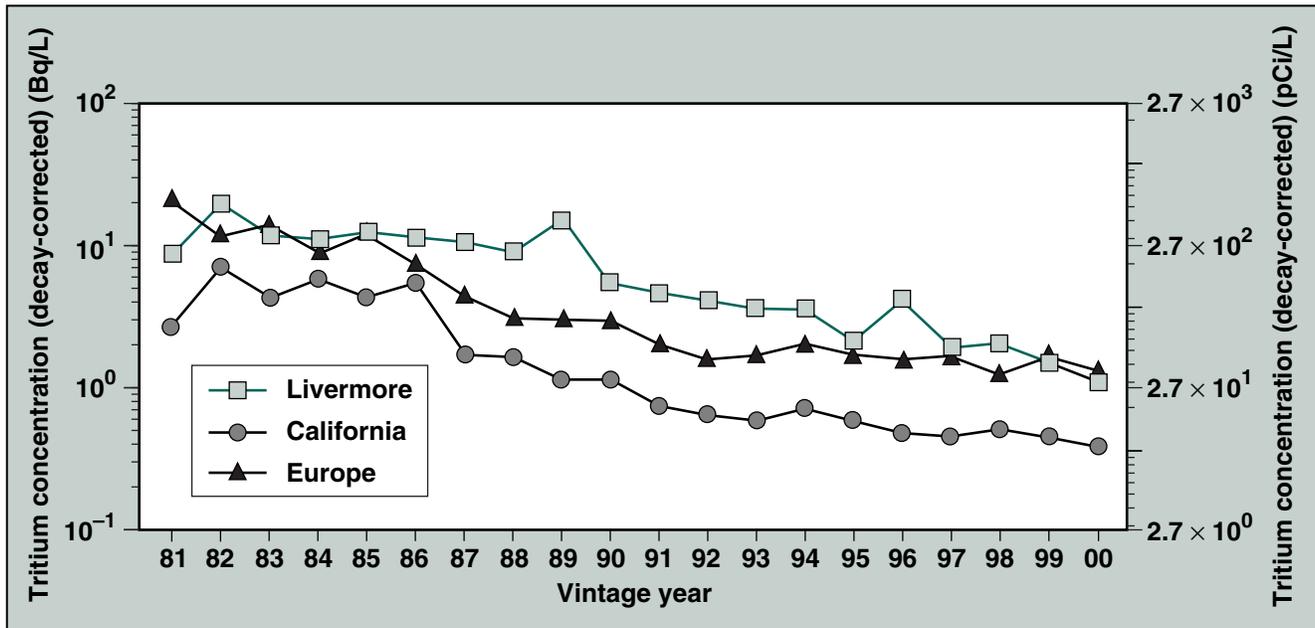


Figure 11-4. Median tritium concentrations in retail wines decay-corrected from the sampling year to the vintage year

Plants can take up tritiated water from two sources: air moisture and soil moisture. When a plant's soil water is contaminated with tritium, and there is little tritium in the air moisture, the tritium concentrations in the plant water will be somewhat lower than those of soil water, but will be much higher than concentrations in air moisture.

Table 11-1 shows all tritium data for vegetation collected at Site 300 during 2001. Historic median values for tritium at Site 300 sampling locations are shown in **Figure 11-5**. Results from 801E and COHO for 2001 were all below detection limits. Locations EVAP and DSW yielded the most results above detection limits. EVAP's median tritium concentration is somewhat higher than that of 2000. DSW's median value is the highest it has been in 15 years; this result is probably an artifact caused by the small sample size, because tritium concentrations in groundwater at Pit 5 are dropping. As shown in **Figure 11-3**, median

concentrations below 1 Bq/L (well below the limits of detection) are assumed equal to 1 Bq/L to avoid plotting large, meaningless differences.

The highest tritium result (2700 Bq/L, about twice the maximum in 2000) for a single vegetation sample occurred at location DSW (see **Table 11-1**). This sampling location is adjacent to a landfill area that contains debris contaminated with tritium from past experiments. Tritium concentrations in vegetation are also above background levels at location EVAP, which is near a spring where groundwater flows near the surface and evaporates. Groundwater near EVAP is contaminated with tritium from Pit 3, Pit 5, and the firing table at Building 850. The DSW and EVAP locations are both within the East and West Firing Area (EFA/WFA) and the Study Area of the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) environmental restoration study areas (see **Chapter 8**).

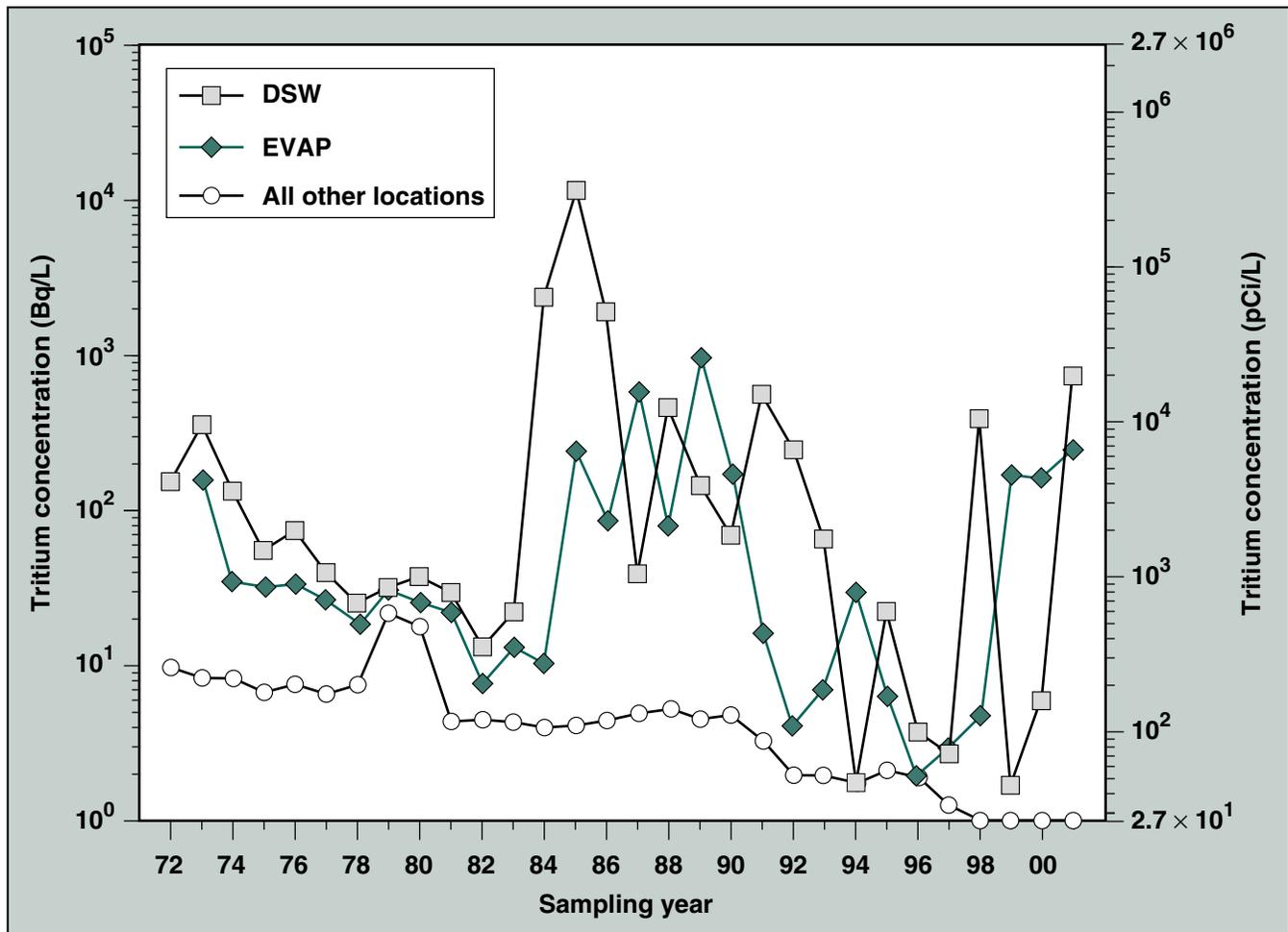


Figure 11-5. Median tritium concentrations in plant water at Site 300 sampling locations, 1971–2001. When the median values are below detection limits, values are plotted arbitrarily as 1 Bq/L.

Relatively high concentrations of tritium in plants at DSW and EVAP are observed only sporadically when the roots of the vegetation come in contact with contaminated groundwater. Evaluation of the 2001 data for Site 300 using Scheffé's *F* procedure yielded no significant difference between 801E, COHO, and EVAP, a result of the high variability of the data and the low number of data points. However, DWS was determined to be different from 801E and COHO at the 5% significance level.

Environmental Impact

In 2001, the environmental impacts of LLNL operations on vegetation and wine, presented below, were small.

Livermore Site Vegetation

LLNL impacts on vegetation in the Livermore Valley remained minimal in 2001. The effective dose equivalents, shown in [Table 11-1](#), were

derived using the dose conversion factor (1.73×10^{-11} Sv/Bq) provided by DOE (U.S. DOE 1988) and the dose pathway model from U.S. Nuclear Regulatory Commission (NRC) Regulatory Guide 1.109 (U.S. NRC 1977). [Appendix A](#) provides a detailed discussion of dose calculation methods. The dose from ingested tritium is based on the conservative assumptions that an adult's diet ([Table A-1, NRC maximum](#)) consists exclusively of leafy vegetables with the measured tritium concentrations, as well as meat and milk from livestock fed on grasses with the same concentrations. In actuality, the vegetables consumed by an adult contain tritium at lower levels than those reported because most vegetables are imported from other areas. Similarly, tritium concentrations in food consumed by local livestock are at or below the concentrations in vegetation measured at the Intermediate and the Far locations. Nevertheless, based on these extremely conservative assumptions, the maximum potential dose from ingestion of vegetables, milk, and meat for 2001 for the Livermore Valley is 69 nSv/y (0.069 μ Sv or 0.0069 mrem).

Doses are calculated based on measured tritium in plant water without considering the contribution of organically bound tritium (OBT). Dose conversion factors of 1.8×10^{-11} Sv/Bq for tritium in the plant or animal water (HTO) and 4.2×10^{-11} Sv/Bq for OBT have been established by the International Commission on Radiological Protection (ICRP 1996). These conversion factors show the relative importance of ingested HTO and OBT to dose.

When vegetables are ingested, the dose from the HTO contribution is greater than the dose from the OBT contribution because the fraction of the vegetable that is organic matter is quite small (10–25%). For example, about 10% of the ingestion dose from leafy vegetables (about 10% dry matter) is contributed by OBT. OBT becomes

increasingly important to dose when the fraction of dry matter increases. Pork, for example, has a dry-matter content of about 30–50% (Ciba-Geigy Ltd. 1981), and the resulting ingestion dose from pork is about half from OBT and half from HTO. The OBT in grain, which is 88% dry matter, contributes nearly 90% of the dose from ingested grain.

Given the different fractions of OBT in different foods, the importance of OBT to ingestion dose depends on what quantities of what kinds of foods are consumed. Accounting for a diet extremely high in OBT and for the relative biological effectiveness of the tritium beta possibly being greater than 1.0 would, at most, give an OBT contribution to dose twice that of HTO (U.S. Department of Health and Human Services 2001). Thus, conservatively, the maximum total tritium dose from ingestion of vegetables, milk, and meat from the Livermore Valley for 2001 cannot exceed 210 nSv (0.21 μ Sv or 0.021 mrem), which is well below any level of concern.

The dose values for PIN1 (shown in [Table 11-1](#)) were calculated in a different manner from those for edible vegetation because it is unreasonable to assume that any person is directly ingesting pine needles. The pine tree is treated as a diffuse source of tritium to the atmosphere via the contaminated transpirational stream. LLNL used an estimated tritium transpiration rate from the tree to estimate the Ci/y used as the source input to the EPA regulatory model CAP88-PC. LLNL modeled air dispersion of the transpired tritium and calculated a resulting dose from inhalation, skin absorption, and potential ingestion from air concentrations at the location of the maximally exposed individual. This total dose is based on the conservative assumptions that 100% of the individual's time is spent at this location and that his/her diet consists exclusively of foods having the same tritium to hydrogen ratio as occurred in air moisture. The



resulting maximum dose for PIN1 of 0.011 nSv/y (1.1×10^{-5} μ Sv or 1.1×10^{-6} mrem) is considerably lower than ingestion doses calculated directly from measured concentrations in vegetation because the tree is only an indirect source of air/vegetation contamination.

Livermore Site Wine

No health standards exist for radionuclides in wine. However, all the wine tritium levels were far below drinking water standards. In fact, even the highest detected Livermore Valley value (2.6 Bq/L or 70 pCi/L) represents only 0.35% of the California drinking water standard (740 Bq/L or 20,000 pCi/L). Doses from wine consumption can be calculated according to methods for water ingestion, as described in [Appendix A](#).

Based on the conservative assumption that wine is consumed at the same rate as the average consumption of water (370 L/year or about 1 L/day), the annual dose that corresponds to the highest detected 2001 Livermore Valley tritium value in wine is 17 nSv (1.7 μ rem). Assuming a more realistic, yet high,¹ average wine consumption (52 L/year or 1 L/week), and the median tritium values from the three sampling areas, the annual doses from Livermore, European, and California wines would be 1.3 nSv (0.13 μ rem), 1.1 nSv (0.11 μ rem), and 0.37 nSv (0.037 μ rem), respectively.

Summary

Very low concentrations of tritium may be found in foodstuffs grown near the Livermore site as a result of LLNL operations. A potential ingestion dose for 2001 that accounts for contributions from HTO

and OBT in vegetables, milk, meat, and wine will realistically be less than 210 nSv (0.21 μ Sv or 0.021 mrem). This estimate is as high or higher than dose estimates calculated using other assumptions (see [Appendix A](#)). This estimate is a factor of 15,000 lower than an annual background dose (\sim 3000 μ Sv or 300 mrem) and a factor of 500 lower than the dose from a typical chest x-ray (100 μ Sv or 10 mrem) (Shleien and Terpilak 1984). Therefore, although tritium levels are slightly elevated near the Livermore site, doses from tritium ingestion are negligible.

Site 300

In general, LLNL impacts on tritium concentrations in vegetation at Site 300 for 2001 were insignificant. With the exception of vegetation from previously identified sites of contamination, the tritium levels at Site 300 were below the limits of detection and comparable to those observed in previous years. The areas where tritium is known to be present in the subsurface soil are well delineated and localized.

The calculated maximum potential annual ingestion dose from vegetation at sampling location DWS, based on the maximum value of 2700 Bq/L (73,000 pCi/L), is 13 μ Sv (1.3 mrem). This dose, based on the conservative modeling assumptions described above, is theoretical—but nevertheless small—because vegetation at Site 300 is not ingested either by people or by livestock.

1. The California Wine Institute, December 2001, states that the average consumption of wine in the United States is 2.01 gal/y (7.6 L/y).

ENVIRONMENTAL RADIATION MONITORING

Introduction

In accordance with federal regulations and applicable portions of Department of Energy (DOE) Orders 5400.1 and 5400.5, Lawrence Livermore National Laboratory monitors the natural background gamma radiation to establish radiation levels in its vicinity and to determine the environmental radiological impact of its operations. Gamma radiation in the environment primarily occurs naturally from terrestrial and cosmic sources. Because environmental radiological monitoring is used as one measure of the potential radiation dose that the public may receive as the result of LLNL operations, LLNL has developed an extensive radiological monitoring network for the Livermore site perimeter, Site 300 perimeter, and off-site locations. Gamma radiation has been measured at the Livermore site since 1973 and at Site 300 since 1988. The absorbed gamma radiation dose imparted to thermoluminescent dosimeters (TLDs) is the result of TLD exposure from both terrestrial and cosmic radiation sources as well as LLNL sources, if any.

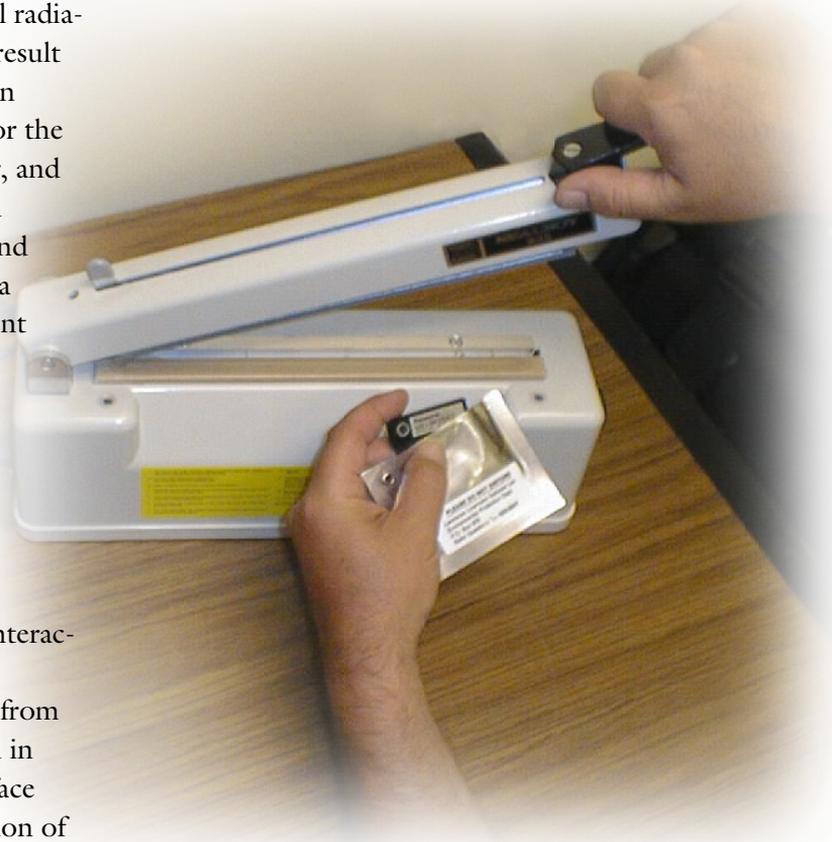
Cosmic Radiation Component

Gamma radiation in air is produced by the interaction of cosmic rays. Cosmic rays consist of high-energy particles and emanate primarily from beyond the solar system. Radiation observed in the lower atmosphere and at the earth's surface are secondary radiations formed in the reaction of

these high-energy particles with nuclei in the upper atmosphere. The cosmic radiation component accounts for about half the observed site annual average gamma radiation.

Terrestrial Radiation Component

Terrestrial gamma radiation is caused by naturally occurring isotopes of the uranium (uranium-238 parent), thorium (thorium-232 parent), and actinium (uranium-235 parent) decay series that are present in soil worldwide and that produce





gamma radiation during radioactive decay. The concentration of naturally occurring radionuclides in soil is variable and is determined by the ratio of thorium-232 to uranium-238 (present in these regions at the time of the earth's formation over four billion years ago), which ranges from 3 to 4 around the world. By characterizing the natural background radiation, LLNL can determine whether or not there is a contribution to gamma exposure from Laboratory operations.

General Methods

LLNL deploys TLDs in the field to assess the environmental impact of laboratory operations at both the Livermore site and Site 300. This assessment is done by comparing the gamma radiation data acquired from the Livermore perimeter site locations to various locations monitored in the Livermore Valley, and gamma radiation data from Site 300 perimeter locations to locations in the City of Tracy and near Site 300.

As previously mentioned, the variability of the naturally occurring radioisotopes present in the soil caused by geological formations is the largest contributor to variations in measurements. Meteorological conditions contribute to seasonal variability, as does cosmic variation.

LLNL deploys TLDs at the beginning of each quarter of the year and retrieves them from the monitoring locations as near to the end of the quarter as possible in order to have a 90-day exposure period. All data are normalized to a 90-day standard quarter basis in order to make valid comparisons for the measurement period.

Details of the TLD calculations are described in an Operations and Regulatory Affairs Division (ORAD) procedure. Reporting of external gamma radiation dose can be found in [Chapter 14](#) of the Data Supplement.

Monitoring Locations

In 2001, external doses from gamma radiation were monitored at 14 Livermore site perimeter locations (shown in [Figure 12-1](#)) and at 22 Livermore Valley locations ([Figure 12-2](#)), which are used for background comparison to perimeter location data. Similarly, gamma doses are monitored at 9 perimeter monitoring locations at Site 300 ([Figure 12-3](#)). In addition to the perimeter locations historically measured at Site 300, the 4 interior locations deployed in 2000 are being maintained. These site locations are depicted in [Figure 12-3](#). Additionally, 2 off-site locations near Site 300 and 2 locations in nearby Tracy are also monitored for comparison to the Site 300 data. Summary dose calculations for all gamma-monitoring locations are presented in [Table 12-1](#).

Results of Gamma Monitoring

[Figure 12-4](#) shows gamma doses for the Livermore site perimeter, Livermore Valley, and Site 300 from 1988 through 2001. Beginning in 1995, all quarterly gamma radiation data points were normalized to 90-day standard quarters, as is the practice of the Nuclear Regulatory Commission (NRC) (Struckmeyer 1994). Correcting the data by this method normalizes the data for comparison and reduces the data variability caused by field duration.

Livermore Site

[Table 12-1](#) presents a summary of the quarterly and annual TLD gamma radiation dose equivalents for the Livermore site perimeter locations and Livermore Valley off-site locations. The annual 2001 dose equivalent from external radiation exposure at the Livermore site perimeter, 0.560 ± 0.002 mSv, is statistically the same as the background external dose measured in the Livermore Valley, 0.557 ± 0.003 mSv. The

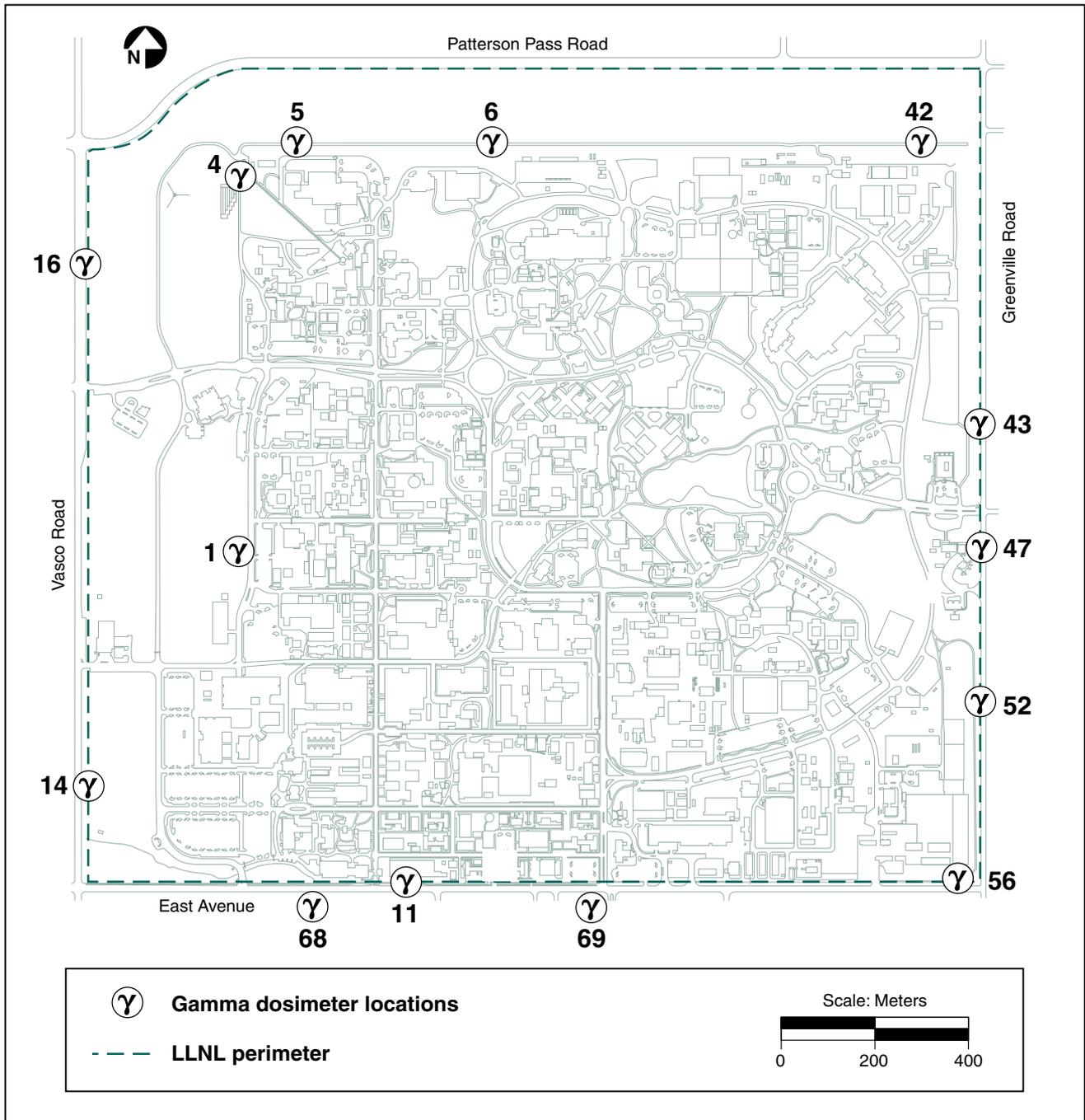


Figure 12-1. Gamma dosimeter locations, Livermore site, 2001

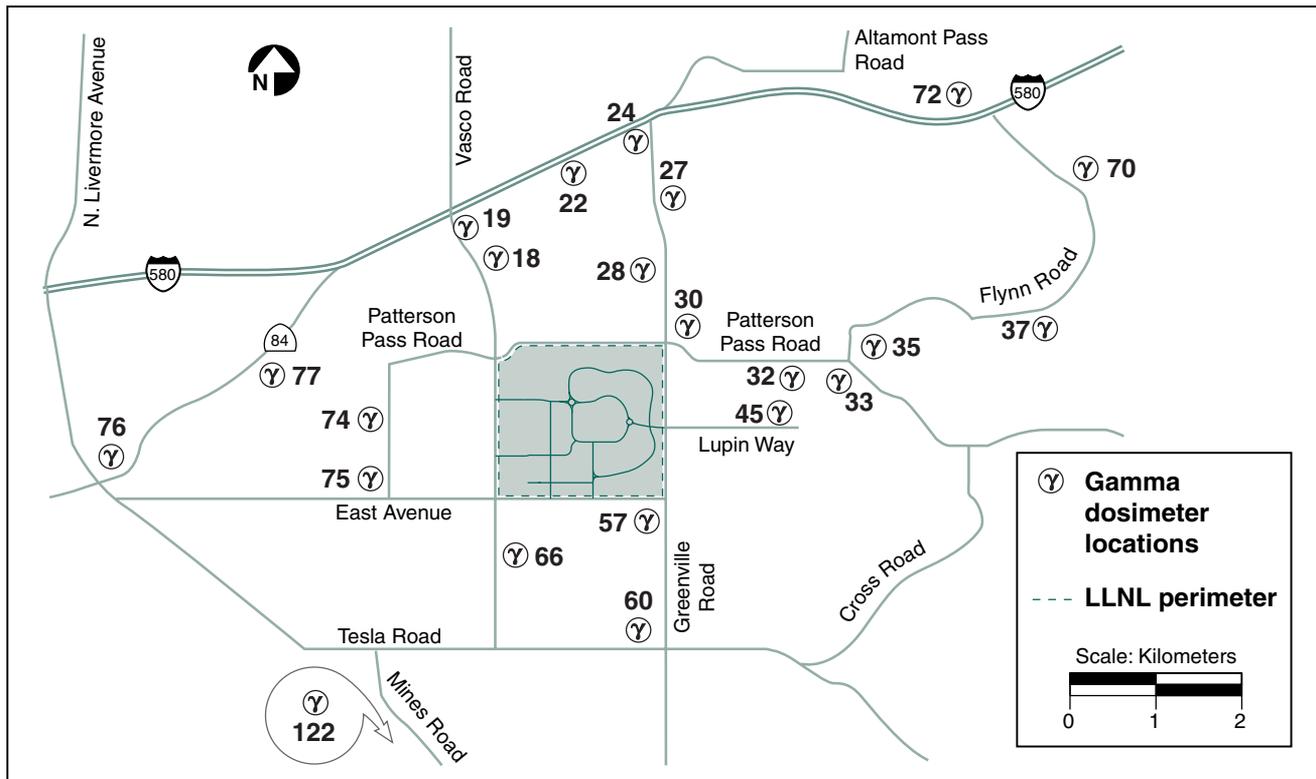


Figure 12-2. Gamma dosimeter locations, Livermore Valley, 2001

independent quarterly means that produce the annual sum for the site perimeter and the Livermore Valley are reported in Table 12-2 of the Data Supplement. All doses fall within the predicted range for background radiation, and no LLNL operational impacts are discernible.

Site 300

As seen in Table 12-1, the measured Site 300 perimeter annual average dose in 2001 was 0.629 ± 0.008 mSv. The measured dose at the off-site locations near Site 300 was 0.663 ± 0.005 mSv. Historically, the off-site dose near Site 300, though slightly higher, is statistically equivalent to the on-site measured dose. The annual off-site dose reported this year is represented by only one complete data set in the first quarter. Locations 94

and 96 were removed in the second quarter because of potential liability issues associated with their location on private property. The annual dose measured for Tracy was 0.581 ± 0.008 mSv and is lower than the annual dose for 2000. All doses are within the predicted range for background radiation, and no LLNL operational impacts are discernible.

The region around Site 300 has higher levels of naturally occurring uranium present in the local geological area called the Neroly Formation. The off-site locations have historically represented the high end of background radiation due to this geological substrate. This area is underlain by a geological substrate composed of alluvial deposits

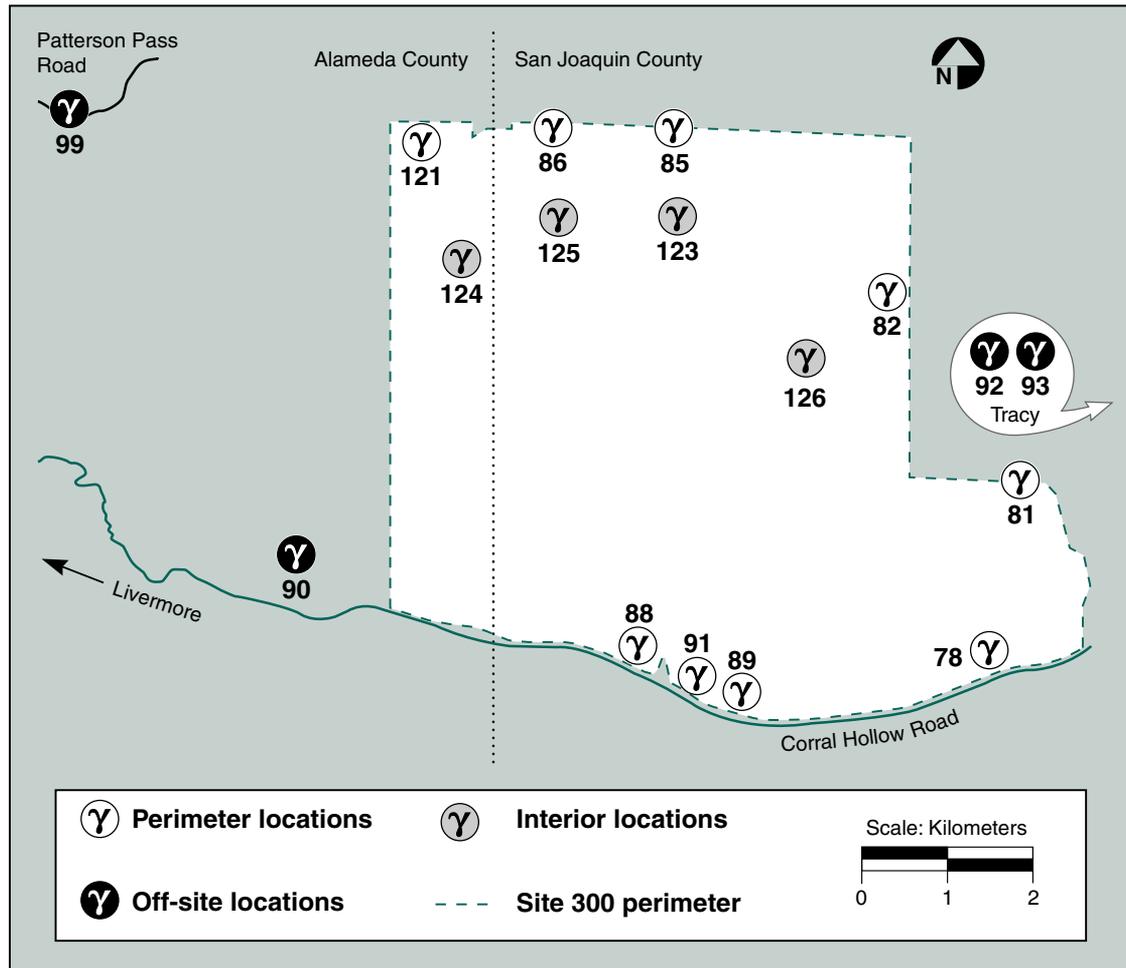


Figure 12-3. Gamma dosimeter locations, Site 300 and vicinity, 2001

of clays, sands, and silts overlying bedrock. The difference in the doses can be directly attributed to the difference in geologic substrates.

Fourteen years of annual average doses at the Livermore site perimeter are listed in [Table 12-2](#) from 1988 to 2001. However, while Site 300 doses are comparable to the Livermore site perimeter and Livermore Valley doses, TLD data collected at Site 300 continue to indicate slightly higher gamma doses, as expected, given the differences in geology among these site substrates.

Environmental Impact

Although the sun cycle may cause the contribution of cosmic radiation to vary, the sum of the measured terrestrial and cosmic radiation dose has been observed to range from 0.55 to 0.60 mSv/y as reported in [Table 12-2](#). In addition, variability due to the local geology and meteorology will also affect this range slightly. Direct radiation doses measured at the Livermore site perimeter in 2001 are near these predicted values and are statistically equivalent to the Livermore Valley doses, which are considered to be natural background levels.

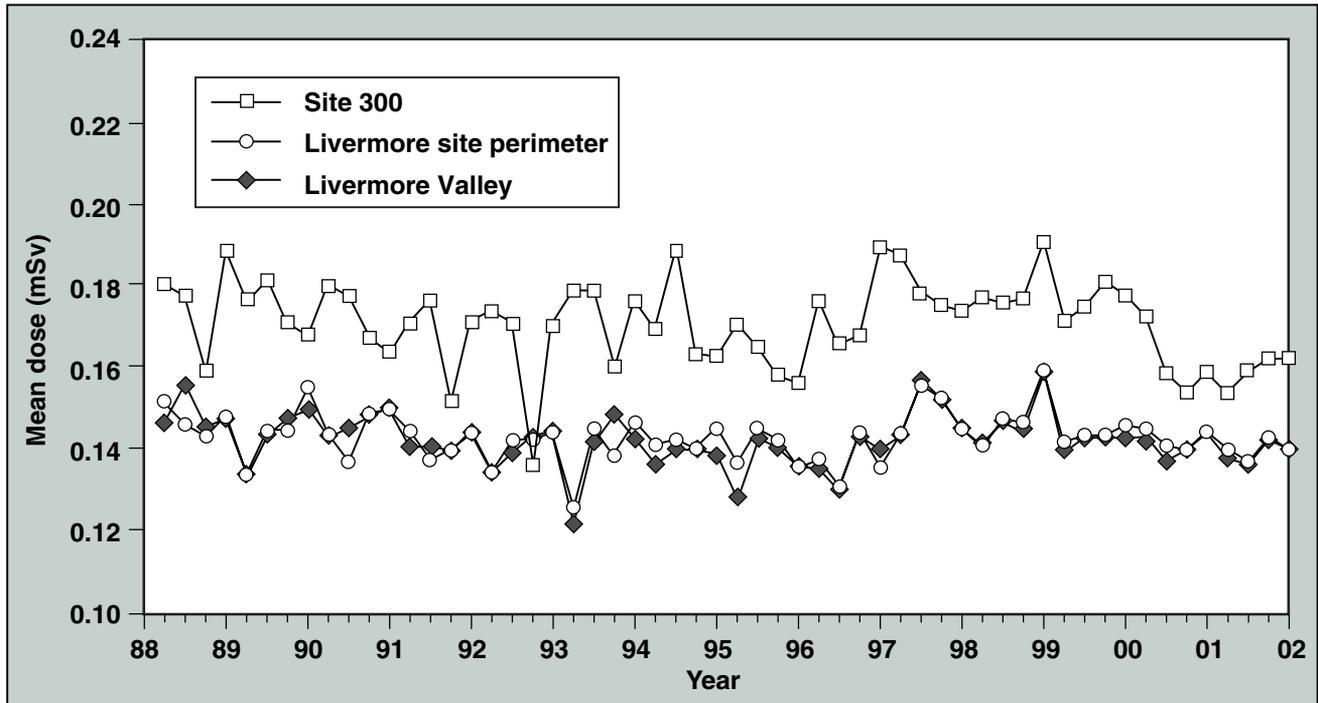


Figure 12-4. Quarterly mean gamma dose measurements at the Livermore site perimeter, Livermore Valley, and Site 300, 1988–2001

Table 12-1. Summary of dose calculations for gamma-monitoring locations (mSv)^(a) at all LLNL sites, 2001

Quarter	Location				
	Livermore site	Livermore Valley	Site 300	Tracy	Near Site 300
	Mean 2 SE ^(b)				
First	0.140 ± 0.012	0.138 ± 0.010	0.154 ± 0.014	0.155 ± 0.048	0.172 ± 0.052
Second	0.137 ± 0.012	0.136 ± 0.016	0.159 ± 0.020	0.134 ± 0.036	0.163 ± 0.066
Third	0.143 ± 0.012	0.142 ± 0.014	0.162 ± 0.016	0.154 ± 0.024	0.173 ± 0.076
Fourth	0.140 ± 0.012	0.141 ± 0.012	0.162 ± 0.020	0.145 ± 0.024	0.163 ± 0.046
Annual dose	0.560 ± 0.002	0.557 ± 0.002	0.637 ± 0.003	0.588 ± 0.009	0.671 ± 0.005

a 1 mSv = 100 mrem

b SE = Standard Error (standard deviation of the mean)

Table 12-2. Annual dose by year at the Livermore site perimeter caused by direct gamma radiation. (a)

Year	mSv	mrem
1988	0.59	59
1989	0.58	58
1990	0.58	58
1991	0.56	56
1992	0.56	56
1993	0.57	57
1994	0.56	56
1995	0.56	56
1996	0.55	55
1997	0.59	59
1998	0.60	60
1999	0.58	58
2000	0.57	57
2001	0.56	56

a Data normalized to standard 90 days per quarter (360 days per year).

Although measured gamma exposure at Site 300 and the local vicinity are slightly higher than reported for the Livermore site and Livermore Valley, their range is attributed primarily to the variation of the geological substrate containing radionuclides of natural origin. The measured annual gamma radiation at LLNL monitoring sites does not exceed average natural background exposure levels.

RADIOLOGICAL DOSE ASSESSMENT

*Robert J. Harrach
Gretchen M. Gallegos
S. Ring Peterson*

Introduction

Radiological doses to the public result from both natural and man-made radiation. The doses received by individuals and populations can be determined by measurements and calculations. This chapter describes Lawrence Livermore National Laboratory's radiological dose assessments, which are made to determine the impact of LLNL operations on the public and the environment. It includes a discussion of the analyses performed to demonstrate LLNL's compliance with the radiological *National Emission Standards for Hazardous Air Pollutants* (NESHAPs; Title 40 Code of Federal Regulations [CFR], Part 61, Subpart H).

Background Information

Because this chapter is written for a diverse readership, ranging from scientists and regulators to interested citizens with limited scientific training, a description is given of concepts, methods, tools, and other basic material in the first few sections as well as in Appendix D. [Part D-1, "Radiation Basics,"](#) covers the different sources and types of radiation and the units used to quantify radiation, and it provides perspective on the wide range of radiation levels that people commonly encounter. [Part D-2, "Radiation Control Measures at LLNL,"](#) sketches the standard operating procedures used to protect employees, the public, and the environment from uncontrolled releases and unsafe levels of radiation.

A discussion of sources, principal public receptors, and other aspects of modeling and monitoring follows the introductory material in the main text, leading to a presentation of key results on dose impacts from operations conducted in 2001. Readers desiring to go directly to these principal new results can turn to the section "[Results of 2001 Radiological Dose Assessment](#)".



Marie Curie



Releases of Radioactivity to Air

Releases of radioactive material to air (for example, in the form of air effluent dispersed from stacks or wind-driven resuspension of contaminated soil) are by far the major source of public radiological exposures from LLNL operations.

In contrast, releases to groundwater, surface water, and sewerable water are not sources of direct public exposures because these waters are not directly consumed or used by the public. Water releases can cause indirect exposures, which are analyzed as special cases. A recent case of this type concerned the potential dose to the public from inhalation and ingestion of soil that had been contaminated by sewer effluent containing radioactivity (U.S. Department of Health and Human Services 1999). Apart from such unusual occurrences, measurements and modeling of radiological releases to air determine LLNL's dose to the public.

Data supporting LLNL's radiological dose assessment are gathered by three principal means: continuous monitoring of stack effluent at selected facilities at the Livermore site (described in [Chapter 4](#)); routine surveillance air monitoring for radioactive particles and gases, both on and off Laboratory property (described in [Chapter 5](#)); and radioactive material usage inventories (described in LLNL's NESHAPs annual reports). The inventories cover noncontinuously monitored or unmonitored facilities housing radioactive materials management areas, and the explosive experiments conducted at Site 300.

Despite this emphasis on air monitoring, it should be noted that LLNL's extensive environmental monitoring program encompasses a variety of media and a wide range of potential contaminants; it is not limited to radioactive ones. In addition to ambient and effluent air monitoring and the three

categories of water monitoring already mentioned, the Laboratory samples soil, vegetation, and wine, and measures environmental (gamma) radiation.

Monitoring has been described extensively since 1971 in LLNL's environmental reports (e.g., Biermann et al. 2001; see also [Chapters 4](#) through [12](#) in the present report) and in LLNL's triennially updated *Environmental Monitoring Plan* (Tate et al. 1999) and its companion volume on procedures and guidance documents.

Air Dispersion and Dose Models

Theoretical/calculational models are needed to describe the transport and dispersion in air of contaminants and the doses received by exposed persons. Various factors dictate this need for modeling: (1) the amounts of LLNL-generated radioactive material dispersed into the atmosphere cause doses thousands of times smaller than those caused by natural background radiation (arising from irradiation by cosmic rays, inhalation of radon gas, exposure to radioactive materials in soil and rock, and ingestion of naturally occurring radionuclides present in our food and water; see [Appendix D, Part D-1](#)), so it is difficult to demonstrate compliance with standards through physical measurements alone; (2) all potentially significant exposure pathways need to be taken into account when estimating dose impacts; and (3) the U.S. Department of Energy (DOE) and the U.S. Environmental Protection Agency (EPA) sanction the use of specific computer codes that implement their approved dosimetry and dispersion models for evaluating potential doses to the public from both routine and unplanned releases. Beyond its role in dose assessment for regulatory compliance, advantages of a well-developed modeling capability include its utility in source design and optimization by estimating effects of hypothetical and/or dangerous sources and in interpreting past events through dose reconstruction.

The computer programs used at LLNL to model air releases and their impacts feature idealized, Gaussian-shaped plumes and can be run on personal computers. The CAP88-PC code incorporates dosimetric and health effects data and equations that are mandated by EPA to be used in compliance assessments (Parks 1992). Furthermore, CAP88-PC accommodates site-specific input data files to characterize meteorological conditions and population distributions for both individual and collective dose evaluations, and the code is relatively easy to use and understand. For these reasons, CAP88-PC has been the “work-horse” modeling tool for LLNL’s regulatory compliance assessments since its availability in March 1992, particularly as applied to chronic releases of radioactivity to air occurring in the course of routine operations.

Radiation Protection Standards

The release of radionuclides from operations at LLNL and the resultant radiological impact to the public are regulated by both DOE and EPA.

DOE environmental radiation protection standards, provided under the authority of the Atomic Energy Act of 1954 and the DOE Organization Act of 1977 (both as amended), are defined in DOE Order 5400.5, *Radiation Protection of the Public and the Environment*. The standards for controlling exposures to the public from operations at DOE facilities that are incorporated in this order are based on recommendations by the International Commission on Radiological Protection (ICRP). The radiological impact to the public is assessed in accordance with the applicable portions of DOE Order 5400.1, *General Environmental Protection*.

The primary DOE radiation standards for protection of the public are 1 millisievert per year (1 mSv/y) or 100 millirem per year (100 mrem/y)

whole-body effective dose equivalent (EDE) for prolonged exposure of a maximally exposed individual in an uncontrolled area and 5 mSv/y (500 mrem/y) EDE for occasional exposure of this individual. (EDEs and other technical terms are discussed in [Appendix D, Part D-1](#) and defined in the [glossary](#) of this report.) These limits pertain to the sum of the EDE from external radiation and the committed 50-year EDE from radioactive materials ingested or inhaled during a particular year that may remain in the body for many years.

Radionuclide emissions to the atmosphere from DOE facilities are further regulated by the EPA, under the authority of Section 112 of the Clean Air Act. Subpart H of NESHAPs, under 40 CFR 61, referenced earlier, sets standards for public exposure to airborne radioactive materials (other than radon) released by DOE facilities; radon is regulated by Subparts Q and T. NESHAPs implements the dosimetry system recommended by the ICRP in Publication 26 (ICRP 1977).

The EPA’s radiation dose standard, which applies only to air emissions, limits the EDE to members of the public caused by operations at a DOE facility to 100 μ Sv/y (10 mrem/y). EPA regulations specify not only the allowed levels, but also the approved methods by which airborne emissions and their impacts must be evaluated. With respect to all new or modified projects, NESHAPs compliance obligations define the requirements to install continuous air-effluent monitoring and to obtain EPA approval before the startup of new operations. NESHAPs regulations require that any operation with the potential to produce an annual-averaged off-site dose greater than or equal to 1 μ Sv/y (0.1 mrem/y), taking full credit for emission-abatement devices such as high-efficiency particulate air (HEPA) filters, must obtain EPA approval prior to the startup of operations. This same calculation, but without taking any credit for emission abatement devices, determines whether or not



continuous monitoring of emissions to air from this project is required. These requirements are spelled out in LLNL's online *Environment, Safety, and Health (ES&H) Manual* in Document 31.1, "Air Quality Compliance," which can be found at the following Internet address:

http://www.llnl.gov/es_and_h/hsm/doc_31.01/doc31-01.html.

Air Emission Sources and Data

Sources

More than a hundred different radioisotopes are used at LLNL for research purposes, including biomedical tracers, tritium, mixed fission products, transuranic isotopes, and others. Radioisotope handling procedures and work enclosures are determined for each project, depending on the isotopes, the quantities being used, and the types of operations being performed. Radioisotope handling and working environments include glove boxes, exhaust hoods, and laboratory bench tops. Exhaust paths to the atmosphere range from triple-HEPA-filtered ventilation systems, to roof vents and stacks lacking abatement devices, to direct dispersal of depleted uranium during explosives testing at Site 300's open-air firing tables, to a variety of diffuse area sources.

Sources of radioactive material emissions to air at LLNL are divided into two categories for purposes of evaluating compliance: point sources (including stacks, roof vents, and Site 300's explosive experiments), and diffuse area sources (including dedicated waste accumulation areas and other areas of known contamination). Sources external to buildings, such as Hazardous Waste Management's "Tank Farm" operations at Building 514 and waste storage at the Building 612 Yard at the Livermore site, are treated as diffuse area sources. Detailed information on releases of radioactivity from

LLNL's operations during 2001 is given in *LLNL NESHAPs 2001 Annual Report* (Harrach et al. 2002).

2001 Air Monitoring

This section briefly describes continuous stack-effluent sampling systems at selected LLNL facilities and ambient air monitors in place at numerous locations on and off LLNL sites. More complete information is provided in [Chapters 4](#) and [5](#).

Continuous Stack Air Effluent Monitoring

Actual measurements of radioactivity in air and effluent flow are the basis for reported emissions from continuously monitored sources. In 2001, Buildings 175, 177, 235, 251, 331, 332, and 491 at the Livermore site had radionuclide air effluent monitoring systems. The number of samplers, the types of samplers, and the analytes of interest in these buildings are described in [Chapter 4](#). All but Building 331 employed filter-type samplers to monitor gross alpha and beta radiation on particles.

Air samples for particulate emissions are extracted downstream of HEPA filters and prior to the discharge point to the atmosphere. Particles are collected on membrane filters. The sample filters are removed and analyzed for gross alpha and beta activity. In the pair of 30-meter stacks of the Tritium Facility (Building 331), the analytes being monitored are elemental gaseous tritium, tritiated water vapor, and total tritium; the sampling utilizes an ionization chamber and molecular sieves (see [Chapter 4](#)). Both the Tritium Facility and Plutonium Facility (Building 322) feature alarmed monitoring systems.

Results of Stack Monitoring for Tritium: Operations in the Tritium Facility in 2001 released a total of 7.4×10^{11} Bq (20 Ci) of tritium. Of this, approximately 6.8×10^{11} Bq (18.3 Ci) were released as tritiated water (HTO). The remaining

8.5% of the tritium released, 6.4×10^{10} Bq (1.7 Ci), was elemental tritium gas (HT). The highest single weekly stack emission from the facility was 2.5×10^{10} Bq (0.67 Ci), of which 2.4×10^{10} Bq (0.64 Ci) was HTO.

Building 331 tritium emissions, as measured by stack monitoring, remained considerably lower in 2001 than emissions that occurred during the 1980s. (Figure 4-2 illustrates the combined HTO and HT emissions from the facility since 1981.) The reduced emissions in 2001 were primarily the result of a reduction in programmatic work compared to previous years. Over the next five years, an increasing trend in emissions may occur as research and development work is performed for new programmatic efforts. However, engineered controls designed to contain and recapture tritium leakage from this effort should maintain relatively low emissions.

Stack Monitoring for Gross Alpha and Gross Beta Radiation: For most discharge points at the other facilities where continuous stack sampling is performed, the results are below the minimum detectable concentration (MDC) of the analysis; sometimes as few as 1 to 4 samples (out of 25 to 50 per year) have concentrations greater than the MDC. Generally, the few samples with results above the MDC are only marginally above. Use of zero values for this type of data can be justified based on knowledge of the facility; the use of tested, multiple stage, HEPA filters in all significant release pathways; and alpha-spectroscopy-based isotopic analyses of selected air sampling filters. These isotopic analyses demonstrate that detected activity on air sampling filters comes from naturally occurring radionuclides, such as radon daughters like polonium, on the air sampling filters. In addition, because of exhaust configurations at some facilities, the monitoring systems sometimes sample air from the ambient atmosphere along with the HEPA-filtered air from facility operations, giving

rise to background atmospheric radioactivity being collected. Because of these considerations, the emissions from such facility operations are reported as zero. As a result, there are no dose consequences, and doses reported for these operations are also zero. Furthermore, even if the MDC values are used in calculations of the emission estimates for these facilities, which would be an extremely conservative approach, the total dose attributable to LLNL activities is not significantly affected. On this basis, none of the facilities monitored for gross alpha and beta had emissions in 2001.

Air Surveillance Monitoring for Radioactive Particles and Gases

Surveillance air monitoring for tritium and radioactive particles has been in place since the 1970s. The data from this ambient air monitoring network provide continuous measurements of the concentrations of radionuclides present in the air at the Livermore site, Site 300, and in the surrounding areas. As described in Chapter 5, LLNL currently maintains 7 continuously operating, high volume, air particulate samplers on the Livermore site, 9 in the Livermore Valley, 8 at Site 300, and 1 in Tracy, and maintains 12 continuously operating tritiated water vapor samplers on the Livermore site, 6 samplers in the Livermore Valley and 1 at Site 300. The samplers are positioned to ensure reasonable probability that any significant airborne concentration of particulate and tritiated water vapor effluents resulting from LLNL operations will be detected.

Many of the surveillance air monitors are placed near diffuse emission sources, such as those near Buildings 292, 331, 514, and 612, as well as in and around the Southeast Quadrant of the Livermore site. As such, their results can be used to estimate or confirm the emissions from the associated diffuse sources. Also included are air particulate and tritiated water vapor monitors positioned at or near the location of the hypothetical maximally



exposed member of the public (defined later in the subsection “[Identification of Key Receptors](#)”) for the Livermore site. Data from air surveillance monitors provide a valuable test of predictions based on air dispersion modeling and can help characterize unplanned releases of radioactive material.

Recognition of Need to Apply Correction

Factors to Results of Tritium Surveillance Air

Monitoring: Recently, it was shown that measured tritium concentrations obtained using a method involving the extraction of water from silica gel—a method used at LLNL since 1973—are in error and require upward correction. It is important to note that this correction, while significantly affecting the concentrations of tritium in ambient air quoted in LLNL’s environmental reports, results in negligible changes in the radiological doses to the public documented in those reports. Only for the special case of a diffuse tritium source having emissions inferred from monitoring data does the correction apply and change the inferred dose for that particular source. In particular, doses to the public attributed to tritium emissions from the pair of 30-meter-high stacks of the Tritium Facility are not affected.

The Environmental Monitoring Radiological Laboratory of the Analytical and Nuclear Chemistry Division at LLNL developed a correction factor that applies to all measured tritium concentrations obtained by this method (Guthrie et al. 2001). The correction factor was developed based on new understanding of the properties of silica gel (Rosson et al. 1998; Rosson et al. 2000).

Put simply, the concentration of tritium measured in water extracted from the silica gel is lower than the concentration of the air moisture absorbed by the silica gel. This phenomenon occurs because tritium from ambient air exchanges with water bound in the silica gel that cannot be removed by

the drying process. The bound water fraction is about 5% or 6% by weight, depending upon the type of silica gel. The magnitude of the correction depends upon the amount of water collected compared with the amount of exchangeable water bound in the silica gel and is specific to the silica gel used by LLNL. For 2001, the average correction factor was 1.6 (range of 1.3 to 2.3, with 99% of the correction factors being less than 2.1). The correction factor was applied to each sample based upon the amount of water collected and the initial weight of the dry silica gel.

An illustration of the quantitative effect produced annually by these corrections over the period 1997–2001 is given in the section “[Results of 2001 Radiological Dose Assessment](#)”. Results of computer modeling are compared to measured concentrations of tritium in air at a dozen surveillance air monitoring locations on or near the Livermore site over that five-year period.

Radionuclide Usage Inventory Update

A partial accounting of LLNL’s radiological emission sources was made in 2001 in accordance with the allowance by EPA that a 100% accounting need be made only every third year. The previous year, when reviewing and reporting on operations conducted in 2000, a 100% accounting was made.

The partial accounting focused on sources in four categories: (1) the group of sources that collectively (in a ranked list) accounted for at least 90% of the dose to the maximally exposed public individual from both the Livermore site and Site 300 in the year 2000 assessment; (2) all “new” sources that commenced emissions in 2001, or sources that showed significantly elevated releases over 2000 levels; (3) all monitored sources; and (4) all sources in the major LLNL waste stream dealt with by Hazardous Waste Management (HWM).

Radionuclide usage inventory forms, with guidance for completing them, were sent to all assurance managers, facility managers, and project-responsible persons connected with activities meeting these criteria for our partial accounting. The forms were completed by experimenters and certified by facility managers. Radionuclide usage data for all Site 300 explosives experiments and all significant stack and diffuse sources at both sites were included in this update.

Dose Assessment Methods and Concepts

Principal Modeling Approaches

Most estimates of individual and collective radiological doses to the public from LLNL operations were obtained using the EPA-developed computer code, CAP88-PC, as noted in the “Introduction”. An LLNL-modified version of this code called CAP88-PC-T, which contains an improved tritium model (submitted to but not yet approved by EPA for use in regulatory compliance evaluations), was also used for purposes of comparison.

The user’s guide for CAP88-PC (Parks 1992) provides useful information, including discussions of the basic equations and key input and output files. Additional information about LLNL-site-specific data files and several important caveats on use of the code can be found in the LLNL radiological dose assessment guidance document (Harrach 1998). The four principal pathways of exposure from air releases — internal exposures from inhalation of air, ingestion of foodstuff and drinking water, external exposures through irradiation from contaminated ground, and immersion in contaminated air — are evaluated by CAP88-PC. The doses are expressed as whole-body EDEs in units of mrem/y (1 mrem = 10 μ Sv). Separate doses for Livermore site and Site 300 emissions are evaluated and reported.

Other codes, such as EPA’s INPUFF code (Peterson and Lavdas 1986) or LLNL’s HOTSPOT code (Homann 1994), can be used as needed to address unplanned releases or transient releases from normal operations or accidents. In 2000, the EPA granted regulatory “guideline model” status to two codes—the AERMOD and CALPUFF codes— which are of considerably greater complexity than CAP88-PC, INPUFF, and HOTSPOT. Many other Gaussian-plume-type computer models are available for modeling specific types of releases; see, for example, the annotated lists in *Atmospheric Dispersion Modeling Resources* (Oak Ridge 1995) and *Supplement B to the Guideline on Air Quality Models (Revised)* (U.S. EPA 1993).

A complementary approach to deriving EDEs using the built-in dosimetry model in CAP88-PC or other codes is to explicitly calculate EDEs using mathematical formulas from the Nuclear Regulatory Commission’s Regulatory Guide 1.109 (U.S. NRC 1977), which incorporate dose conversion factors consistent with those in the International Commission on Radiation Protection’s Publication 30 (ICRP 1980). This approach, outlined in Appendix A of this report, has been used at LLNL since 1979 and can be used to evaluate annual doses to the public inferred from sampling of local environmental media (air, water, vegetation, and wine).

Identification of Key Receptors

When assessing probable off-site impacts, LLNL pays particular attention to doses received by three hypothetical receptors. First is the dose to the site-wide maximally exposed individual member of the public (SW-MEI; defined below). Second is the dose to the maximally exposed individual (MEI) member of the public from a given source point.



Third is the collective or “population” dose received by people residing within 80 km of either of the two LLNL sites.

The SW-MEI is defined as the hypothetical member of the public at a single, publicly accessible location (where members of the public reside or abide) who receives the greatest LLNL-induced EDE from all sources at a site. For LLNL to comply with the NESHAPs regulations, the LLNL SW-MEI cannot receive an EDE greater than 10 mrem/y (100 μ Sv/y) from releases of radioactive material to air. Public facilities that could be the location of the SW-MEI include schools, churches, businesses, and residences. This hypothetical person is assumed to remain at this location 24 hours per day, 365 days per year, continuously breathing air having the ground-level radionuclide concentration, and consuming a specified fraction of food and drinking water that is affected by the releases of radioactivity from the site. Thus, the SW-MEI dose is not received by any actual individual and is used as a conservative estimate of the highest possible dose to any member of the public. The location of the SW-MEI is sensitive to the frequency distribution of wind speeds and directions and locations of key sources in a given year and can change from one year to the next.

At the Livermore site, evaluation showed that the SW-MEI in 2001 was located at the UNCLE Credit Union, about 10 m outside the controlled eastern perimeter of the site. This location lies 948 m from the Tritium Facility (Building 331), in an east-northeast direction (the typical prevailing wind direction).

At Site 300, the SW-MEI occupied a position on the south-central boundary of the site bordering the Carnegie State Vehicular Recreation Area, approximately 3.2 km south-southeast of the firing table at Building 851. These SW-MEI locations are depicted in [Figure 13-1](#) and [Figure 13-2](#).

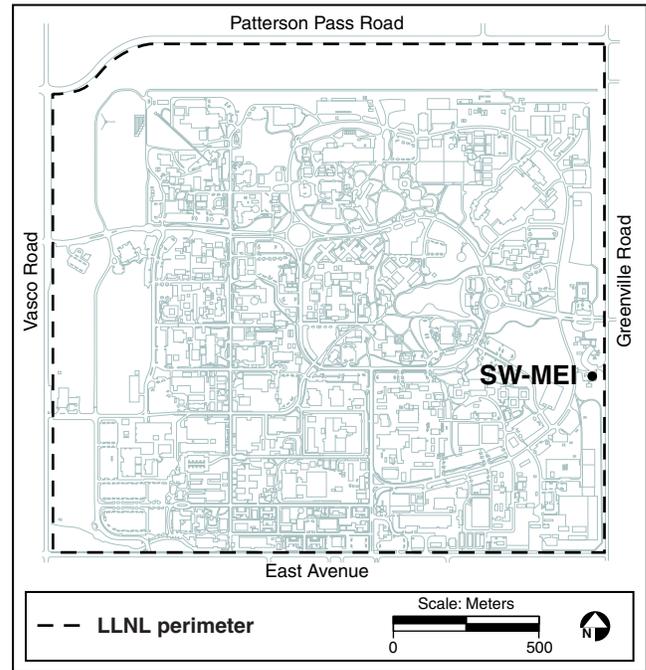


Figure 13-1. Location of the site-wide maximally exposed individual (SW-MEI) at the Livermore site, 2001

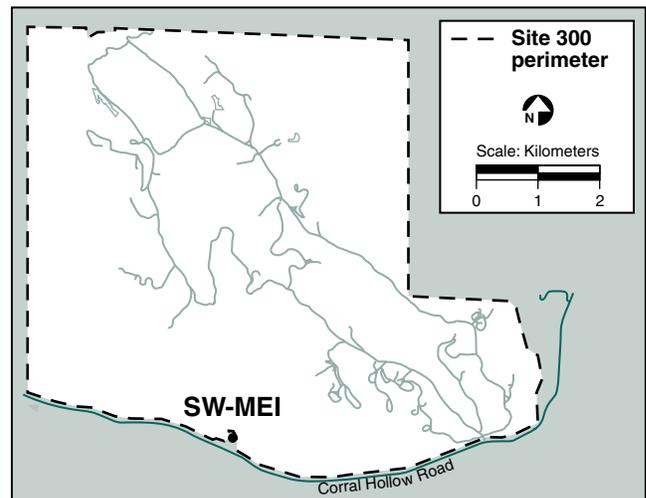


Figure 13-2. Location of the site-wide maximally exposed individual (SW-MEI) at Site 300, 2001



While the SW-MEI location is determined collectively by all sources at a site and coincides with an actual publicly accessible facility, the location of the MEI is any point of unrestricted public access receiving the largest potential dose from a given source and is generally different for each emission point. Such a point typically occurs at the site perimeter, and is often referred to as the maximum “fence line” dose. However, the off-site maximum dose could occur some distance beyond the perimeter (e.g., when a stack is close to the perimeter).

All new or modified LLNL projects in which releases of radioactivity to the environment may occur are reviewed for joint compliance with NESHAPs and the National Environmental Policy Act (NEPA). Dose to the MEI is used to evaluate whether continuous monitoring of the emissions from a given project is required, and whether it is necessary to petition the EPA for permission to start up the activity.

Summary of Input Parameters to CAP88-PC

General Model Inputs

Basic input parameters for running the CAP88-PC model include the specification of radionuclides, their emission rates in curies per year (1 Ci = 3.7×10^{10} Bq), and data on the nature of the emissions (e.g., stack parameters, including height, diameter, and emission velocity). A complete listing of required input data is given in the *User's Guide for CAP88-PC* (Parks 1992).

Meteorological Data

All model runs used actual 2001 Livermore site and Site 300 meteorological data collected from the meteorological towers for each site. At these towers, wind speed and direction are sampled every few seconds, temperature is sampled every minute, and all are averaged into quarter-hour increments,

time tagged, and computer recorded. The data are converted into a CAP88-PC input wind file using EPA guidelines.

Surrogate Radionuclides

CAP88-PC contains a library of 265 radionuclides; however, it does not contain all the radionuclides in use at LLNL. As a consequence, it was necessary in a few cases to derive surrogate radionuclides to estimate EDEs. Attachment 2 in *LLNL NESHAPs 2001 Annual Report* (Harrach et al. 2002) shows the surrogate radionuclides used by LLNL in CAP88-PC over the years.

Population Inputs

Population distributions centered on the two LLNL sites were compiled from the LandScan Global Population 1998 Database developed by Dr. Jerome Dobson at Oak Ridge National Laboratory. The population data files (distribution of population with distance and direction) used in the 2001 modeling effort are the same as those described in *LLNL NESHAPs 2000 Annual Report* (Gallegos et al. 2001).

Land Use and Agricultural Inputs

Options for model inputs regarding agricultural characteristics and land use are established by the EPA, and the particular designation selected can strongly influence the ingestion dose received by the population being evaluated. The “user entered” option was again selected for the CAP88-PC modeling effort for 2001. The values entered corresponded to the “local agriculture” option (i.e., everything is home produced), with one exception—all milk consumed was assumed to be imported for individual dose assessment. The assumption that all milk comes from local cows is not supported by the agricultural activities conducted in the area. For population dose assessments, all food is considered to be grown within an 80 km radius about the site; default densities of agricultural products in California are used.



Source Specification

The source term for each emission point in the calculations was determined by one of two methods: For continuously monitored sources, the sampling data (curies released per unit time) for each radionuclide were used directly. For unmonitored facilities, the radionuclide usage inventories, together with time factors and EPA-specified physical state factors, were used to estimate the potential annual emissions to air from a source. The time factors are used to adjust for the fact that the radionuclide may not always be in the same facility all year or may be encapsulated or enclosed for a substantial part of the year. The time factors are chosen to allow a reasonable estimate of the amount of radioactive material that may potentially be released into the atmosphere. The EPA-specified factors for potential release to air of materials in different physical states (solid, liquid, powder, or gas) are those stated in 40 CFR Part 61, Appendix D. If the material was an unconfined gas, then the factor 1.0 was used; for liquids and powders, 1.0×10^{-3} was used; and for solids, 1.0×10^{-6} was used.

The U.S. EPA has granted approval for LLNL to use alternative physical state factors for elemental uranium, uranium/niobium alloy, and elemental plutonium; see Table 4 in *LLNL NESHAPs 2001 Annual Report* (Harrach et al. 2002). The physical-state-dependent release fraction and the time factor are used to adjust (by multiplication) the total annual usage inventory to yield the potential annual release to air.

In addition, emission control abatement factors (40 CFR 61, Appendix D), when applicable, were applied. Each HEPA filter stage was given a 0.01 abatement factor. Abatement factors are taken into account in an evaluation for start up of operations, but are not included in the evaluation of need to install continuous monitoring of emissions.

Special Modeling Challenges

Among the sources at LLNL, explosives tests using depleted uranium at Site 300 and diffuse sources at both sites required special attention.

Site 300 Explosives Experiments: Some of the assemblies for Site 300 explosives experiments contain depleted uranium (DU) and possibly other radioactive materials. (The radioactive material does not contribute to the explosive energy, which is entirely chemical in origin.) The explosives assemblies are placed on an open-air firing table and detonated. Only limited data are available to characterize the initial state of the cloud of explosive decomposition products created by the detonation because properties of the cloud are not routinely measured in the experiments. Empirical scaling laws can be used, however, to define the size and height of the cloud using explosives inventories.

When the assembly contains DU, the three uranium isotopes with atomic weights 238, 235, and 234 are assumed to occur in the cloud in the weight percentages 99.8, 0.2, and 5×10^{-4} . Their masses are multiplied by their specific activities to determine the total activity for each isotope in the cloud. For simplicity, it is assumed that all the uranium is dispersed as a gaseous cloud, and that the median particle size is the CAP88-PC default value of 1 μm .

The assumption that all uranium is aerosolized and dispersed as a cloud results in a highly conservative off-site dose estimation. We believe a more realistic release-to-air fraction for the uranium is no greater than 0.2, but we lack sufficient data to use a value other than 1.0. CAP88-PC simulates each shot as a low level, steady state, stack-type emission occurring over one year. An alternative modeling methodology for treating these short duration explosive

events, based on a “puff” code, was submitted to EPA for approval in 1992, but LLNL was directed to use the CAP88-PC code for these calculations.

Diffuse Sources: Diffuse emissions generally arise from extended-area sources external to buildings. Such sources are difficult to quantify. At present, there are no EPA-mandated methods for estimation or measurement of diffuse sources; dose calculations associated with this type of source are left to the discretion of the DOE facility. Dose assessments for Livermore site and Site 300 diffuse sources are variously derived based on radionuclide usage inventory data, environmental surveillance monitoring data, samples of contaminated materials, and other methods. The doses from principal diffuse sources in 2001 are described in *LLNL NESHAPs 2001 Annual Report* (Harrach et al. 2002).

Modeling Dose from Tritium

Tritium (^3H) emissions account for the major dose from operations at the Livermore site. These emissions exist in two major chemical forms: tritium oxide or tritiated water vapor (HTO) and tritium gas (HT). The CAP88-PC code’s tritium model calculates dose from inhalation, skin absorption, and ingestion of tritium, but only in its HTO form. CAP88-PC’s tritium model is based on the specific activity model, which assumes that the tritium-to-hydrogen ratio in body water is the same as in air moisture. Because the specific activity model is linked in CAP88-PC with relatively high dose coefficients for HTO, the model’s dose predictions generally err on the high side.

Doses from unit concentration of HT in air are a factor of 15,000 times lower than those from unit concentration of HTO in air (ICRP 1995). Thus, doses from inhaled HT can safely be ignored unless the air concentration is extremely high. A release of HT cannot be ignored, however, because HT that

reaches the ground is rapidly and efficiently converted to HTO by microorganisms in soil (McFarlane, Rogers, and Bradley 1990) and to a lesser extent in vegetation (Sweet and Murphy 1984).

A third important form of tritium to consider is organically bound tritium (OBT), which is formed by plants during photosynthesis and incorporated by animals when ingested. Animals also metabolize some OBT from ingested or inhaled HTO. The ICRP dose coefficient for OBT is about 2.3 times higher than that of HTO, because the biological half-life of OBT in the body is longer than that of HTO, which is eliminated at the same rate as body water.

A new, simple tritium model developed at LLNL, called NEWTRIT, calculates ingestion dose from both HTO and OBT and accounts for conversion of HT to HTO in the environment after releases of HT (Peterson and Davis 2002). Both for this and last year’s report, LLNL has used the NEWTRIT model incorporated into CAP88-PC, (called CAP88-PC-T) in addition to the default CAP88-PC code, to estimate doses from significant sources of tritium emissions. A brief discussion of the NEWTRIT model was presented in last year’s NESHAPs annual report (Gallegos et al. 2001).

The NEWTRIT model was presented to EPA and DOE at a meeting of the Health Physics Society (Cleveland, Ohio, June 2001), and the associated paper was published in that society’s journal (Peterson and Davis 2002).

In October 2001, LLNL sent a letter to EPA Region IX requesting consideration of an alternative methodology for calculating doses from atmospheric releases of HTO and HT for use in demonstrating compliance with radionuclide NESHAPs (40 CFR 61 Subpart H). Copies of NEWTRIT, CAP88-PC-T and associated



documentation were given to EPA and several DOE laboratories that had expressed interest. A decision has not been made as of this writing, but LLNL is hopeful that NEWTRIT, or a similar approach to modeling releases of HT and HTO for regulatory compliance, will be accepted.

Reporting the Contribution of Tritium to Total Dose

Prior to the *Environmental Report 1998*, LLNL considered only the contribution to tritium dose of HTO releases. In April 1999, EPA mandated that LLNL use a more conservative approach when calculating dose to the public for NESHAPs compliance purposes, by treating all HT released as though it were HTO, rather than treating the dose from HT as negligible.

The introduction of NEWTRIT gives a third version of the contribution of tritium releases to total dose from LLNL operations. Starting with the present report, only the results derived using the latter two approaches will be quoted: (1) the CAP88-PC result inputting all curies of HTO released, plus an additional number of curies of HTO equal to the number of curies of HT released, and (2) the result from CAP88-PC-T (i.e., using the NEWTRIT model for tritium), inputting separately the number of curies of HTO and HT released. It should be noted that this tritium dose problem is important only for the Livermore site; at Site 300, tritium makes a negligible contribution to the public dose.

Results of 2001 Radiological Dose Assessment

This section summarizes the doses to the most exposed public individuals from LLNL operations in 2001, shows the temporal trends by comparison to previous years, presents the potential doses to the populations residing within 80 km of either the Livermore site or Site 300, and places the potential

doses from LLNL operations in perspective with doses from other sources. Comments are provided on dose to biota and an illustration is given of the possible effect of silica gel correction factors on comparisons between modeling and monitoring.

Total Dose to Site-Wide Maximally Exposed Individuals

For the Livermore site, the dose calculated for the SW-MEI from diffuse emissions in 2001 totaled 0.11 μSv (0.011 mrem). The dose due to point sources was 0.057 μSv (0.0057 mrem). When combined, the total annual dose was 0.17 μSv (0.017 mrem), 66% from diffuse and 34% from point sources.

The 0.17 μSv (0.017 mrem) total dose includes Tritium Facility HT emissions modeled as HTO, as directed by EPA Region IX. The SW-MEI dose calculated using NEWTRIT for tritium emissions from both point and diffuse sources at the Livermore site was 0.13 μSv (0.013 mrem).

The total dose to the Site 300 SW-MEI from operations in 2001 was 0.54 μSv (0.054 mrem). Point source emissions from firing table explosives experiments accounted for 0.50 μSv (0.050 mrem), or 93%, of this total, while 0.037 μSv (0.0037 mrem), or about 7%, was contributed by a diffuse source representing resuspension by wind of soil throughout the site containing low levels of depleted uranium.

Tritium accounted for more than three-quarters of the Livermore site's calculated dose, while at Site 300 practically the entire calculated dose was due to the isotopes uranium-238, uranium-235, and uranium-234 in depleted uranium. Regarding pathways, the relative significance of inhalation and ingestion depends on the assumptions made about the origin of food consumed. The assumption when assessing individual LLNL doses that milk is

imported while the remainder of the food is produced locally results in ingestion dose exceeding inhalation dose in the case of tritium, approximately in the percentages 80% to 20%. For uranium, these numbers are nearly reversed: 17% by the ingestion pathway versus 83% via inhalation. LLNL doses from air immersion and ground irradiation are negligible for both tritium and uranium.

Table 13-1 shows the facilities or sources that accounted for more than 90% of the doses to the SW-MEI for the Livermore site and Site 300 in 2001. Although LLNL has nearly 200 sources releasing radioactive material to air, most are very minor; nearly the entire radiological dose to the public comes from fewer than a dozen sources.

The trends in dose to the SW-MEI from emissions at the Livermore site and Site 300 over the last 12 years are shown in **Table 13-2**. The general pattern, particularly over the last decade, shows year-to-year fluctuations around a quite low dose level, staying at or below about 1% of the federal standard.

The SW-MEI dose estimates are intentionally conservative, predicting potential doses that are generally higher than would actually be experienced by any member of the public. Potential doses from Site 300 firing table operations are especially so, as explained in the section “**Special Modeling Challenges.**”

Table 13-3 shows the Site 300 SW-MEI dose values attributed to firing table experiments for 1990 through 2001 exhibited along with the total amounts of depleted uranium and the total quantity of high explosives used each year in the experiments. (Only explosives experiments that included depleted uranium are considered here; most have none.) The 2001 total was indicative of increased firing table activity compared to the previous year but quite typical of levels in the past decade (see also the “Point source dose” column for Site 300 in **Table 13-2**).

Table 13-1. List of facilities or sources whose emissions accounted for more than 90% of the SW-MEI doses for the Livermore site and Site 300 in 2001

Facility (source category)	CAP88-PC dose in $\mu\text{Sv/y}$	CAP88-PC percentage contribution to total dose
Livermore site		
Building 612 Yard (diffuse source)	0.082 ^(a)	48
Building 331 stacks (point source)	0.043 ^(a)	25
Building 514 Tank Farm (diffuse source)	0.013	8
Southeast Quadrant (diffuse source)	0.0088	5
Building 612, R102 (point source)	0.0062	4
Building 514 Evaporator (point source)	0.0058	3
Site 300		
Building 851 Firing Table (point source)	0.50	93
Soil resuspension (diffuse source)	0.037	7

^a When LLNL's NEWTRIT model is used in CAP88-PC in place of CAP88-PC's default tritium model, the doses for Building 612 yard and Building 331 stacks become 0.0061 mrem and 0.0031 mrem, respectively, and their percentages of the total dose from Livermore site operations each drop by 1%.



Table 13-2. Doses (in μSv) calculated for the sitewide maximally exposed individual (SW-MEI) for the Livermore site and Site 300, 1990 to 2001

Year	Total dose	Point source dose	Diffuse source dose
Livermore site			
2001	0.17 ^(a)	0.057 ^(a)	0.11
2000	0.38 ^(a)	0.17 ^(a)	0.21
1999	1.2 ^(a)	0.94 ^(a)	0.28
1998	0.55 ^(a)	0.31 ^(a)	0.24
1997	0.97	0.78	0.19
1996	0.93	0.48	0.45
1995	0.41	0.19	0.22
1994	0.65	0.42	0.23
1993	0.66	0.40	0.26
1992	0.79	0.69	0.10
1991	2.34	— ^(b)	— ^(b)
1990	2.40	— ^(b)	— ^(b)
Site 300			
2001	0.54	0.50	0.037
2000	0.19	0.15	0.037
1999	0.35	0.34	0.012
1998	0.24	0.19	0.050
1997	0.20	0.11	0.088
1996	0.33	0.33	0.0045
1995	0.23	0.20	0.030
1994	0.81	0.49	0.32
1993	0.37	0.11	0.26
1992	0.21	0.21	— ^(c)
1991	0.44	0.44	— ^(c)
1990	0.57	0.57	— ^(c)

- a The dose includes HT emissions modeled as HTO as directed by EPA Region IX. EPA Region IX acknowledges that such modeling results in a conservative overestimation of the dose. This methodology is used for purposes of compliance.
- b Diffuse source doses were not reported separately from the total dose for the Livermore site for 1990 and 1991.
- c No diffuse emissions were reported at Site 300 before 1993.

Table 13-3. Annual dose to the SW-MEI from explosives experiments on firing tables at Site 300, 1990–2001, related to the total quantity of depleted uranium used in the experiments and the total quantity of high explosives driving the detonations

Year	Annual dose to SW-MEI		Total depleted uranium used in experiments (kg)	Total HE ^(a) used in depleted uranium experiments (kg)
	μSv	mrem		
2001	0.50	0.050	187	104
2000	0.15	0.015	43	34
1999	0.34	0.034	216	168
1998	0.19	0.019	230	192
1997	0.11	0.011	163	122
1996	0.33	0.033)	272	112
1995	0.20	0.020	165	199
1994	0.49	0.049	230	134
1993	0.11	0.011	99	74
1992	0.21	0.021	151	360
1991	0.44	0.044	221	330
1990	0.57	0.057	340	170

^a HE = high explosives

Doses from Unplanned Releases

There were no unplanned atmospheric releases of radionuclides at the Livermore site or Site 300 in 2001.

Population Doses

Population doses, or collective EDEs, for both LLNL sites were calculated, using CAP88-PC, out to a distance of 80 km in all directions from the site centers. CAP88-PC evaluates the four principal exposure pathways: ingestion via intakes of food and water, inhalation, air immersion, and irradiation by contaminated ground surface.

Population centers affected by LLNL emissions include the relatively nearby communities of Livermore and Tracy; the more distant metropolitan areas of Oakland, San Francisco, and San Jose;

and the San Joaquin Valley communities of Modesto and Stockton. Within the 80 km outer distance specified by DOE, there are 6.9 million residents included for the Livermore site population dose determination, and 6.0 million for Site 300. Population data files (distribution of population with distance and direction) used for the present report were the same as in the previous year; see Tables 7 and 8 in *LLNL NESHAPs 2000 Annual Report* (Gallegos et al. 2001).

The CAP88-PC result for potential population dose attributed to 2001 Livermore site operations was 0.0016 person-Sv (0.16 person-rem). This amount is less than typical, primarily because the stack releases from the Tritium Facility were unusually low in 2001.



The corresponding collective EDE from Site 300 operations in 2001 was 0.094 person-Sv (9.4 person-rem). This value, while within the normal range seen from year to year, exceeds the 0.025 person-Sv (2.5 person-rem) for 2000 as a result of increased firing table activity.

Effect of Silica Gel Correction Factors on Modeling vs. Monitoring Comparison

LLNL's results for measured concentrations of tritium in ambient air require correction in light of new understanding of the effects of chemically bound water in "dry" silica gel (see Data Supplement, Chapter 5). LLNL's reported doses are negligibly affected by these corrections, since modeling, not monitoring, is used to determine dose to the public. These corrections do influence LLNL's opinions regarding the margin of conservatism represented in LLNL's modeling.

Comparisons between air concentrations predicted by CAP88-PC and measured air tritium concentrations have been included in LLNL's NESHAPs reports for the past five years. All of these comparisons now need revision, replacing the original measured values by their corrected counterparts.

Unfortunately, this is not possible for years prior to 2001. Two of several reasons for this inability to correct old data are that (1) the correction factor is different for each batch of silica gel, which was changed from time to time in the past (most recently in May 2000), and (2) the initial dry-weights of the silica gel must be known for the correction factor determination, but these were not recorded and cannot be reconstructed.

In lieu of a better alternative, a conservatively high multiplicative correction factor of 2.1 was chosen to apply to air concentrations measured prior to 2001 to allow for the possibility that the silica gel used in previous years had more bound water than

that used presently. (Approximately 99% of the results for 2001 had a correction factor less than or equal to 2.1.).

Using a correction factor of 2.1 for years 1997 through 2000 and the actual (measured) sample-to-sample correction factors for 2001, revised predicted-to-observed (P/O) ratios of tritium concentrations in air at Livermore site perimeter locations and ZON7 were obtained. These were compared with the ratios using uncorrected measured values, with results as shown in Table 13-4. Without correction, 35 of the 40 P/O ratios were greater than 1.0, with the lowest being 0.69 at COW in 2001 and the highest 11 at SALV in 2000. When the observations are increased by applying correction factors, 30 of the P/O ratios are greater than 1.0, with the lowest being 0.40 at COW in 1997 and the highest 5.1 at SALV in 2000.

The differences between the sets of P/O ratios with and without correction are not regarded as significant. Considering the uncertainty in the numerator "P" alone, differences of this same general magnitude are expected to arise from use of a Gaussian plume dispersion model (such as used by CAP88-PC). For example, a comparison of AIRDOS-EPA predictions of air concentrations for various radionuclides (uranium-234, uranium-238, krypton-85, and tritium) with measurements at six different sites concluded that the 90% confidence interval for the accuracy of the CAP88-PC dispersion model ranges from a factor of 0.3 to 4.4, based on 51 samples (Jack Faucett Assoc. 1987).

Doses to the Public Placed in Perspective

These levels of variation in population and SW-MEI doses from one year to the next are within the expected range of operations-driven fluctuations in small radiation quantities. A frame of reference to gauge the magnitude of these LLNL doses is

Table 13-4. Uncorrected (upper) and corrected (lower) ratios of predicted-to-observed air concentrations of tritiated water at Livermore site perimeter locations and ZON7, 1997–2001

Monitor	1997	1998	1999	2000	2001
CAFE	1.9	3.4	6.3	6.1	2.0
	0.89	1.6	3.0	2.9	1.5
COW	0.84	1.0	1.6	1.1	0.58
	0.40	0.49	0.77	0.50	0.41
MESQ	3.3	5.6	4.0	5.0	1.5
	1.6	2.6	1.9	2.4	1.0
MET	3.2	2.4	3.1	2.4	1.6
	1.5	1.2	1.5	1.1	1.2
POOL	0.99	2.2	3.9	4.4	1.0
	0.47	1.1	1.9	2.1	0.79
SALV	1.5	6.9	3.7	11.0	3.8
	0.73	3.3	1.8	5.1	3.9
VIS	3.0	2.4	5.7	3.0	1.5
	1.4	1.2	2.7	1.4	1.1
ZON7	3.9	3.2	5.5	3.0	2.1
	1.9	1.5	2.6	1.4	1.3

provided in [Table 13-5](#). The table compares the conservatively estimated population doses and doses to the maximally exposed public individuals caused by LLNL operations against average doses received in the United States from exposure to natural background radiation and medical treatments. The population doses attributed to LLNL operations in 2001 are about 200,000 times smaller than ones from natural background radiation; the estimated maximum potential doses to individual members of the public from operations at the two LLNL sites in 2001 are more than 5,500 times smaller than ones received from background radiation in the natural environment.

Estimate of Dose to Biota

In recent years, it has been recognized that a past principle of radiological protection—that by protecting man, other living things are also

protected—is not adequate. In 2000, DOE presented its standards for protection of the natural environment from the effects of ionizing radiation in its detailed guidance document “DOE Standard (Proposed): A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota” (U.S. DOE 2002). DOE sites are requested to calculate dose to biota based upon this guidance. The guidance includes a manual, spreadsheets, and a database giving biota concentration guides (BCGs). Cases where human access to an area of exposure is restricted or exposure pathways favor biota exposure are especially important to consider. The effort required to show compliance is minimized by several features of the guidance: its use of a graded approach; its allowance of use of existing generic and site-specific data (not requiring new monitoring programs tailored to biota); and the fact that current and proposed standards are not very restrictive. Regarding the latter, the limit on


Table 13-5. Comparison of background (natural and man-made) and LLNL radiation doses, 2001

Location/source	Individual dose ^(a)		Population dose ^(b)	
	(μ Sv)	(mrem)	(person-Sv)	(person-rem)
Livermore site sources				
Atmospheric emissions	0.17	0.017	0.0016	0.16
Site 300 sources				
Atmospheric emissions	0.54	0.054	0.094	9.4
Other sources^(c)				
Natural radioactivity ^(d,e)				
Cosmic radiation	300	30	1900	190,000
Terrestrial radiation	300	30	1900	190,000
Internal (food consumption)	400	40	2500	250,000
Radon	2000	200	12,500	1,250,000
Medical radiation (diagnostic procedures) ^(e)	530	53	3,300	330,000
Weapons test fallout ^(e)	11	1.1	68	6800
Nuclear fuel cycle	4	0.4	25	2500

a For LLNL sources, this dose represents that experienced by the SW-MEI member of the public.

b The population dose is the collective (combined) dose for all individuals residing within an 80-km radius of LLNL (approximately 6.9 million people for the Livermore site and 6.0 million for Site 300), calculated with respect to distance and direction from each site.

c From National Council on Radiation Protection and Measurements (NCRP 1987a, b)

d These values vary with location.

e This dose is an average over the U.S. population.

absorbed dose is 10 mGy/d (1 rad/d) for aquatic animals and terrestrial plants, and 1 mGy/d (0.1 rad/d) for terrestrial animals. (See [Appendix D, Part D-1](#), Radiation Basics, and the [Glossary](#) for a discussion of radiation units.)

Screening calculations for LLNL impacts were performed in 2001 using the electronic spreadsheet provided with the guidance. Each radionuclide in each medium (soil, sediment, surface water) is assigned a derived concentration limit in the guidance. For each measured maximum concentration input to the spreadsheet, a fraction of the derived concentration limit for that radionuclide is automatically calculated, and the fractions are summed for each medium.

For aquatic biota, the sum of the fractions for water exposure are added to the sum of the fractions for sediment exposure. Similarly, the fractions for water and soil are summed for terrestrial biota. If the sums for the aquatic and terrestrial biota are both less than 1.0 mGy/d (0.1 rad/d), the site has passed the screening analysis, and the biota are assumed to be protected without further analysis.

In the LLNL assessment, the maximum concentration of each radionuclide measured in soils, sediments, and surface waters during 2001, whether measured on the Livermore site, off site in the Livermore Valley, or at Site 300, was entered into the screening calculation. Measurements of storm water runoff were used, although it is questionable

whether biota would be exposed to this concentration for more than a very short while. Principal measured radionuclides were americium-241 (non-detects), cesium-137, cobalt-60 (non-detects), tritium, plutonium-239, thorium-228, uranium-234, uranium-235 and uranium-238. Natural background levels of beryllium-7, potassium-40, radium-226 and radium-228 were also measured but not used as input to the spreadsheet. For LLNL, the sum of the fractions for aquatic biota was 0.21, and the sum for terrestrial biota was 0.016. Both are indicative of doses to aquatic and terrestrial biota from LLNL operations that are well below allowable dose limits.

Summary and Conclusion

The annual radiological dose from all emissions at the Livermore site and Site 300 in 2001 was found to be well below the applicable standards for radiation protection of the public, in particular the NESHAPs standard. This standard limits to 100 $\mu\text{Sv}/\text{y}$ (10 mrem/y) the EDE to any member of the public, arising as a result of releases of radioactive material to air from DOE facilities. Using EPA-mandated computer models and actual LLNL meteorology appropriate to the two sites, the potential doses to the LLNL SW-MEI members of the public from operations in 2001 were evaluated, with the following results:

- Livermore site: 0.17 μSv (0.017 mrem)—34% from point-source emissions, 66% from diffuse-source emissions—calculated by modeling releases of elemental gaseous tritium as tritiated water vapor, for compliance purposes as directed by EPA Region IX.
- Site 300: 0.54 μSv (0.054 mrem)—93% from explosive experiments, which are classified as point-sources, 7% from diffuse-source emissions.

The major radionuclides accounting for the doses were tritium at the Livermore site and the three isotopes in depleted uranium (uranium-234, uranium-235, and uranium-238) at Site 300. The only significant exposure pathway was release of radioactive material to air, leading to doses by inhalation and ingestion.

The collective EDE or population dose attributable to LLNL operations in 2001 was estimated to be 0.0016 person-Sv (0.16 person-rem) for the Livermore site and 0.094 person-Sv (9.4 person-rem) for Site 300. These doses include potentially exposed populations of 6.9 million people for the Livermore site and 6.0 million people for Site 300 living within a distance of 80 km from the site centers.

The doses to the SW-MEI members of the public resulting from Livermore site and Site 300 operations in 2001 were below 0.6% of the federal standard and were more than 5500 times smaller than the dose from background radiation. The population doses from LLNL operations in 2001 were about 200,000 times smaller than those caused by natural radioactivity in the environment (see [Table 13-5](#)).

Potential doses to aquatic and terrestrial biota from LLNL operations were assessed and found to be well below DOE allowable dose limits.

We conclude that the potential radiological doses from LLNL operations were well below regulatory standards and were very small compared with doses normally received by these populations from natural background radiation sources, even though highly conservative assumptions were used in the determinations of LLNL doses. These maximum credible doses to the public indicate that LLNL's use of radionuclides had no significant impact on public health during 2001.

QUALITY ASSURANCE

Lucinda M. Clark
Donald H. MacQueen

Introduction

Quality assurance (QA) is a system of activities and processes put in place to ensure that monitoring and measurement data meet user requirements and needs. Quality control (QC) consists of procedures used to verify that prescribed standards of performance in the monitoring and measurement process are met. U.S. Department of Energy (DOE) orders and guidance mandate QA requirements for environmental monitoring of DOE facilities. DOE Order 5400.1 identifies QA requirements for radiological effluent and surveillance monitoring and specifies that a QA program consistent with the DOE order addressing quality assurance is established. This order sets forth policy, requirements, and responsibilities for the establishment and maintenance of plans and actions that assure quality in DOE programs.

Lawrence Livermore National Laboratory conducted QA activities in 2001 at the Livermore site and Site 300 in accordance with the *Environmental Protection Department Quality Assurance Management Plan* (Revision 4), which is based on DOE Order 414.1A and prescribes a risk-based, graded approach to QA. This process promotes the selective application of QA and management controls based on the risk associated with each activity in order to maximize effectiveness and efficiency in resource use.

The DOE *Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance* (U.S. DOE 1991) requires that an environmental monitoring plan be prepared. LLNL environmental monitoring is conducted according to procedures published in Appendix B of the LLNL *Environmental Monitoring Plan* (Tate et al. 1999).



LLNL and commercial laboratories analyze environmental monitoring samples using U.S. Environmental Protection Agency (EPA) standard methods when available. When EPA standard methods are not available, custom analytical procedures, usually developed at LLNL, are used. The radiochemical methods used by LLNL laboratories are described in procedures unique to the laboratory performing the analyses. LLNL uses only State of California-certified laboratories to analyze its environmental monitoring samples. In addition, LLNL requires all analytical laboratories to maintain adequate QA programs and documentation of methods.

Quality Assurance Activities

Nonconformance reporting and tracking is a process used for ensuring that Environmental Protection Department (EPD) activities meet the department's QA requirements and that problems are identified, resolved, and prevented from recurring. EPD reports and tracks problems using Nonconformance Reports (NCRs) and Analytical Lab Problem Reporting Forms.

EPD generated 30 Nonconformance Reports (NCRs) and 20 Analytical Lab Problem Reporting Forms related to environmental monitoring in 2001. These 50 reported problems can be compared to 76 in 2000 and 111 in 1999. The primary reason for the decrease in reported problems in 2001 appears to be an inconsistent interpretation of which problems require NCRs. Environmental monitoring and QA staff are currently working on developing better criteria to be used to make this determination. In addition, QA staff are attending regular meetings of environmental monitoring personnel to emphasize the need for documenting problems and to answer any questions that may arise.

Thirty-four of the 50 problems reported in 2001 were due to problems with analytical laboratories. Thirteen were due to documentation or procedural errors. Of the remaining 3 issues, 2 were related to equipment malfunction and the other was related to questionable results.

LLNL addresses analytical laboratory problems with the appropriate laboratory as they arise. Many of the documented problems related to analytical laboratories concerned minor documentation or paperwork errors, which were corrected soon after they were identified. Other problems—such as missed holding times, late analytical results, and typographical errors on data reports—accounted for the remaining analytical laboratory issues. These problems were corrected by reanalysis, resampling, reissued reports, or corrected paperwork, and associated sample results were not affected.

LLNL addresses internal documentation, training, and procedural errors by conducting formal and informal training. These errors generally do not result in lost samples, but may require extra work on the part of sampling and data management personnel to resolve or compensate for the errors.

QA staff also track and report planned environmental monitoring samples that are not collected for any reason. A summary of these lost samples appears in [Table 14-1](#).

Analytical Laboratories

LLNL continued to operate under the Blanket Service Agreements (BSAs) put into place with seven analytical laboratories in March 1999. LLNL continues to work closely with these analytical laboratories to minimize the occurrence of problems.

Table 14-1. Sampling completeness in 2001 for the Livermore site and Site 300

Environmental medium	Number of analyses planned	Number of analyses completed	Completeness (%)	Reason(s) for lost samples
Air particulate				
Radiological parameters (Livermore)	1188	1154	97	No power at location (22), power off at arrival/GFI tripped (5), unacceptable flow rate (4), could not access location (2), motor problems (1)
Beryllium (Livermore)	96	96	100	
Radiological parameters (Site 300)	728	727	99.9	Could not access location (1)
Beryllium (Site 300)	72	72	100	
Air tritium				
Livermore site	499	467	94	Insufficient flow (13), no power at location (9), broken flask (6), outliers (4)
Site 300	26	25	96	Outlier (1)
Soil and Sediment				
Livermore	42	42	100	
Site 300	30	30	100	
Arroyo sediment (Livermore site only)	43	43	100	
Vegetation and Foodstuffs				
Livermore site and vicinity	64	64	100	
Site 300	20	20	100	
Wine	25	25	100	
Thermoluminescent dosimeters (TLDs)				
Livermore site perimeter	76	76	100	
Livermore Valley	100	77	87	TLD missing (13)
Site 300	82	79	96	TLD missing (3)
Rain				
Livermore site	76	75	99	Insufficient sample volume (1)
Site 300	20	20	100	

Table 14-1. Sampling completeness in 2001 for the Livermore site and Site 300 (continued)

Environmental medium	Number of analyses planned	Number of analyses completed	Completeness (%)	Reason(s) for lost samples
Storm water runoff				
Livermore site	903	809	90	Insufficient rainfall to produce runoff (43), sampling error (34), no time to sample (15), sampler oversight (1), broke in transit to lab (1)
Site 300	338	138	41	Insufficient rainfall to produce runoff (193), sampling error (4), analytical lab error (3)
Drainage Retention Basin				
Field measurements	822	781	95	Equipment malfunction (24), sampler oversight (17)
Samples	87	86	99	Analytical lab error (1)
Releases	81	81	100	
Groundwater				
Livermore site	369	358	97	Well did not produce enough water for sampling (11)
Livermore Valley wells	29	26	90	No sample provided (2), well out of order (1)
Site 300				
Building 829 network	297	225	76	Wells dry (72)
Barcads	101	56	55	Barcads inoperable (45)
Elk Ravine	180	166	92	Well dry (14)
Pit 1	427	419	98	Sampler error (8)
Pit 6	498	454	91	Well dry (44)
Pit 7	423	403	95	Pump inoperable (11), sampler error (7), well sampling problem (2)
Pit 8	34	26	76	Well inaccessible due to construction (8)
Pit 9	419	49	100	
Offsite surveillance (annual)	64	64	100	
Offsite surveillance (quarterly)	196	168	86	Well inaccessible (23), lab error (5)

Table 14-1. Sampling completeness in 2001 for the Livermore site and Site 300 (continued)

Environmental medium	Number of analyses planned	Number of analyses completed	Completeness (%)	Reason(s) for lost samples
Sewage				
B196	924	924	100	
C196	324	324	100	
LWRP ^(a) effluent	128	128	100	
Digester sludge	80	80	100	
WDR-96-248				
Surface impoundment wastewater	68	68	100	
Surface impoundment groundwater	155	155	100	
Sewage ponds wastewater	41	41	100	
Sewage ponds groundwater	88	88	100	
Miscellaneous aqueous samples				
Other surface water (Livermore only)	58	58	100	
Cooling towers (Site 300 only)	26	26	100	

^a LWRP = Livermore Water Reclamation Plant

Participation in Laboratory Intercomparison Studies

The LLNL Chemistry and Materials Science Environmental Services' (CES) Environmental Monitoring Radiation Laboratory (EMRL) and the Hazards Control Department's Analytical Laboratory (HCAL) participated in the DOE Environmental Monitoring Laboratory (EML) intercomparison studies program. A review of the EML studies indicates that 38 of 41 results reported by CES and 8 of 10 results reported by HCAL fell within the established acceptance

control limits. Further discussion of unacceptable results and corrective actions taken is presented in the Data Supplement.

CES EMRL participated in two DOE Mixed Analyte Performance Evaluation Program (MAPEP) studies in 2001. Nineteen of nineteen analytes reported fell within acceptable limits.

Although contract laboratories are also required to participate in laboratory intercomparison programs, permission to publish their results for comparison purposes was not granted for 2001.

LLNL uses the results of intercomparison program data to identify and monitor trends in performance and to solicit corrective action responses for unacceptable results. If a laboratory performs unacceptably for a particular test in two consecutive performance evaluation studies, LLNL may choose to select another laboratory to perform the affected analyses until the original laboratory can demonstrate that the problem has been corrected.

If an off-site laboratory continues to perform unacceptably or fails to prepare and implement acceptable corrective action responses, the LLNL Procurement Department will formally notify the laboratory of its unsatisfactory performance. If the problem persists, the off-site laboratory's BSA could be terminated. If an on-site laboratory continues to perform unacceptably, use of that laboratory could be suspended until the problem is corrected.

Duplicate Analyses

Duplicate or collocated samples are distinct samples of the same matrix collected as closely to the same point in space and time as possible. Collocated samples processed and analyzed *by the same laboratory* provide intralaboratory information about the precision of the entire measurement system, including sample acquisition, homogeneity, handling, shipping, storage, preparation, and analysis. Collocated samples processed and analyzed *by different laboratories* provide interlaboratory information about the precision of the entire measurement system (U.S. EPA 1987). Collocated samples may also be used to identify errors such as mislabeled samples or data entry errors.

Table 14-2, **Table 14-3**, and **Table 14-4** present statistical data for collocated sample pairs, grouped by sample matrix and analyte. Samples from both the Livermore site and Site 300 are included. **Table 14-2** and **Table 14-3** are based on data

pairs in which both values are detections (see “**Summary Statistics**”). **Table 14-4** is based on data pairs in which either or both values are nondetections.

Precision is measured by the percent relative standard deviation (%RSD); see the *EPA's Data Quality Objectives for Remedial Response Activities: Development Process*, Section 4.6 (U.S. EPA 1987). Acceptable values for %RSD vary greatly with matrix, analyte, and analytical method; however, lower values represent better precision. The results for %RSD given in **Table 14-2** are the 75th percentile of the individual precision values.

Regression analysis consists of fitting a straight line to the collocated sample pairs. Good agreement is indicated when the data lie close to a line with a slope equal to 1 and an intercept equal to 0, as illustrated in **Figure 14-1**. Allowing for normal analytical variation, the slope of the fitted line should be between 0.7 and 1.3, and the absolute value of the intercept should be less than the detection limit. The coefficient of determination (r^2) should be greater than 0.8. These criteria apply to pairs in which both results are above the detection limit.

When there were more than eight data pairs with both results in each pair considered detections, precision and regression analyses were performed; those results are presented in **Table 14-2**. When there were eight or fewer data pairs with both results above the detection limit, the ratios of the individual duplicate sample pairs were averaged; the mean, minimum, and maximum ratios for selected analytes are given in **Table 14-3**. The mean ratio should be between 0.7 and 1.3.

When one of the results in a pair is a nondetection, then the other result should be less than two times the detection limit. **Table 14-4** identifies the

Table 14-2. Quality assurance collocated sampling. Summary statistics for analytes with more than eight pairs in which both results were above the detection limit

Matrix	Analyte	N ^(a)	%RSD ^(b)	Slope	r ² ^(c)	Intercept
Air	Gross alpha ^(d)	63	28.4	0.991	0.81	3.95×10^{-6} Bq/m ³
	Gross beta	103	13.7	0.973	0.92	2.83×10^{-5} Bq/m ³
	Beryllium	18	14.8	0.849	0.85	1.76 pg/m ³
	Tritium	25	32.3	0.703	0.95	0.0427 Bq/m ³
Groundwater	Gross beta ^(d)	22	34.6	3.51	0.04	-0.0262 Bq/L
	Arsenic	16	10.9	1.01	0.98	0.00104 mg/L
	Bicarbonate alk (as CaCO ₃)	9	4.01	0.875	0.92	31.5 mg/L
	Nickel ^(d)	9	23.6	0.41	0.78	0.00603 mg/L
	Nitrate (as NO ₃)	20	1.98	1.04	0.92	0.907 mg/L
	pH	9	0.37	0.941	0.95	0.49 Units
	Potassium	29	1.61	0.968	1.0	0.23 mg/L
	Uranium-234+233	19	9.33	0.954	1.0	0.00265 Bq/L
	Uranium-235+236 ^(d)	15	36.7	1.3	0.94	-0.000443 Bq/L
	Uranium-238	19	7.55	0.948	1.0	0.00186 Bq/L
Runoff (from rain)	Barium ^(d)	9	6.15	0.855	0.59	0.0218 mg/L
	Boron	9	8.32	1.22	1.0	-0.0835 mg/L
	Chromium ^(d)	9	3.63	1.1	0.78	0.000417 mg/L
	Copper ^(e)	9	12.9	0.655	0.64	0.00245 mg/L
	Iron ^(d)	9	37.8	1.07	0.42	0.73 mg/L
	Nickel ^(e)	9	23.6	0.964	0.51	0.002 mg/L
	pH	10	1.56	0.84	0.83	1.34 Units
Sewer	Gross beta	51	6.93	0.912	0.81	8.34×10^{-5} Bq/mL

a Number of collocated pairs included in regression analysis

b 75th percentile of percent relative standard deviations (%RSD) where $\%RSD = \left(\frac{200}{\sqrt{2}}\right) \frac{|x_1 - x_2|}{x_1 + x_2}$ and x_1 and x_2 are the reported concentrations of each routine-duplicate pair

c Coefficient of determination

d Outside acceptable range of slope or r² because of outliers

e Outside acceptable range of slope or r² because of variability

Table 14-3. Quality assurance collocated sampling. Summary statistics for selected analytes with eight or fewer pairs in which both results were above the detection limit

Matrix	Analyte	N	Mean ratio	Minimum ratio	Maximum ratio
Air	Uranium-234+233	3	1.2	0.65	1.8
	Uranium-238	3	1.5	0.89	2.1
Aqueous	Gross beta	6	1.2	0.72	2.1
	Tritium	6	0.99	0.62	1.6
Groundwater	Gross alpha	7	0.89	0.54	1.2
	Tritium	8	1.2	0.74	3
	Radium-226	6	0.94	0.65	1.4
Rain	Tritium	1	1.5	1.5	1.5
Runoff (from rain)	Gross alpha	1	1.3	1.3	1.3
	Gross beta	3	2.4	0.98	5.1
	Tritium	2	1.1	0.68	1.6
	Uranium-234+233	3	1.1	0.94	1.4
	Uranium-235+236	2	1.1	0.84	1.4
	Uranium-238	3	1.1	0.92	1.4
Soil	Gross alpha	1	0.59	0.59	0.59
	Gross beta	1	0.45	0.45	0.45
	Cesium-137	3	0.99	0.92	1.1
	Tritium	1	1	1	1
	Tritium	1	0.79	0.79	0.79
	Potassium-40	4	1	0.91	1.2
	Plutonium-238	1	1.7	1.7	1.7
	Plutonium-239+240	3	6.3	0.054	18
	Radium-226	4	1.1	0.96	1.1
	Radium-228	4	1	0.91	1.1
	Thorium-228	4	1	0.94	1.1
	Uranium-235	4	1	0.78	1.3
	Uranium-238	4	1	0.78	1.3
	Sewer	Gross alpha	7	0.83	0.41
Tritium		2	1	0.99	1
Vegetation	Tritium	5	1.5	0.71	3.6

Table 14-4. Quality assurance collocated sampling. Summary statistics for analytes with at least four pairs in which one or both results were below the detection limit.

Media	Analyte	Number of inconsistent pairs	Number of pairs	Percent of inconsistent pairs
Air	Uranium-234+233	1	9	11
	Uranium-235+236	2	24	8.3
	Uranium-238	2	9	22
Groundwater	Gross alpha	1	16	6.2
	Bis(2-ethylhexyl)phthalate	1	13	7.7
	Copper	1	18	5.6
	Nitrate (as NO ₃)	1	5	20
	Trichloroethene	1	18	5.6
Runoff (from rain)	Oil and grease	1	8	12
Sewer	Gross alpha	1	45	2.2
	Benzyl alcohol	1	4	25

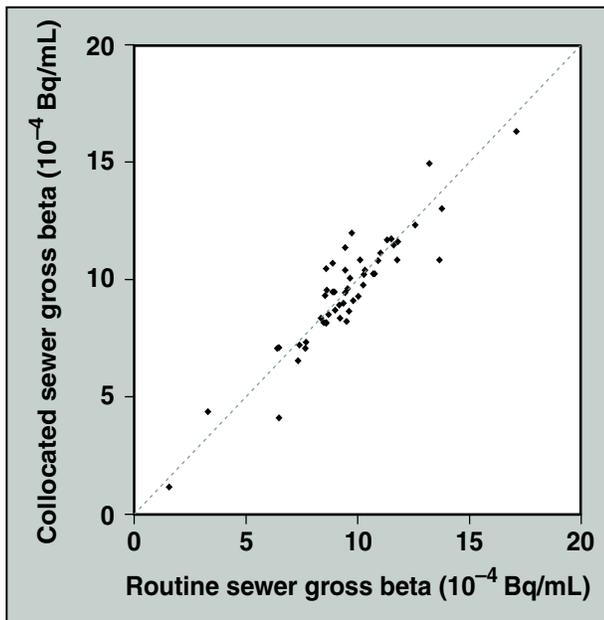


Figure 14-1. Gross beta concentrations from collocated samples. These samples lie close to a line with slope equal to 1 and intercept equal to 0.

sample media and analytes for which at least one pair failed this criterion. Analytes with fewer than four pairs are omitted from the table.

Collocated sample comparisons are more variable when the members of the pair are analyzed by different methods or with different criteria for analytical precision. For example, radiological analyses using different counting times or different laboratory aliquot sizes will have different amounts of variability. Different criteria are rarely, if ever, used in LLNL environmental monitoring sampling. Different criteria are sometimes used in special studies when more than one agency is involved.

Routine and collated sample results show good agreement: 90% of the pairs have a precision better than 20%. Data sets not meeting our precision criteria fall into one of two categories. The first category, outliers, can occur because of data

transcription errors, measurement errors, or real but anomalous results. Of the 31 data sets reported in [Table 14-2](#), 10 did not meet the criterion for acceptability because of outliers. [Figure 14-2](#) illustrates a set of collocated pairs with one outlier.

Three other results do not meet the criterion for acceptability because they consist of data sets where there is a lot of scatter. This tends to be typical of nondetections and measurements at extremely low concentrations, as illustrated in [Figure 14-3](#). Low concentrations of radionuclides on particulates in air highlight this effect, because one or two radionuclide-containing particles on an air filter can significantly affect results. Other causes of high variability are sampling and analytical methodology. Analyses of total organic carbon and total organic halides in water are particularly difficult to control. Of the 31 data sets in [Table 14-2](#), three show sufficient variability in results to make them fall outside the acceptable range.

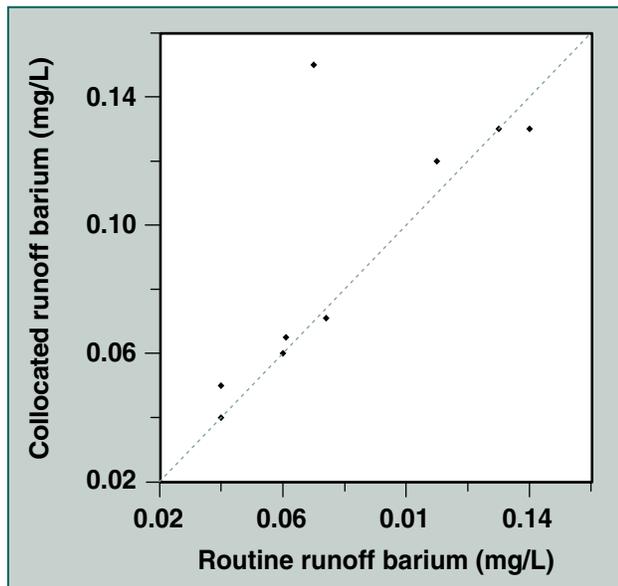


Figure 14-2. Runoff barium concentrations from collocated samples showing an outlier

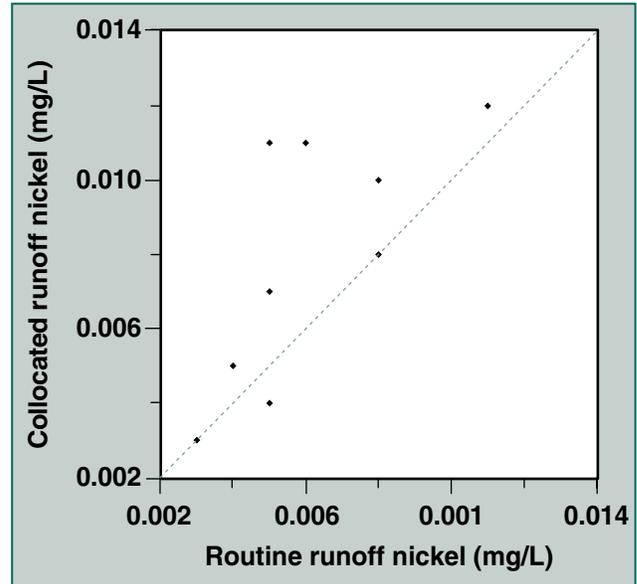


Figure 14-3. Runoff nickel concentrations from collocated samples showing a lot of scatter

Radiation Units

Data for 2001 have been reported in Système Internationale (SI) units to conform with standard scientific practices and federal law. Values in the text are reported in becquerels (Bq) and millisieverts (mSv); equivalent values in picocuries (pCi) and millirem (mrem) are given in parentheses.

See [Appendix D](#) for a more detailed discussion of radiation units.

Radiological Data

The precision of radiological analytical results is displayed in the Data Supplement tables as the 2σ uncertainty. The uncertainties are not used in summary statistic calculations. Any radiological result exhibiting a 2σ uncertainty greater than or equal to 100% is considered to be a nondetection. The reported concentration is derived from the number of sample counts minus the number of

background counts. Therefore, a sample with a low concentration may have a negative value; such results are reported in the tables and used in the calculation of summary statistics and statistical comparisons.

Some Data Supplement tables provide radioactivity limit-of-sensitivity values instead of a reported concentration when the radiological result is below the detection criterion. Such results are displayed in tables with a less-than symbol.

Nonradiological Data

Nonradiological data reported as being below the reporting limit are also displayed in tables with a less-than symbol. The reporting limit values are used in the calculation of summary statistics, as explained below.

Statistical Comparisons

Standard comparison techniques (such as regression, t-tests, and analysis of variance) have been used where appropriate to determine the statistical significance of trends or differences between means. When such a comparison is made, it is explicitly stated in the text as being “statistically significant” or “not statistically significant.” Other uses of the word “significant” in the text do not imply that statistical tests have been performed. Instead, these uses relate to the concept of practical significance and are based on professional judgment.

Summary Statistics

Determinations of measures of central tendency and associated measures of dispersion are calculated according to the *Environmental Monitoring Plan* (Tate et al. 1999). For data sets that do not contain values below the detection criterion, the measures of central tendency and dispersion are the median and interquartile range (IQR). The IQR is the

range that encompasses the middle 50% of the data set. The IQR is calculated by subtracting the 25th percentile of the data set from the 75th percentile of the data set. When necessary, the percentiles are interpolated from the data. Software vendors may use slightly different formulas for calculating percentiles. Radiological data sets that include values less than zero may have an IQR greater than the median.

For data sets with one or more, but fewer than one-half, of the values below the detection criterion, the measure of central tendency is the median. If the values of the detection limits and the number of values below the detection limit permit (determined on a case-by-case basis), dispersion is reported as the IQR. Otherwise, no measure of dispersion is reported. Statistics are calculated using the reported detection limit value for nonradiological data or the reported value for radiological data.

For data sets with one-half or more of the values below the detection criterion, the central tendency is reported as less than the median value. Dispersion is not reported.

Data Presentation

Analytical laboratory data, and values calculated from analytical laboratory data, are normally displayed with at most three significant digits. Significant trailing zeros may be omitted.

Summary statistics are calculated from values that have already been rounded (if necessary), and are then rounded to an appropriate number of significant digits.

Quality Assurance Process for the Environmental Report

Unlike the preceding discussion, which focused on standards of accuracy and precision in data acquisition and reporting, a discussion of QA/QC procedures for a technical publication must deal with how to retain content accuracy through the publication process. Because publication of a large, data-rich document like this site annual environmental report involves many operations and many people, the chances of introducing errors are great. At the same time, ensuring quality is more difficult because a publication is less amenable to the statistical processes used in standard quality assurance methods.

The QA procedure we used concentrated on the tables and figures in the report and enlisted authors, contributors, and technicians to check the accuracy of sections other than those they had authored or contributed to. In 2001, the illustrations and tables in the main volume and the tables in the Data Supplement were checked.

Checkers were assigned illustrations and tables and given a copy of each item they were to check along with a quality control form to fill out as they checked the item. Items to be checked included figure captions and table titles for clarity and accuracy, data accuracy and completeness, figure labels and table headings, units, significant digits, and consistency with text.

When checking numerical data, checkers randomly selected 10% of the data and compared it to values in the master database. If all 10% agreed with the database, further checking was considered unnecessary. If there was disagreement in the data, the checker compared another 10% of the data with the database values. If more errors were found, the entire table or illustration had to be checked against the data in the database.

A coordinator guided the process to ensure that forms were tracked and the proper approvals were obtained. Completed quality control forms and the corrected illustrations or tables were returned to the report editors, who were responsible for ensuring that changes, with the agreement of the original contributor, were made. This QA check resulted in the correction of data errors and omissions on 10% of the illustrations, 18% of the tables in the main volume, and 42% of the tables in the Data Supplement. Other corrections were made to footnotes, headings, titles in tables, graph axes, callouts, and captions in figures.

APPENDIX A.

METHODS OF DOSE CALCULATIONS

S. Ring Peterson

Introduction

Lawrence Livermore National Laboratory (LLNL) calculates doses to the public for radiation protection purposes using the U.S. Environmental Protection Agency's (EPA's) model, CAP88-PC (Parks 1992, 1997). Modeled doses are discussed in detail in Chapter 13. Emission rates of radionuclides from stacks and diffuse sources are used as input to CAP88-PC. Alternatively, doses may be calculated from concentrations in air, vegetation, water, and wine measured during routine monitoring. Because CAP88-PC is expected to overestimate doses to the public, doses calculated from environmental measurements should be lower, even when assumptions about intake rates are conservative. Calculating dose from measured environmental concentrations will reduce the uncertainty and increase the accuracy of the dose assessment.

Although various radionuclides are released to the environment in small quantities by LLNL activities, tritium is the only radionuclide that can be measured in the local food chain. Furthermore, tritium is the radionuclide primarily responsible for the low dose received by the public. Thus, although some of the equations presented in this chapter can be applied to any radionuclide, only the dose from tritium will be calculated and discussed here.

In this appendix, two different models that may be used to calculate dose from measured environmental concentrations are presented. One model, the Nuclear Regulatory Commission's (NRC) Regulatory Guide 1.109 (U.S. NRC 1977), has been used by LLNL since 1979 (Silver et al. 1980) to calculate ingestion doses from measured environmental concentrations of tritiated water (HTO). Doses have been based on the assumption of maximum annual intake of water, leafy vegetables, milk and meat. Inhalation doses have also been calculated based on measured air concentrations.

Equations that derive bulk transfer parameter values used in [Chapters 5, 7, and 11](#) to calculate doses from inhalation and ingestion of water and locally produced foodstuffs based on measured concentrations in the various media are presented here. Similarly, bulk transfer parameter values are derived to calculate the inhalation dose from predicted air concentrations of tritiated hydrogen gas (HT) and the immersion dose from swimming. In addition, for comparison, bulk transfer parameter values based on the NRC 1.109 equations with different assumptions are presented.

Doses that account for the contribution of organically bound tritium (OBT) are also calculated using NRC 1.109 HTO concentrations and consumption rates. These doses are compared with those predicted for 2001 by NEWTRIT, the other model used to calculate doses from environmental measurements in this appendix. NEWTRIT has been recently developed (Peterson and Davis 2002) and proposed to the Environmental Protection Agency (EPA) as an improved regulatory model to calculate dose contributions from OBT and doses from releases of both HTO and HT.

Overview of CAP88-PC, NRC 1.109 and NEWTRIT

The annual whole-body dose rate from ingestion of a particular food or drink is expressible as a product of three factors, regardless of model. These three factors are (1) the rate at which the food or drink is consumed (e.g., kg/y), (2) the radionuclide concentration in the food or drink (e.g., Bq/kg), and (3) the dose coefficient for the radionuclide (e.g., $\mu\text{Sv/Bq}$). Calculating the dose contribution from inhalation will be similar (e.g., $\text{m}^3/\text{y} \times \text{Bq}/\text{m}^3 \times \mu\text{Sv}/\text{Bq}$).

Each of the three models, CAP88-PC, NRC 1.109, and NEWTRIT, approaches this calculation of dose from exposure to environmental tritium in a somewhat different way. CAP88-PC and NRC 1.109 only calculate doses from HTO inhalation and ingestion, while NEWTRIT calculates doses from inhalation of HTO and HT and ingestion of HTO and OBT.

Given a source term (Ci/y), CAP88-PC calculates the air concentration (pCi/m^3) at a particular location using a Gaussian dispersion model. Assuming a default annual absolute humidity of $8 \text{ g}/\text{m}^3$, CAP88-PC calculates the concentration of HTO in air moisture. The HTO in vegetables, milk and meat is assumed in equilibrium with the HTO in air moisture. The daily diet is assumed to consist of 1560 g of water obtained from food and 1440 g of drinking water (Moore et al. 1979). The fractions of daily water obtained from food that represent vegetables, milk, and meat are 0.505, 0.310, and 0.185 respectively. For an atmospheric release of HTO, drinking water is assumed to have only 1% the tritium concentration of the air moisture because drinking water is assumed to be groundwater.

Measured concentrations of HTO in air (for inhalation dose), water (for drinking water dose), and vegetation (for dose from food ingestion) can be used in NRC 1.109 to calculate doses from exposure to tritium. The equations are shown in detail in the next section. Historically at LLNL, concentrations in milk and meat have been calculated based on the assumption that pasture ingested by animals has the same tritium concentration as the median measured concentration of HTO in vegetation. Ingestion dose to man was then calculated based on maximum annual intake rates of leafy vegetables, milk, and meat.

This approach, although still used for calculations in [Chapter 11](#) and demonstrated in the equations presented here, ignored the important contribution of tritium in the animal's drinking water to the concentration in the animal product. It also ignored the potential contribution to dose from vegetables other than leafy ones. For comparison with doses based on the highly unrealistic assumption of maximum annual intake that are reported in [Chapters 5, 7, and 11](#), dose calculations using NRC 1.109 will be presented that are based on an average annual intake of a fairly complete diet. The milk and meat concentrations that comprise that diet include the contributions from HTO in both ingested vegetation and drinking water.

NEWTRIT calculates doses from releases of HT and HTO based on predicted or measured air concentrations. The default absolute humidity, like that in CAP88-PC, is $8 \text{ g}/\text{m}^3$, but a site-specific absolute humidity may be substituted. The model is formulated in terms of the tritium-to-hydrogen ratio in each environmental compartment. However, with each transfer, a small reduction in the ratio is introduced to reflect dilution observed in nature. Drinking water for animals is assumed to have half the concentration

of air moisture because small bodies of water exhibit that level of contamination near an atmospheric source of tritium. Drinking water for people is assumed to have 10% the HTO concentration of air moisture, which is the concentration of tritium expected in a large body of water near an atmospheric source of tritium. NEWTRIT accounts for dose from ingested OB³T, as well as HTO. Based on experimental data, NEWTRIT accounts for the conversion of HT to HTO in the soil and the consequent emission of HTO to the atmosphere from the soil. Doses calculated from a release of HT include inhalation of HT, inhalation and skin-absorption of HTO, ingestion of HTO from drinking water and foods, and ingestion of OB³T from foods. Doses from a unit release of HT are expected to be about 10% those from a unit release of HTO, given the default absolute humidity. The diet in NEWTRIT is the same as that in GENII (Napier et al. 1988), and it is assumed that all the food ingested has been grown at the location at which the air concentrations have been estimated.

Each model recommends different consumption rates (see [Table A-1](#)). In Appendix E of the NRC Regulatory Guide 1.109, two annual diets are recommended, one for maximum intake and one for average intake. The diet shown for CAP88-PC is derived from water equivalent annual ingestion rates (kg/y) of vegetables, milk, and meat based on values for fresh weight, protein, carbohydrate, and fat fractions (Ciba-Geigy Ltd. 1981). Assumptions about the fractions of fruit, grain, root crops, and fruit vegetables that make up “plant products” come from NRC Regulatory Guide 1.109. Clearly, based on consumption alone (see [Table A-1](#)), doses from these models will be different.

Table A-1. Examples of annual inhalation and ingestion rates

	NRC 1.109 maximum	NRC 1.109 average	CAP88-PC	NEWTRIT
Leafy vegetables/other plant products (kg)	64/520	— ^(a) /190	— ^(a) /333	15/276
Milk (L)	310	110	183	230
Meat (kg)	110	95	113	98.5
Drinking water (L)	730	370	526	440
Inhalation (m ³)	8000	8000	8038	8521

^a Leafy vegetables are included with the other plant products.

Each of the three models uses different dose coefficients. The dose coefficients used in the calculations of HTO dose from NRC 1.109 were obtained from the committed dose equivalent tables for DOE dose calculations (U.S. DOE 1988). They are similar to those specified in ICRP 72, *Age dependent doses to members of the public from intake of radionuclides* (ICRP 1996), which are used in NEWTRIT. The dose calculation for inhalation of tritiated hydrogen (HT) gas uses a dose coefficient from ICRP 71, (ICRP 1995). A comparison of dose coefficients is shown in [Table A-2](#).

Assumptions play such a very important part in predicting dose that assumptions must be clearly elucidated, so that the apparent differences in dose predictions may be understood.

Table A-2. Comparison of dose coefficients for tritium ($\mu\text{Sv/Bq}$)

	DOE	CAP88-PC ^(a)	ICRP
HTO (inhalation, skin absorption)	1.73×10^{-5}	3.41×10^{-5}	1.8×10^{-5}
HT (inhalation)	$3.31 \times 10^{-13(b)}$	— ^(c)	1.8×10^{-9}
HTO (ingestion)	1.73×10^{-5}	2.43×10^{-5}	1.8×10^{-5}
OBT (ingestion)	— ^(c)	— ^(c)	4.2×10^{-5}

- a Computer code required by the EPA for modeling air emissions of radionuclides
- b Units are $\mu\text{Sv/Bq} \times \text{s/m}^3$ because dose is considered external from air submersion.
- c Not taken into account

Dose Calculation Methods

Although the analytical laboratories report concentrations in pCi and CAP88-PC’s dose coefficients have units of mrem/pCi, LLNL uses Système Internationale (SI) units of becquerel (Bq) for concentration and millisievert (mSv), microsievert (μSv), or nanosievert (nSv) for dose in compliance with Presidential Executive Order 12770, Metric Usage in Federal Government Programs (July 25, 1991). The conversion factors are as follows:

$$1 \text{ Bq} = 27 \text{ pCi}$$

$$1 \text{ mSv} = 100 \text{ mrem}; 1 \mu\text{Sv} = 0.1 \text{ mrem}; 1 \text{ nSv} = 0.1 \mu\text{rem}$$

All units have been converted to SI units throughout this appendix.

Note: In some of the following equations, the dimensions associated with a multiplicative factor are not shown explicitly; the dimensions of the dependent variable and measured quantity are shown explicitly.

Dose Calculation Methods for Chapters 5, 7, and 11 Using NRC 1.109

In the following subsections, equations from NRC 1.109 provide guidance to estimate the annual dose from inhalation and from tritium ingested from water (or wine) and food (e.g., leafy vegetables, milk, and meat) based on median observed values for 2001.

Calculating Annual Dose from Potable Water (Chapter 7)

The effective dose equivalent for tritium in drinking water (D_{water}) in $\mu\text{Sv/y}$ is calculated using the following equation:

$$D_{\text{water}} (\mu\text{Sv/y}) = U_w \times DC_{\text{HTO}} \times C_w \tag{A-1}$$

where

U_w = water consumption rate (L/y)

DC_{HTO} = dose coefficient for HTO ($\mu\text{Sv/Bq}$) (U.S. DOE 1988)

C_w = concentration of tritium measured in drinking water (Bq/L)

The tritium dose from ingestion of potable water, assuming maximum intake of water, is then

$$\begin{aligned} D_{\text{water}} (\mu\text{Sv/y}) &= 730 (\text{L/y}) \times 1.73 \times 10^{-5} (\mu\text{Sv/Bq}) \times C_w (\text{Bq/L}) \\ &= 1.3 \times 10^{-2} \times C_w (\text{Bq/L}) \end{aligned}$$

In Chapter 7, this equation is used to estimate doses from drinking water. Assuming different quantities are consumed, this equation can also be used to calculate the effective dose equivalent from wine (see Chapter 11).

Calculating Annual Dose from Food Ingestion (Chapter 11)

The effective dose equivalent from ingestion of food (D_{food}) is calculated by summing the dose contributions from leafy vegetables, meat, and milk to the diet. The concentrations in these foodstuffs are calculated from measured concentrations in annual grasses or weeds (see Chapter 11) using the equations from NRC Regulatory Guide 1.109.

Leafy Vegetables: For dose calculations, the assumption is that the leafy vegetables are 100% water; therefore, Bq/L = Bq/kg fresh weight.

$$D_{\text{veg}} (\mu\text{Sv/y}) = U_{\text{veg}} \times DC_{\text{HTO}} \times C_{\text{veg}} \quad (\text{A-2})$$

where

U_{veg} = intake rate of leafy vegetables (kg/y)

DC_{HTO} = dose coefficient for HTO ($\mu\text{Sv/Bq}$) (U.S. DOE 1988)

C_{veg} = concentration measured in annual grasses and weeds (Bq/L)

The tritium dose from ingestion of leafy vegetables, assuming maximum intake, is then

$$\begin{aligned} D_{\text{veg}} (\mu\text{Sv/y}) &= 64 (\text{kg/y}) \times 1.73 \times 10^{-5} (\mu\text{Sv/Bq}) \times C_{\text{veg}} (\text{Bq/kg}) \\ &= 1.1 \times 10^{-3} \times C_{\text{veg}} (\text{Bq/L}) \end{aligned}$$

Meat (Beef): To calculate dose from ingestion of meat, first the concentration of tritium in the meat must be calculated from the measured concentration in vegetation.

$$C_{\text{meat_veg}} = F_f (\text{d/kg}) \times Q_f (\text{kg/d}) \times C_{\text{veg}} (\text{Bq/kg}) \times \exp(-\lambda_i t_s) \quad (\text{A-3})$$

where

F_f = average fraction of an animal's daily intake of radionuclide appearing in each kilogram of animal flesh [(Bq/kg) in meat per (Bq/d) ingested by the animal] = 1.2×10^{-2} d/kg

Q_f = amount of feed consumed = 50 kg/d

C_{veg} = concentration measured in vegetation (Bq/kg)

λ_i = radiological decay constant = 1.5×10^{-4} /d

t_s = time from slaughter to consumption = 20 d

Therefore

$$\begin{aligned} C_{\text{meat_veg}} &= 1.2 \times 10^{-2} (\text{d/kg}) \times 50 (\text{kg/d}) \times C_{\text{veg}} (\text{Bq/kg}) \times \exp[(-1.5 \times 10^{-4}) \times 20] \\ &= 0.6 \times C_{\text{veg}} (\text{Bq/kg}) \end{aligned}$$

The dose from ingestion of meat is calculated:

$$D_{\text{meat}} (\mu\text{Sv/y}) = U_{\text{meat}} \times C_{\text{meat}} \times DC_{\text{HTO}} \quad (\text{A-4})$$

where

U_{meat} = maximum intake rate (kg/y)

C_{meat} = predicted concentration in meat at time of consumption from the contribution of vegetation
= $C_{\text{meat_veg}}$ (Bq/kg)

DC_{HTO} = dose coefficient for HTO ($\mu\text{Sv/Bq}$) (U.S. DOE 1988)

The tritium dose rate from meat consumption is then

$$\begin{aligned} D_{\text{meat}} (\mu\text{Sv/y}) &= 110 (\text{kg/y}) \times [0.6 \times C_{\text{veg}} (\text{Bq/kg})] \times 1.73 \times 10^{-5} (\mu\text{Sv/Bq}) \\ &= 1.1 \times 10^{-3} \times C_{\text{veg}} (\text{Bq/L}) \end{aligned}$$

Cow Milk: To calculate dose from ingestion of milk, first the concentration of tritium in the milk must be calculated from the measured tritium concentration in vegetation.

$$C_{\text{milk_veg}} = F_m \text{ (d/L)} \times Q_f \text{ (kg/d)} \times C_{\text{veg}} \text{ (Bq/kg)} \times \exp(-\lambda_i t_f) \quad (\text{A-5})$$

where

F_m = average fraction of an animal's daily intake of radionuclide appearing in each kilogram of milk
 [(Bq/L) in milk per (Bq/d) ingested by the animal] = 1.0×10^{-2} d/L

Q_f = amount of feed consumed by the milk cow = 50 kg/d

C_{veg} = concentration measured in vegetation (Bq/kg)

λ_i = radiological decay constant = 1.5×10^{-4} /d

t_f = time from milking to milk consumption = 2 d

Therefore

$$\begin{aligned} C_{\text{milk_veg}} &= 1.0 \times 10^{-2} \text{ (d/L)} \times 50 \text{ (kg/d)} \times C_{\text{veg}} \text{ (Bq/kg)} \times \exp[(-1.5 \times 10^{-4}) \times 2] \\ &= 0.5 \times C_{\text{veg}} \text{ (Bq/L)} \end{aligned}$$

The dose from consumption of milk is calculated:

$$D_{\text{milk}} \text{ (}\mu\text{Sv/y)} = U_{\text{milk}} \times C_{\text{milk}} \times DC_{\text{HTO}} \quad (\text{A-6})$$

where

U_{milk} = maximum intake rate (L/y)

C_{milk} = predicted concentration in milk at time of consumption from the contribution of vegetation
 = $C_{\text{milk_veg}}$ (Bq/kg)

DC_{HTO} = dose coefficient for HTO ($\mu\text{Sv/Bq}$)

The tritium dose rate from directly consumed milk is then

$$\begin{aligned} D_{\text{milk}} \text{ (}\mu\text{Sv/y)} &= 310 \text{ (L/y)} \times [0.5 \times C_{\text{veg}} \text{ (Bq/kg)}] \times 1.73 \times 10^{-5} \text{ (}\mu\text{Sv/Bq)} \\ &= 2.7 \times 10^{-3} \times C_{\text{veg}} \text{ (Bq/L)} \end{aligned}$$

Total Food Ingestion: The annual dose from food ingestion as calculated in Chapter 11 based on measured HTO in vegetation is then:

$$D_{\text{food}} (\mu\text{Sv}/\text{y}) = D_{\text{veg}} + D_{\text{meat}} + D_{\text{milk}} \quad (\text{A-7})$$

where

$$D_{\text{veg}} = \text{dose from ingestion of leafy vegetables } (\mu\text{Sv}/\text{y})$$

$$D_{\text{meat}} = \text{dose from ingestion of meat } (\mu\text{Sv}/\text{y})$$

$$D_{\text{milk}} = \text{dose from ingestion of milk } (\mu\text{Sv}/\text{y})$$

Therefore

$$\begin{aligned} D_{\text{food}} (\mu\text{Sv}/\text{y}) &= 1.1 \times 10^{-3} \times C_{\text{veg}} (\text{Bq}/\text{L}) && (\text{dose from leafy vegetables}) \\ &+ 1.1 \times 10^{-3} \times C_{\text{veg}} (\text{Bq}/\text{L}) && (\text{dose from meat}) \\ &+ 2.7 \times 10^{-3} \times C_{\text{veg}} (\text{Bq}/\text{L}) && (\text{dose from milk}) \\ &= 4.9 \times 10^{-3} \times C_{\text{veg}} (\text{Bq}/\text{L}) \end{aligned}$$

Calculating Annual Inhalation and Skin Absorption Doses of HTO (Chapter 5)

Doses caused by inhalation of tritium-contaminated air can be estimated in a way analogous to the preceding treatment of ingestion doses. The starting point is to evaluate the tritium concentration in air, χ (Bq/m^3), at the location of interest. Measurements of tritium in air are found in Chapter 5.

The dose from HTO arises from the processes of inhalation and skin absorption. For inhalation/skin absorption dose, the known concentration of tritium in the air is multiplied by the inhalation rate of a human to obtain the number of becquerels of tritium inhaled. Dose coefficients provided by the DOE (U.S. DOE 1988) are used to relate the intake of radioactive material into the body to dose commitment. The dose coefficient for inhalation is the same as for ingestion. However, to account for skin absorption, the inhalation factor is multiplied by 1.5. These dose factors provide estimates of the 50-year dose from a one-year intake of radioactivity.

The inhalation/skin absorption dose is expressible as

$$D_{\text{inh/sa}} (\mu\text{Sv}/\text{y}) = 1.5 \times U_{\text{air}} \times C_{\text{air}} \times DC_{\text{HTO_inh}} \quad (\text{A-8})$$

where

1.5 = factor that accounts for skin absorption

U_{air} = air intake rate (m^3/y)

C_{air} = HTO concentration measured in air at the receptor (Bq/m^3)

$DC_{\text{HTO_inh}}$ = dose coefficient for inhalation ($\mu\text{Sv}/\text{Bq}$) (U.S. DOE 1988)

The whole-body inhalation/skin-absorption dose rate from HTO is then

$$\begin{aligned} D_{\text{inh/sa}} (\mu\text{Sv}/\text{y}) &= 1.5 \times 8000 \text{ m}^3/\text{y} \times C_{\text{air}} \times 1.73 \times 10^{-5} \mu\text{Sv}/\text{Bq} \\ &= 0.21 \times C_{\text{air}} (\text{Bq}/\text{m}^3) \end{aligned}$$

Doses in [Chapter 5](#) are calculated as shown here. The breathing rate of $8000 \text{ m}^3/\text{y}$ was corrected in 1999 from the $8400 \text{ m}^3/\text{y}$ used in previous years to conform to NRC 1.109.

Guidance to Calculate Annual Ingestion Dose with NRC 1.109 Using Modified Assumptions: Drinking Water for Animals and Annual Average Ingestion Rates for People

The calculations shown above of ingestion dose for Chapter 11, historically used to calculate doses from measurements at LLNL, do not account for ingestion of tritiated drinking water by animals, and yet drinking water is an important pathway. In 1998, in this appendix, a new approach to calculating the ingestion dose using NRC 1.109 was introduced that included drinking water for animals. In 1999, two further changes were introduced: (1) the annual ingestion rate for an individual was changed to include produce as well as leafy vegetables and (2) average ingestion rates replaced maximum ingestion rates (see [Table A-1](#)).

To calculate concentrations of tritium in meat and milk resulting from ingestion of water, the contribution of drinking water must be calculated using eqs A-3 and A-5 with two substitutions: (1) the daily intake of water (50 L/d for beef cattle and 60 L/d for milk cows) must replace daily intake of pasture and (2) the measured concentration in potable water must replace the measured concentration in vegetation. When dose is calculated using eqs A-4 and A-6, the tritium contributed by drinking water must be added to the tritium contributed by the vegetation to obtain the concentration in meat or milk from both ingestion sources.

To calculate dose from average rather than maximum ingestion rates, the average NRC 1.109 consumption rates from [Table A-1](#) are substituted into eqs A-1, A-2, A-4, and A-6.

Complete equations that account for these assumptions may be found in Larson et al. (2000). Bulk transfer factor parameter values based on these assumptions have been calculated using eqs A-1 through A-6. They are summarized and compared in **Table A-3** with the values used for the calculations in **Chapters 5, 7,** and **11**.

Table A-3. Comparison of the two sets of bulk transfer factors based on different assumptions to calculate doses using NRC 1.109

Doses	Assumptions for SAER	Alternate assumptions: tritium in milk and meat comes from pasture and drinking water; average annual diet	
Inhalation and skin absorption: $D_{inh/sa}$	See Chapter 5 $0.21 \times C_{air}$ (Bq/m ³)	$0.21 \times C_{air}$ (Bq/m ³)	
Drinking water: D_{water}	See Chapter 7 $1.3 \times 10^{-2} \times C_w$	$6.4 \times 10^{-3} \times C_w$	
Food Ingestion:	See Chapter 11 Factor $\times C_{veg}$ (Bq/kg)	Factor $\times C_{veg}$ (Bq/kg)	Factor $\times C_w$ (Bq/L)
D_{veg}	1.1×10^{-3}	3.3×10^{-3} +	NA
D_{meat}	1.1×10^{-3}	9.9×10^{-4} +	9.9×10^{-4}
D_{milk}	2.7×10^{-3}	9.5×10^{-4} +	1.1×10^{-3}

Method to calculate dose from ingestion of OB

Models that account only for dose from HTO have come under attack in recent years. As shown in **Table A-2**, the dose coefficient for OB is 2.3 times greater than that of HTO. When it is assumed (as in CAP88-PC and NRC 1.109) that all ingested tritium is HTO, there is a possibility, depending on other assumptions in the models, that dose may be underestimated. It is easy enough to calculate the probable contribution of OB to dose, even from a model that only calculates concentrations of HTO and dose from HTO.

At LLNL, the HTO concentration of the plant water is measured in Bq/L. The concentration of tritium in fresh weight plant is the sum of the tritium in the water fraction (HTO) plus the tritium in the dry matter fraction (OB):

$$\begin{aligned}
 \text{Bq/kg fresh weight plant} &= (\text{Bq/L (measured HTO)} \times F_{fw}) \\
 &+ (\text{Bq/L (measured HTO)} \times F_{dm} \times W_{eq}) \qquad \qquad \qquad \text{(A-9)}
 \end{aligned}$$

where

F_{fw} = water fraction of the plant (L/kg)

F_{dm} = dry matter fraction of the plant (kg/kg)

W_{eq} = water equivalent factor (L/kg) = amount of water generated through the combustion of the dry material in the sample = [(percent protein \times 0.07) + (percent fat \times 0.12) + (percent carbohydrate \times 0.062)] / 100 \times (1/fraction of mass of water that is hydrogen)

where

0.07 = fraction of hydrogen in proteins

0.12 = fraction of hydrogen in fats

0.062 = fraction of hydrogen in carbohydrates

2/18 = fraction of mass of water that is hydrogen

Values of water fractions and fractions of protein, fat, carbohydrate, and ash for a wide variety of foodstuffs can be found in Ciba-Geigy Ltd. (1981). The W_{eq} varies with the type of food and can be calculated from these data. A median value of W_{eq} for a normal array of foodstuffs is about 0.6 L/kg.

Similarly, concentrations of HTO and OBT per kilogram milk or meat can be estimated based on the total concentrations of milk and meat calculated using eqs A-3 and A-5, including the contribution of drinking water.

Examples of concentrations of various foodstuffs based on the 2001 median tritium concentrations in plant water (4.8 Bq/L) and rain water (0.69 Bq/L) at VIS (**Table A-4**) are shown below. These equations follow the format of eq A-9, where the total concentration of tritium per kilogram edible food is the sum of the HTO and OBT contributions, respectively.

Lettuce $(4.8 \times 0.948) + (4.8 \times 0.052 \times 0.602) = 4.55 + 0.15 = 4.7$ Bq/kg fresh weight

Potato $(4.8 \times 0.798) + (4.8 \times 0.202 \times 0.568) = 3.83 + 0.55 = 4.38$ Bq/kg fresh weight

Whole milk $(2.8 \times 0.885) + (2.8 \times 0.115 \times 0.746) = 2.49 + 0.24 = 2.73$ Bq/kg fresh weight

Lean sirloin $(3.3 \times 0.718) + (3.3 \times 0.282 \times 0.724) = 2.36 + 0.67 = 3.03$ Bq/kg fresh weight

To calculate dose that accounts for OBT, the concentration of HTO or OBT in each foodstuff must be multiplied by the appropriate dose coefficient (**Table A-2**) and by the quantity consumed. The total food ingestion dose is then the sum of the HTO and OBT dose contributions.

Method to calculate dose from inhalation of HT

In the recent past, HT doses were treated as immersion doses (Eckermann and Ryman 1993) because HT has a low-energy beta particle and behaves similarly to ^{41}Ar . However, the dose from HT is dominated by the small fraction that is metabolized. HT is therefore treated as a soluble gas (ICRP 1995), and an inhalation dose is calculated.

For tritium gas (HT), an inhalation dose is expressible as

$$D_{\text{inh_HT}} (\mu\text{Sv}/\text{y}) = C_{\text{air_HT}} \times U_{\text{air}} \times \text{DC}_{\text{HT}} \quad (\text{A-10})$$

where

$C_{\text{air_HT}}$ = concentration of HT in air at location X; estimated by dispersion modeling (Bq/m^3)

U_{air} = air intake rate (m^3/y)

DC_{HT} = effective dose per unit intake ($\mu\text{Sv}/\text{Bq}$) (ICRP 1995)

Therefore

$$D_{\text{inh_HT}} (\mu\text{Sv}/\text{y}) = C_{\text{air_HT}} (\text{Bq}/\text{m}^3) \times 8000 \text{ m}^3/\text{y} \times 1.8 \times 10^{-9} \mu\text{Sv}/\text{Bq}$$

The tritium dose rate from inhalation of HT is then (based on predicted HT in air):

$$D_{\text{inh_HT}} (\mu\text{Sv}/\text{y}) = 1.4 \times 10^{-5} \times C_{\text{air_HT}} (\text{Bq}/\text{m}^3)$$

Method to calculate dose from swimming

Immersion in water is another pathway to dose from tritium because tritium can be absorbed through the skin. The intake of water by skin diffusion is 0.4 mL/min (Osborne 1968). A high estimate of time spent swimming in the LLNL pool would be 250 hours a year. The amount of water absorbed through the skin in this period would be 6 L.

Dose from immersion in water can be expressed as:

$$D_{\text{imm_HTO}} (\mu\text{Sv}/\text{y}) = C_{\text{pool}} (\text{Bq}/\text{L}) \times U_{\text{pool}} (\text{L}/\text{y}) \times \text{DC}_{\text{HTO}} (\mu\text{Sv}/\text{Bq}) \quad (\text{A-11})$$

where

C_{pool} = median annual concentration of HTO in the LLNL swimming pool (Bq/L)

U_{pool} = intake rate of water through the skin (L/y)

DC_{HTO} = effective dose per unit intake HTO ($\mu\text{Sv/Bq}$) (ICRP 1996)

The whole-body skin absorption dose from swimming is:

$$\begin{aligned} D_{\text{imm_HTO}} (\mu\text{Sv/y}) &= C_{\text{pool}} (\text{Bq/L}) \times 6 \text{ L/y} \times 1.8 \times 10^{-5} \mu\text{Sv/Bq} \\ &= 1.1 \times 10^{-4} C_{\text{pool}} (\text{Bq/L}) \end{aligned}$$

Dose Predictions

Regulatory Dose Predictions

Observed and Predicted Input to Models

Concentrations of tritium in the air ([Chapter 5](#)) are monitored at 8 perimeter locations, including the Visitors Center (VIS), which is a convenient location for comparing doses from different modeling approaches because measurements of tritium in vegetation and rainfall are also taken at VIS. Furthermore, VIS is close to the location of the site-wide maximally exposed individual.

Median concentrations measured in the air, vegetation ([Chapter 11](#)) and rainwater ([Chapter 7](#)) for VIS are shown in [Table A-4](#) along with air concentrations at VIS predicted for releases from the Tritium Facility and the Building 612 yard by CAP88-PC. If the contribution of all LLNL sources of tritium had been estimated at VIS, the predicted concentrations of tritium in air would be somewhat higher. The concentrations of tritium in wine ([Chapter 11](#)) and the LLNL swimming pool ([Chapter 7](#)) are also shown in [Table A-4](#).

Table A-4. Observed tritium concentrations in various environmental media at VIS and in the vicinity of Livermore, and concentrations of HTO and HT in the air at VIS predicted by CAP88-PC from releases from the Tritium Facility and the Building 612 yard. All data are for 2001.

	Median Observed HTO Concentrations	Predicted Tritium Concentrations
Air concentration (Bq/m^3)		
HTO	0.058	0.063
HT	n/a ^(a)	0.0024
Vegetation (Bq/L)	4.8	n/a ^(a)
Rain (Bq/L)	0.69 ^(b)	n/a ^(a)
Livermore Valley Wine (Bq/L)	1.5	n/a ^(a)
LLNL Swimming Pool (Bq/L)	0.34 ^(b)	n/a ^(a)

a n/a = not applicable

b = Below the normal limit of detection

CAP88-PC doses are calculated based on measured or estimated source terms. Doses using NEWTRIT can be estimated using either observed or predicted air concentrations. Measured concentrations in vegetation, air, and rainfall can be used as input to NRC 1.109 to calculate doses. The assumption for all calculations is that the exposed person never leaves the Visitors Center and is entirely self-sufficient in that all vegetables (including grain) ingested are grown at the Visitors Center. Furthermore, all animals used for food live there too and consume pasture grown there.

Drinking water for both animals and people (in NRC 1.109) is rainwater at the median concentration for the entire year. The assumption that drinking water has the concentration of rain water is usually conservative and should result in a higher estimated dose than the true probable dose in the Livermore Valley because Livermore Valley drinking water comes primarily from distant sources or from groundwater, neither of which is affected by locally emitted tritium. The use of different models and different assumptions will result in very different dose predictions ([Table A-5](#) and [Table A-6](#)). Because the protection of the public is paramount, it should be shown by more than one model and more than one set of assumptions that the dose to the public is acceptably low.

Comparison of Model Predictions for inhalation and ingestion of HTO: CAP88-PC and NRC 1.109

Results in [Table A-5](#) compare doses predicted by CAP88-PC and the NRC 1.109 model with two different sets of assumptions. Results for NRC 1.109 in the middle column of [Table A-5](#) were calculated using the historical assumptions that have been used in the SAER for dose calculations in the appropriate chapters (i.e., no drinking water for animals and maximum annual ingestion rates of leafy vegetables, milk and meat). Numbers for NRC 1.109 in the right-hand column were calculated based on the assumption of drinking water for animals and an annual average diet. All results are based on the assumption that ingested tritium is only HTO.

The CAP88-PC predictions are all higher than either set of NRC results except for drinking water. The default assumption in CAP88-PC is that drinking water is only 1% as contaminated as air moisture (or 0.073 Bq/L); in NRC 1.109, the assumption has been made that the individual is drinking water with a concentration of 0.69 Bq/L (equal to rain water). Thus, for 2001, the dose from drinking water in NRC 1.109 can be as much as nearly 20% of the total dose, depending upon other assumptions, while in CAP88-PC, the drinking water contribution is about 1% of the total dose. This illustrates the importance of tritium concentrations in drinking water to total dose.

Comparison of Model Predictions for HTO inhalation and ingestion and OBT ingestion: NRC 1.109 and NEWTRIT

Using the assumptions of the NRC 1.109 model (animals drink rainwater and the annual diet is average) and estimated concentrations of HTO and OBT in Bq/kg fresh weight of food, doses for total tritium (HTO and OBT) can be calculated for NRC 1.109 ([Table A-6](#)). The contribution of OBT increases the doses over those shown for NRC 1.109 in [Table A-5](#) by 31%, 15% and 43% for vegetables (including grain), milk, and meat respectively.

Table A-5. Comparison of hypothetical annual doses from only HTO at the Visitors Center

Dose (nSv/y)	CAP88-PC ^(a) (from predicted air concentrations)	NRC 1.109 (from observed concentrations)— SAER assumptions	NRC 1.109 (from observed concentrations)— new assumptions
Inhalation and skin absorption	17.	12	12
Vegetables	55.	5.3	16
Milk	[34.]	13	5.3
Meat	20.	5.3	5.4
Drinking water	1.0	9.0	4.4
Total ingestion dose (food and water)	76. [110.]	33.	31.
Total dose from HTO	93. [127.]	45.	43.

a Numbers in brackets (e.g., dose from milk) are not calculated for reported LLNL doses. See *LLNL NESHAPs 2000 Annual Report* (Gallegos et al. 2001), *Guidance for Radiological Dose Assessment* (Harrach 1999), and [Chapter 13](#). Doses from CAP88-PC are based on predicted HTO concentrations at VIS for B331 and the B612 yard ([Table A-4](#)).

Table A-6. Comparison of hypothetical annual doses from HTO and OBT at the Visitors Center

Dose (nSv/y)	NRC 1.109 (from observed air and vegetation concentrations) ^(a)	NEWTRIT ^(b) for HTO (from observed air concentrations)	NEWTRIT ^(b) for released HTO (from predicted air concentrations)	NEWTRIT ^(b) for released HT (from predicted air concentrations)
Inhalation	12.	13.	14.	0.035
Vegetables ^(b)	21.	34.	36.	0.16
Milk	6.1	22.	22.	0.079
Meat	7.7	11.	11.	0.036
Drinking water	4.4	5.8	6.0	0.015
Total ingestion (food and water)	39.	73.	75.	0.29
Total dose from HTO and OBT	51.	86.	89.	0.33

a This column corresponds to the far right column in [Table A-5](#) but accounts for OBT.

b The total tritium dose predicted by NEWTRIT for HT and HTO released from the Tritium Facility will be the sum of the NEWTRIT results for predicted air concentrations of HT and HTO or the sum of the HT results for predicted air concentrations plus the HTO results based on observed air concentrations. NEWTRIT was used in default mode.

c Includes leafy vegetables, fruit, fruit vegetables, root vegetables and grain

In **Table A-6**, doses from NRC 1.109 that account for OBT are compared with doses calculated by NEWTRIT. Differences are due to different assumptions about diets (see **Table A-1**) and the fact that NEWTRIT's concentrations in vegetables, milk, and meat are higher than those of NRC 1.109. NEWTRIT's concentrations are driven by the tritium concentration in air moisture (7.3 Bq/L, the 2001 median value), which results in a higher concentration in vegetation water (6.5 Bq/L) than was observed (4.8 Bq/L). Furthermore, the drinking water tritium contribution to milk and meat is greater for NEWTRIT than for NRC 1.109 for 2001. The contribution of drinking water to human dose in NRC 1.109 is similar to that of NEWTRIT. 10% of the median air moisture concentration measured at VIS is 0.73 Bq/L, which is about the same as the concentration of rainwater, but NEWTRIT's drinking water ingestion rate is higher (**Table A-1**).

Also shown in **Table A-6** is the estimated dose from the release of HT from the Tritium Facility. A tiny contribution to total dose from inhalation (3.7×10^5 nSv/y, not shown explicitly) arises from air concentrations of tritiated hydrogen (HT) gas, based on an air concentration of 0.0024 Bq/m³ estimated by the dispersion model in CAP88-PC. The inhalation dose, shown in **Table A-6**, from the release of HT is due to conversion of HT to HTO in the soil and the emission of HTO to air. Emitted HTO is incorporated into plants. For 2001, the release rate of HT was very small compared with the release of HTO from the Tritium Facility. As a result, the dose from HT is only about 0.4% that of the dose from the released HTO. Measured HTO concentrations in air and vegetation account for the dose from any HT that has been converted to HTO in the environment.

The assumptions behind the models in **Table A-5** and **Table A-6** are all designed to predict highly conservative doses for regulatory purposes that will not be exceeded by any member of the public. The lowest dose from **Table A-5** and **Table A-6** (43 nSv/y for NRC 1.109, assumptions of animal drinking water and average diet) is about a factor of three below the highest dose, which was calculated with CAP88-PC for a complete diet.

Realistic Dose Estimates

NEWTRIT is the model best suited for a realistic dose assessment because it accounts for doses from releases of HT and HTO separately and determines the contribution of OBT to dose. Furthermore, its default parameter values may be altered to account for site-specific data. For example, in this calculation, the average absolute humidity for 2001 at LLNL (7.6 g/m³) was used instead of the default (8 g/m³). If it were possible for a person to live at the Visitors Center, it would still be highly unlikely that they would spend all their time there, or that all their food would be homegrown. This person also might drink local wine and swim in the LLNL swimming pool. Doses from swimming and drinking wine can be calculated with the equations presented in this appendix. Doses for 2001, based on realistic yet conservative assumptions, are shown in **Table A-7**.

The total annual "realistic" dose from **Table A-7** is therefore 23 nSv/y, a factor of about 5.5 below the maximum dose predicted by CAP88-PC, and a factor of 3.7 below the dose from observed concentrations predicted by NEWTRIT, neither of which accounts for wine or swimming.

Table A-7. Realistic, yet conservative, assumptions and consequent doses for the tritium exposure of an individual living at the Visitors Center in 2001 based on observed HTO in air concentrations and predicted HT in air concentrations

Source of dose	Annual dose (nSv)	Assumption
Inhalation	8.9	Breathes air at VIS 16 hours a day, all year
Ingesting food, including OBT	13.0	Raises and eats 50% homegrown leafy vegetables, fruit vegetables, fruits and root crops, no homegrown milk or grain and 20% homegrown meat (chickens and eggs). Assume the feed for the chickens is 50% homegrown; chickens drink water from puddles at 50% air moisture.
Drinking water	0.61	Drinks well water at 1% the concentration of air moisture.
Drinking wine	1.4	Drinks one bottle of Livermore Valley wine each week
Immersion	0.015	Swims in the LLNL pool 100 hours per year

All calculated doses presented here are about 1% or less of the EPA's radiation dose limit to the member of the public from an atmospheric release (100 $\mu\text{Sv}/\text{y}$). CAP88-PC's dose, by far the highest, is just 1.3% of an annual effective dose equivalent of 10 μSv , which corresponds to the National Council on Radiation Protection and Measurements' (1987a) concept of Negligible Individual Risk Level. Thus, even though artificially high, this dose is still small.

APPENDIX B.

ENVIRONMENTAL DOE ORDERS IN WORK SMART STANDARDS

Topic	Order number and title	Relevant portion
Sanitary Sewer Discharges	DOE O 5400.5 Chg. 2, Radiation Protection of the Public and the Environment	Chapter I, Paragraph 5.b., Treatment of Liquid Radioactive Waste Streams (using BAT)
		Chapter I, Paragraph 7, Discharges to Sanitary Sewer
		Chapter II, Paragraph 3.d.2, Controlling Long-term Buildup of Radionuclides in Solids
CERCLA:Site Remediation	DOE O 414.1, Quality Assurance	Attachment 1, Contractor Requirements Document
Environmental Monitoring	DOE O 231.1, Environment, Safety, and Health Reporting	Paragraph 5.d.2, Annual Site Environmental Reports (requires report on annual basis)—included in DOE O 231.1 Chg. 2, ES&H Reporting, Paragraph 3. Applicability, and Attachment 1, Contractor Requirements Document
	DOE O 5400.1, General Environmental Protection Program	Chapter III, Paragraph 4.a., Groundwater Protection Management Program, and Chapter IV, paragraph 1.a. Requirement for Environmental Monitoring, 3. Preoperational Monitoring of Facilities, Sites, and Operations, 4. Environmental Monitoring Plan, 5. Environmental Monitoring General Requirements, 6. Meteorological Monitoring Requirements, and 10.c. Laboratory Quality Assessment—included in DOE O 5400.1 Chg. 1, Chapter III, Paragraph 4(a), 4(b), 4(c) and Chapter IV, Paragraph 1(a), 3, 4, 5, 6, and 10(c)
	DOE O 5400.5 Chg. 2, Radiation Protection of the Public and the Environment	Chapter II, Requirements for Radiation Protection of the Public and the Environment, Paragraph 1 (except 1.a.3.c. and 1.c), Public Dose Limits, 2. ALARA, 5. Release of Property Having Residual Radioactive Material, 6. Demonstration of Compliance with the Dose Limits, and 8.a. Record Content
		Chapter III, Derived Concentration Guides for Air and Water
		Chapter IV, Residual Radioactive Material
Water Discharges — Storage Tanks	DOE O 420.1 Chg 2, Facility Safety	§ 4.4 Natural Phenomena Hazards Mitigation for DOE facilities—included in DOE O 420.1 Chg. 2, Facility Safety, Attachment 2, Contractor Requirements Document, Paragraph 4 (except 4.1.2, 4.1.3, and excluding the invocation of ANS 8.9, ANS 8.10, and ANS 8.17)
Waste—Radioactive	DOE O 435.1, Radioactive Waste Management	Attachment 1, Contractor Requirements Document
Waste Minimization/ Pollution Prevention	DOE O 5400.1 Chg. 1, General Environmental Protection Program	Chapter III, Paragraph 4.a, 4.b, 4.c and Chapter IV, Paragraph 1.a, 3, 4, 5, 6, and 10.c

APPENDIX C.

REPORTS FOR REGULATORY AGENCIES

Title	Agency	Frequency
AB2588 Emissions Report	Bay Area Air Quality Management District San Joaquin Valley Unified Air Pollution Control District	Every 2 years
Air Emission Permit Renewals and Emissions Report	Bay Area Air Quality Management District San Joaquin Valley Unified Air Pollution Control District	Yearly
Recycling Unit Contingency/Business Plans	Department of Toxic Substances Control	As required
Conditional Exemption Unit Contingency Plans	Department of Toxic Substances Control	As required
PCB Annual Report	Environmental Protection Agency	Yearly
Medical Waste Permit	Alameda County Emergency Health Services and Department of Public Health Services, San Joaquin County	As required
Explosive Waste Treatment Facility—Site 300 Permit	Department of Toxic Substances Control	Every 10 years
Main Site Part A&B Hazardous Waste Permit (includes contingency plans and closure plans)	Department of Toxic Substances Control	Every 10 years
Site 300 Container Storage Area (B883) and Explosive Waste Storage Facility Permit	Department of Toxic Substances Control	Every 10 years
Cultural Resource Management Plan	Department of Energy California State Historic Preservation Officer	As required
RCRA Section 3016 Report, Inventory of Federal Agency Hazardous Waste Facilities	Department of Energy Environmental Protection Agency	As required
Less-than-90-Day Waste Accumulation Area Contingency Plans	Department of Toxic Substances Control	As required
SB14 Documentation Plan	Department of Toxic Substance Control	Every 4 years
Ozone Depleting Chemicals Phase Out Report	Department of Energy Environmental Protection Agency	Yearly
DOE Annual Waste Minimization Report	Department of Energy	Yearly
Waste Minimization Certification for Site 300	Department of Toxic Substances Control	Yearly
NEPA Reviews, Proposed LLNL/Department of Energy Projects	Department of Energy	As required

Title	Agency	Frequency
CEQA Review for Department of Energy/UC Contract Renewal	University of California	Before contract renewal
CEQA Reviews, Proposed LLNL/UC Projects	University of California	As required
Spill Prevention Control and Countermeasures Plans (Livermore Site and Site 300) Plan	Environmental Protection Agency San Francisco Bay Regional Water Quality Control Board Central Valley Regional Water Quality Control Board Alameda County Environmental Health Services or Department of Public Health Services, San Joaquin County	Every 3 years or when there are significant changes
Closure Plans for any hazardous waste/product underground storage tanks (USTs) removed from service	Alameda County Environmental Health Services or Department of Public Health Services, San Joaquin County	As required
Closure Reports for any hazardous waste/product USTs removed from service	Alameda County Environmental Health Services or Department of Public Health Services, San Joaquin County	As required
Monitoring Program and Emergency Response Plan for any hazardous waste/ product USTs	Alameda County Environmental Health Services or Department of Public Health Services, San Joaquin County	As required
Closure Reports for greater than 90-day hazardous waste aboveground storage tanks (ASTs) operated under Interim Status and removed from service	Department of Toxic Substances Control	As required
Engineering Assessments for RCRA hazardous waste tanks	Alameda County Environmental Health Services or Department of Public Health Services, San Joaquin County	As required
Installation Plans for new hazardous waste/product UST	Alameda County Environmental Health Services or Department of Public Health Services, San Joaquin County	As required
Hazardous Waste/Product UST Operating Permit	Alameda County Environmental Health Services or Department of Public Health Services, San Joaquin County	Annually
Less-than-90-Day Hazardous Waste Tank Contingency Plans (for Hazardous Tank Systems at Livermore Site)	Department of Toxic Substances Control	As required
Tank Monitoring Program for Hazardous Waste ASTs	Alameda County Environmental Health Services or Department of Public Health Services, San Joaquin County	Prior to new tank use
Tank Modification/Approval Plans for hazardous waste/product USTs	Alameda County Environmental Health Services or Department of Public Health Services, San Joaquin County	As required
Monthly Sewer Monitoring Report	Livermore Water Reclamation Plant	Monthly

Title	Agency	Frequency
Site 300 Pits 1 and 7 Compliance Monitoring Reports	Central Valley Regional Water Quality Control Board Environmental Protection Agency Department of Toxic Substances Control	Quarterly and yearly
Site 300 Quarterly Cooling Tower Discharge Report	Central Valley Regional Water Quality Control Board	Quarterly
Wastewater Point-Source Monitoring Semi-Annual Report	Livermore Water Reclamation Plant	Twice a year
Storm Water Pollution Prevention Plans (Livermore Site and Site 300)	San Francisco Bay Regional Water Quality Control Board Central Valley Regional Water Quality Control Board	As required
Storm Water Pollution Prevention Plans for Construction (Livermore Site and Site 300)	San Francisco Bay Regional Water Quality Control Board Central Valley Regional Water Quality Control Board	As required
Ground Water Protection Management Program	Department of Energy	Every 3 years or as required
Storm Water Monitoring Programs (Livermore Site and Site 300)	San Francisco Bay Regional Water Quality Control Board Central Valley Regional Water Quality Control Board	As required
Industrial Storm Water Discharge Annual Reports (Livermore Site and Site 300) and Site 300 Cooling Tower Annual Report	San Francisco Bay Regional Water Quality Control Board Central Valley Regional Water Quality Control Board	Yearly
Storm Water Pollution Prevention Annual Certifications for Construction Projects (Livermore Site and Site 300)	San Francisco Bay Regional Water Quality Control Board Central Valley Regional Water Quality Control Board	Yearly
Quarterly and Annual Compliance Reports for Explosive Process Area Surface Impoundments, Sewage Evaporation and Percolation Ponds, and Percolation Pits	Central Valley Regional Water Quality Control Board	Quarterly and yearly
DRB Quarterly/Annual Monitoring Reports	Department of Toxic Substances Control San Francisco Bay Regional Water Quality Control Board Environmental Protection Agency Department of Energy	Quarterly and yearly
Hazardous Material Business Plan and Chemical Inventory	Alameda County Health Care Services Agency and San Joaquin County Office of Emergency Services	Yearly or as required
SARA 311/Material Safety Data Sheet (MSDS) Reporting	California Emergency Planning and Response Commission	As required

Title	Agency	Frequency
SARA 313/Toxic Release Inventory	Department of Energy/State and Federal EPA	Yearly
Beryllium in Ambient Air Monitoring	Bay Area Air Quality Management District	Quarterly
Radiological NESHAPs Annual Report	Environmental Protection Agency	Yearly
Environmental Monitoring Plan	Department of Energy	Every three years
Site Annual Environmental Report	Department of Energy	Yearly
Biennial Hazardous Waste Report	Department of Toxic Substances Control (under Environmental Protection Agency delegated authority)	Every 2 years
Annual Hazardous Waste Report	Department of Toxic Substances Control	Yearly
Conceptual Site Treatment Plan (CSTP) Draft Site Treatment Plan (DSTP) Final Site Treatment Plan (FSTP)	Department of Toxic Substances Control Environmental Protection Agency Department of Energy	As required
Safety Analysis Report	Department of Energy	As required
Contingency Plans	Department of Toxic Substances Control	As required
Closure Plans	Department of Toxic Substances Control	As required
EIR Mitigation Monitoring Annual Report	University of California	Yearly
FFA-CERCLA Reports	Environmental Protection Agency Department of Toxic Substances Control San Francisco Bay Regional Water Quality Control Board Central Valley Regional Water Quality Control Board Department of Energy/EM-40	As required
Wastewater Discharge/Chemical Storage Permit Application	Livermore Water Reclamation Plant	Yearly
Ground Water Discharges to Sanitary Sewer Annual Self-Monitoring Report	Livermore Water Reclamation Plant	Yearly
Above Ground Petroleum Tank Storage Statement	State Water Resources Control Board	Every 2 years
Arroyo Maintenance Monitoring Report	San Francisco Bay Regional Water Quality Control Board	Annually when there is an exceedance of a receiving water limit
Blue Elderberry Bush Cuttings Report pursuant to Biological Assessment for Fire Trail Grading at Site 300	San Francisco Bay Regional Water Quality Control Board	As required if cutting is needed
WDR 99-086 for Arroyo Las Positas Maintenance; Provision 20: Maintenance Impact Study Results	San Francisco Bay Regional Water Quality Control Board	January 16, 2006

Title	Agency	Frequency
Annual report for Arroyo Las Positas Maintenance: Biological Assessment/Biological Opinion Section 7 consultation	United States Fish and Wildlife Service	Yearly if applicable
Building 829 Closure Monitoring Report	Department of Toxic Substances Control	Annually
Pit 6 Closure Monitoring Report	Department of Toxic Substances Control Environmental Protection Agency Central Valley Regional Water Quality Control Board Department of Energy	Quarterly
Arroyo Las Positas Mitigation Monitoring	Army Corps of Engineers	Annually
Low Threat Discharges Quarterly Monitoring Report	Central Valley Regional Water Quality Control Board	Quarterly

APPENDIX D. SUPPLEMENTARY TOPICS ON RADIOLOGICAL DOSE

*Robert J. Harrach
Gretchen M. Gallegos
S. Ring Peterson*

D-1: Radiation Basics

Natural and Man-Made Radiation

By far, the greatest part of radiation received by the world's population comes from natural sources—primarily cosmic rays that impinge on the earth's atmosphere from space and radionuclides naturally present in our environment, such as radioactive materials in soil and rocks. Among these terrestrial sources are carbon-14, potassium-40, rubidium-87, uranium-238, thorium-232, and other radioactive elements, such as radon, that arise from decay of uranium and thorium. The source of human exposure to natural radiation can be external (from substances staying outside the body) or internal (from substances inhaled in air or ingested in food and water). Individual doses vary with location. The level of cosmic radiation increases with altitude because less air is overhead to act as a shield. The earth's poles receive more cosmic radiation than the equatorial regions because the earth's magnetic field diverts the radiation. The levels of terrestrial radiation differ from place to place around the United States and around the world, mainly because of variations in soil and rock composition.

Adding to this pervasive natural or background radiation is man-made radiation from radionuclides used in medicine, consumer products, energy production, and nuclear weapons production. Exposure to man-made sources can be controlled more readily than exposure to most natural sources. However, nuclear explosives tested in the

atmosphere in the 1950s and 1960s spread radioactivity across the surface of the globe, and the 1986 nuclear reactor accident at Chernobyl affected a large area. At present, medical treatment is the largest common source of public exposure to man-made radiation. Individual medical doses vary enormously—someone who has never had an x-ray examination may receive zero medical dose while patients undergoing treatment for cancer may receive many thousands of times the annual-average dose they would receive from natural radiation. Another source of public exposure to man-made radiation is consumer products, including luminous-dial watches, smoke detectors, and tobacco products.

Radioactivity

Generally, naturally occurring isotopes are stable, but notable exceptions include carbon-14, potassium-40, thorium-232, uranium-235, and uranium-238, which occur naturally but are radioactive. There are three main categories of nuclear decay: alpha, beta, and gamma. Alpha decay is the spontaneous emission of an alpha particle (a bound state of two protons and two neutrons—the nucleus of a helium atom) from a nucleus containing a large number of protons (most commonly 82 or more). Beta decay is the spontaneous conversion of a neutron to a proton in the nucleus with the emission of an electron, and gamma decay is the spontaneous emission of high-energy photons (high-frequency electromagnetic radiation) by nuclei.

Radioisotopes decay at quite different rates; the “half-life,” or length of time for half of the atoms to decay, spans a wide range from small fractions of a second to millions of years. For example, tritium (the radioactive form of hydrogen) has a 12.3-year half-life, compared to 24,131 years for plutonium-239.

Some radioisotopes decay by forming radioisotopes that, in turn, decay into other radioisotopes until a stable state is achieved. For example, an atom of uranium-238 can undergo alpha decay, leaving behind a daughter, thorium-234, which is also radioactive. The transformations of the decay chain continue, ending with the formation of lead-206, a stable isotope.

Radioactivity can be hazardous because radiation (alpha particles, beta particles, gamma rays, and other subatomic particles such as neutrons) can be released with great energy. This energy is capable of altering the electronic configuration of atoms and molecules, especially by stripping one or more electrons off the atoms of the irradiated material, thereby disrupting the chemical activity in living cells. If the disruption is severe enough to overwhelm the normal restorative powers of the cell, the cell may die or become permanently damaged. Cells are exposed to many naturally occurring sources of disruption, including naturally toxic chemicals in food, microbes that cause disease, high-energy radiation from outer space (cosmic rays), and heat and light (including the sun’s rays, which can cause sunburn and skin cancer). Consequently, cells and living organisms have evolved the capacity to survive limited amounts of damage, including that caused by radioactivity.

Three main factors determine the radiation-induced damage that might be caused to living tissue: the number of radioactive nuclei that are present, the rate at which they give off energy, and the effectiveness of energy transfer to the host

medium, i.e., how the radiation interacts with the tissue. Alpha radiation can be halted by a piece of paper and can scarcely penetrate the dead outer layers of skin. Radioisotopes that give off alpha radiation are generally not health hazards unless they get inside the body through an open wound or are ingested or inhaled. In those cases, alpha radiation can be especially damaging because its disruptive energy can be deposited within a small distance, resulting in significant energy deposition in a few cells. Beta radiation from nuclear decay typically penetrates a centimeter or two of living tissue. It, therefore, deposits energy over many cells, decreasing the damage to any single cell. Gamma radiation is extremely penetrating and can pass through most materials, being significantly attenuated only by thick slabs of dense materials, such as lead.

Measurement of Radioactivity and Dose

The rate at which a nucleus decays is expressed in either units of becquerels (abbreviated Bq) where 1 Bq is one decay per second, or alternatively in curies (abbreviated Ci), where 1 Ci equals 3.7×10^{10} (37 billion) decays per second, or 3.7×10^{10} Bq. (This is approximately equal to the decay rate of 1 gram of pure radium). Becquerels and curies are not measures of the effect of radiation on living tissue; the effect on living tissue depends on the efficiency of energy deposition as the radiation traverses matter.

The amount of energy deposited in living tissue is called the “dose.” The amount of radiation energy absorbed per gram of tissue is called the “absorbed dose” and is expressed in units of rads or grays (Gy), where 1 Gy equals 100 rads; 1 Gy equals 1 joule per kilogram. Because an absorbed dose produced by alpha radiation is more damaging to living tissue than the same dose produced by beta or gamma radiation, the absorbed dose is multiplied by a quality factor to

give the dose equivalent. The quality factor for alpha radiation is 20; for beta and gamma, 1. The dose equivalent is measured in units of rem or sieverts (Sv) with 1 Sv equal to 100 rem. Also commonly used are millirem (mrem) and millisievert (mSv), which are one-thousandth of a rem and sievert, respectively.

Just as one type of radiation can be more damaging than others, some parts of the body are potentially more vulnerable to radiation damage than are others; therefore, the different parts of the body are given weightings. For example, a radiation dose from iodine-131 is more likely to cause cancer in the thyroid than in the lung. The reproductive organs are of particular concern because of the potential risk of genetic damage. Once particular organs are weighted appropriately, the dose equivalent becomes the “effective dose equivalent” (EDE), also expressed in rem or sievert. This allows dose equivalents from nonuniform exposure of the body to be expressed in terms of an EDE that is numerically equal to the dose from uniform exposure of the whole body that entails the same risk as the nonuniform exposure.

The EDE describes doses to individuals. When individual EDEs received by a group of people are summed, the result is called the “collective effective dose equivalent,” often referred to as the “population dose,” and is expressed in person-sievert or person-rem. Finally, to account for the long-term effects of radionuclides as they continue to decay and affect generations of people, we calculate the dose over many years, summing the effect over time. This is termed the “collective effective dose equivalent commitment.” Most of our discussion in this appendix deals with the EDE and the collective EDE.

Doses from Natural and Man-Made Radioactivity

Annual average radiation doses from natural and other common sources in the United States have been estimated by the National Council on Radiation Protection and Measurement (1987b). The average radiation dose from natural sources is 3.0 mSv/y (300 mrem/y). Approximately 0.3 mSv/y (30 mrem/y) of this exposure comes from high-energy radiation from outer space (cosmic rays). Terrestrial sources, mainly radionuclides in rock and soil, also account for approximately 0.3 mSv/y (30 mrem/y) of the average natural dose. Another significant part of the dose comes from radionuclides ingested through food and drink, resulting in approximately 0.4 mSv/y (40 mrem/y). Potassium-40 and carbon-14 are common radionuclides in food.

The remaining 2.0 mSv/y (200 mrem/y) or 67% of the average dose from natural sources in the United States comes from radon gas. Radon is one of the major radionuclides produced by uranium decay, and inhalation dose is dominated by radon’s short-lived decay products.

As noted earlier, medical treatment is the largest common source of public exposure to man-made radiation, and most of it is delivered as medical x-rays. These contribute 0.39 mSv (39 mrem) to the average whole-body annual dose in the United States. Nuclear medicine contributes 0.14 mSv (14 mrem) to the average dose, and consumer products add 0.1 mSv (10 mrem). Thus, for a typical member of the public in the United States, radiation from medical procedures and consumer products results in a dose of approximately 0.63 mSv/y (63 mrem/y). The annual average

dose from other man-made sources, including fallout from nuclear testing, is less than 0.03 mSv (3 mrem). As described in [Chapter 13](#), the contributions from LLNL operations to the dose of even the most affected resident are on the order of 1 μ Sv/y (0.1 mrem/y), which is a small fraction of the average doses from natural and man-made radioactivity (see [Table 13-5](#)).

Deviations from the average levels can be quite large, depending on an individual's place of residency, occupation, eating habits, and other lifestyle choices, such as frequency of air travel. Radon dose, for example, varies significantly with geographic location; levels several times higher than the average occur in some regions of the United States. At LLNL and its environs, radon-induced doses as low as half the average are typical. Doses from cosmic rays increase with elevation above sea level, producing several tenths of mSv (tens of mrem) differences between cosmic-ray doses in coastal and mountain communities, and imparting a dose of about 0.05 mSv (5 mrem) to a passenger flying round-trip between Los Angeles and New York City.

A useful Internet reference with links to a large quantity of material on effects and risks from radiation is the "Radiation Information Network" at the following Internet address:

<http://www.physics.isu.edu/radinf/>.

D-2: Radiation Control Measures at LLNL

Radioisotopes used at LLNL include uranium, transuranics, biomedical tracers, tritium, and mixed-fission products. Protection of employees and the public from the uncontrolled release of radioactive materials into the environment is a primary consideration for LLNL. This effort takes several forms, as summarized here. More detailed

information can be found in LLNL's online *ES&H Manual*; see, for example, Documents 2.01 and 2.02 at the following Internet addresses:

http://www.llnl.gov/es_and_h/hsm/doc_2.01/doc2-01.html.

http://www.llnl.gov/es_and_h/hsm/doc_2.02/doc2-02.html.

When an operation or facility is designed at LLNL, a thorough assessment of potential radiation hazards is conducted, and radioisotope-handling procedures and work enclosures are determined for each project, depending on the isotope, the quantity being used, and the type of operations being performed. Radioisotope handling and working environments include glove boxes, exhaust hoods, and laboratory bench tops. The controls might include limiting physical access and using shielding, filters, and remote handling equipment. Exhaust paths to the atmosphere include HEPA-filtered stacks, stacks without abatement devices, roof vents, and ordinary room air ventilation channels.

Appropriate monitoring, control, training, emergency response, and other requirements are called out in various facility documents related to each operation. These may include a discipline action plan (DAP), Integration Work Sheet (IWS), safety analysis report (SAR), operational safety plan (OSP), and/or facility safety plan (FSP), and will include a document reviewing the operation under the NEPA compliance guidelines. These documents are reviewed by environmental analysts, industrial hygienists, and health physicists to assess the safety of the operation, its compliance with current occupational and public health and environmental standards, the adequacy of proposed engineering and administrative controls, and the adequacy of proposed training requirements for personnel. This part of the control program

enables LLNL personnel who work with radiation and radioactivity to recognize and prevent the execution of unsafe operations.

Another form of LLNL's radiation control program involves direct monitoring of the workplace environment. This monitoring includes sampling of the air and surfaces in the facilities where radioactive materials are handled, as well as the use of personal dosimetry and bioassay programs to monitor potential worker exposure to direct radiation and radioactive isotopes. Direct monitoring of the workplace environment helps to determine the effectiveness of a facility's radiation control program as well as providing information on worker exposures.

The surveillance and effluent monitoring of radiation in air, ground and surface waters, sewerable water, soil and sediment, and vegetation and foodstuff, as discussed in [Chapters 2 and 4](#) through [11](#) of this report, play an important role in LLNL's program to control radiation releases. These measurements can signal anomalous releases, should they occur, and they directly gauge the degree of success of LLNL's radionuclide discharge control program in limiting exposures of the public. LLNL implemented a quality assurance/quality control (QA/QC) process to ensure the accuracy, precision, and reliability of these monitoring data (see [Chapter 14](#) of this report and the "Quality Control for 1999 Radiological Accounting Update and Modeling" section, in the LLNL NESHAPs 1999 Annual Report [Gallegos et al. 2000]).

In addition to routine QA/QC measures carried out each year, special audits by outside agencies and self-assessments are performed occasionally. Examples are the Safety Management Evaluation (SME) audit performed by DOE in 1996, the public health assessment conducted by the Agency for Toxic Substances and Disease Registry (ATSDR) at the Livermore site in 1999-2000, and the self-assessment by LLNL's Assurance Review Office (ARO) conducted during 1999.

Development of the Livermore Valley and the San Joaquin Valley has enlarged the populations and decreased the distance between sources of emissions and the residents who might be exposed. People live and work within several hundred meters of LLNL's boundaries. It is, therefore, increasingly important that the Laboratory's assessments provide the best information possible regarding the radiological impact of its operations.

APPENDIX E. ERRATA

Nancy J. Woods

Protocol for Handling Errata in LLNL Environmental Reports

The primary form of publication for the LLNL site environmental annual report (SAER) is electronic, either on CD (compact disk) or on the Internet. The secondary form is hard copy, which is produced from the electronic copy. Hard copy is made available to the public at local libraries.

Because there are both publicly distributed and Internet versions of the report, the two versions must be fully equivalent, both in their original versions as first presented to the public, and as they are changed (noted as published errata) subsequent to publication.

In October 1998, LLNL developed a protocol for making post-publication revisions to the Internet versions of SAERs. The main criteria are that (1) the SAER home page must simply and clearly convey what revisions, if any, have been made to a particular report, and directly link to an errata information section; (2) the Internet version of the SAER must be accurately maintained; (3) each SAER accessible on the Internet at any time shall be the most current version of the report, incorporating all revisions; and (4) the content of the Internet and distributed versions of the SAER must be the same, in the sense that the published version plus its errata, if any, must provide the same information as the current (revised) Internet version.

Presently SAERs covering calendar years 1994 through 2000 can be accessed on the Internet at the address of the LLNL SAER homepage: <http://www.llnl.gov/saer>. Both the main volume and the data supplement volume of each individual report can be viewed in its most up-to-date form. A link to an errata section provides a complete record of post-publication changes that have been made.

Record of Changes to 2000 SAER

The following changes have been made to the Internet version of the main volume.

- On page 5-18, two typographic errors were made in the first paragraph in the sentence about gross beta results. The sentence in question should read as follows. “The median gross beta activity is 5.0×10^{-4} Bq/m³ (1.3×10^{-14} Ci/m³).”
- On page 7-13, the first sentence of the last paragraph should read as follows: “Sampling of surface runoff in the vicinity of the transporter near Building 343 found tritium concentrations as high as 41,100 Bq/L.”
- On page 8-8, Figure 8-4, the symbols for wells were inadvertently shifted approximately 1000 m west.

- In Chapter 9, it was stated that all of the wells monitored for tritium in the Livermore Valley were drinking water supply wells. This is not the case; some were monitoring wells, not supply wells.
- On page 9-3, the last sentence in the first (incomplete) paragraph should read as follows: “Groundwater samples were obtained during 2000 from 20 of 23 wells in the Livermore Valley (see **Figure 9-1**) and measured for tritium activity.”
- On page 9-3, the legend for Figure 9-1 should read “Monitoring well” not “Water supply well”.
- On page 9-19, the first sentence of the third complete paragraph in the second column should read as follows: “Measurements of water samples obtained during the summer of 2000 from 20 wells (some of the wells were either dry or not sampled for some other reason in 2000) in the Livermore Valley continue to show very low tritium levels compared with the 740 Bq/L (20,000 pCi/L) maximum contaminant level (MCL) established by the California Department of Health Services.”

The following changes have been made to the Internet version of the Data Supplement.

- On page 7-5, Table 7-2, the value for the L-3RDS-RO location on 4/17/00 should be 41070 ± 80 .
- Several tables contain too many significant figures. The maximum number of significant digits that should appear is three. The tables that contain more than three significant digits are 7-1, 7-2, 7-3, and 7-7.

Record of Changes to 1999 SAER

The following changes have been made to the Internet version of the main volume.

- In Chapter 9, it was stated that all of the wells monitored for tritium in the Livermore Valley were drinking water supply wells. This is not the case; some were monitoring wells, not supply wells.
- On page 9-3, the last sentence in the first paragraph should read as follows: “Groundwater samples were obtained during 1999 from 18 of 21 wells in the Livermore Valley (see **Figure 9-1**) and measured for tritium activity.”
- On page 9-3, the legend for Figure 9-1 should read “Monitoring well” not “Water supply well”.
- On page 9-23, the first sentence of the third complete paragraph should read as follows: “Measurements of water samples obtained during the summer of 1999 from 18 wells (some of the wells were dry in 1999) in the Livermore Valley continue to show very low tritium levels compared with the 740 Bq/L (20,000 pCi/L) maximum contaminant level (MCL) established by the State of California.”

Record of Changes to 1995 SAER

The following changes have been made to the Internet version of the main volume.

- In Chapter 9, it was stated that all of the wells monitored for tritium in the Livermore Valley were drinking water supply wells. This is not the case; some were monitoring wells, not supply wells.

- On page 9-15, the first sentence of the first paragraph should read as follows: “In order to protect downgradient users of ground water, LLNL has been monitoring tritium in wells hydraulically downgradient of LLNL since 1988.”
- On page 9-16, the first sentence of the first paragraph should read as follows: “Tritium measurements of water samples collected during the summer of 1995 from 21 wells in the Livermore Valley are given in Table 9-10.”
- On page 9-18, the second sentence of the first paragraph should read as follows: “The median activities of tritium in these downgradient wells increased from 3.45 Bq/L (93.2 pCi/L) in 1988 to 4.59 Bq/L (124 pCi/L) in 1989.”

REFERENCES

- Aarons, J., M. Dresen, L. Berg, F. Hoffman, G. Howard, R. Bainer, E. Folsom, R. Blake, Z. Demir, V. Dibley, K. Folks, B. Heffner, J. Karachewski, M. Maley, W. McConachie, W.W. McNabb, G. Metzger, C. Noyes, T. Pico, M. Ridley and S. Shukla, eds. (2000), *LLNL Ground Water Project 1999 Annual Report*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-126020-99).
- Aarons, J., M. Dresen, L. Berg, F. Hoffman, G. Howard, R. Bainer, E. Folsom, R. Blake, Z. Demir, V. Dibley, K. Folks, B. Heffner, J. Karachewski, M. Maley, K. Mansoor, W. McConachie, W. W. McNabb, G. Metzger, C. Noyes, T. Pico, and M. Ridley (2001), *LLNL Ground Water Project 2000 Annual Report*, Livermore, CA (UCRL-AR-126020-00).
- Agency for Toxic Substances Disease Registry (2000), *Health Consultation, Lawrence Livermore National Laboratory, Big Trees Park 1998 Sampling*, Livermore, California, Federal Facilities Assessment Branch, Division of Health Assessment and Consultation, Agency for Toxic Substances and Disease Registry (CERCLIS No. CA2890012584).
- Althouse, P. E. (1998), *Radiological Background Levels Found in Glass Fiber Filters Used for Low-Level Environmental Surveillance Air Sampling*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-JC-131844).
- Bainer, R. W., and K. Abbott (2001), Letter Report: LLNL Livermore Site First Quarter Self-Monitoring Report, dated May 31, 2001.
- Bainer, R. W., and H. Joma (2001a), Letter Report: LLNL Livermore Site Second Quarter Self-Monitoring Report, dated August 31, 2001.
- Bainer, R. W., and H. Joma (2001b), Letter Report: LLNL Livermore Site Third Quarter Self-Monitoring Report, dated November 31, 2001.
- Bainer, R. W., and H. Joma (2002a), Letter Report: LLNL Livermore Site Fourth Quarter Self-Monitoring Report, dated February 28, 2002.
- Berg, L. L., E. N. Folsom, M. D. Dresen, R. W. Bainer, and A. L. Lamarre, eds. (1997), *Explanation of Significant Differences for Metals Discharge Limits at the Lawrence Livermore National Laboratory Livermore Site*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-125927).
- Biermann, A. H., P. E. Althouse, N. A. Bertoldo, R. G. Blake, S. L. Brigdon, R. A. Brown, C. G. Campbell, E. Christofferson, L. M. Clark, K. J. Folks, G. M. Gallegos, A. R. Grayson, R. J. Harrach, J. M. Larson, D. H. MacQueen, S. Mathews, B. Nisbet, S. R. Peterson, M. J. Taffet, P. J. Tate, R. J. Vellinger, and R. A. Williams (2001), *Environmental Report 2000*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-50027-00).
- Blake, R. G., C. M. Noyes, and M. P. Maley (1995), *Hydrostratigraphic Analysis—The Key to Cost-Effective Ground Water Cleanup at Lawrence Livermore National Laboratory*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-JC-120614).
- Brown, R. (2001a), *LLNL Experimental Test Site 300 Compliance Monitoring Report for Waste Discharge Requirements 96-248, First Quarter Report 2001*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-125915-01-1).
- Brown, R. (2001b), *LLNL Experimental Test Site 300 Compliance Monitoring Report for Waste Discharge Requirements 96-248, Second Quarter Report 2001*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-125915-01-2).

- Brown, R. (2001c), *LLNL Experimental Test Site 300 Compliance Monitoring Report for Waste Discharge Requirements 96-248, Third Quarter Report 2001*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-125915-01-3).
- Brown, R. (2002), *LLNL Experimental Test Site 300 Compliance Monitoring Report for Waste Discharge Requirements 96-248, Annual/Fourth Quarter Report 2001*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-125915-01-4).
- Campbell, C. G. (2001a), *Lawrence Livermore National Laboratory Site 300 Annual Storm Water Report for Waste Discharge Requirements 97-03-DWQ*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-144362).
- Campbell, C. G. (2001b), *Lawrence Livermore National Laboratory Livermore Site Annual Storm Water Report for Waste Discharge Requirements 95-174*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-26783-01).
- Campbell, C. G., K. Folks, S. Mathews, and R. Martinelli (2002), *Algae Toxicity from Upstream Storm Water Runoff: A Source Investigation*. Submitted to Environmental Management April 2002.
- Cantwell, B., and J. Celeste (1998), *National Ignition Facility Pollution Prevention and Waste Minimization Plan*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-131194).
- Carlsen, T., E. Espeland, and A. Smith (2001), *Rare Plant Restoration and Monitoring at Lawrence Livermore National Laboratory Site 300 Project Progress Report Fiscal Year 2001 October 2000–September 2001*. Lawrence Livermore National Laboratory, Livermore, CA January 2002. (UCRL-AR-142408).
- Carpenter, D. W., J. J. Sweeney, P. W. Kasameyer, N. R. Burkhard, K. G. Knauss, and R. J. Shelmon (1984), *Geology of the Lawrence Livermore National Laboratory Site and Adjacent Areas*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-53316).
- Celeste, J., S. Coleman, B. Nisbet, and B. Campbell (1998), *A Comprehensive Opportunity Assessment for Pollution Prevention at Lawrence Livermore National Laboratory*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-127890).
- Christofferson, E., and D. H. MacQueen (2001a), *LLNL Experimental Test Site 300 Compliance Monitoring Program for RCRA-Closed Landfill Pits 1 and 7, First Quarter Report, January–March 2001*, Lawrence Livermore National Laboratory, Livermore, CA (UCAR-10191-01-1).
- Christofferson, E., and D. H. MacQueen (2001b), *LLNL Experimental Test Site 300 Compliance Monitoring Program for RCRA-Closed Landfill Pits 1 and 7, Second Quarter Report, April–June 2001*, Lawrence Livermore National Laboratory, Livermore, CA (UCAR-10191-01-2).
- Christofferson, E., and D. H. MacQueen (2001c), *LLNL Experimental Test Site 300 Compliance Monitoring Program for RCRA-Closed Landfill Pits 1 and 7, Third Quarter Report, July–September 2001*, Lawrence Livermore National Laboratory, Livermore, CA (UCAR-10191-01-3).
- Christofferson, E., and D. H. MacQueen (2002), *LLNL Experimental Test Site 300 Compliance Monitoring Program for RCRA-Closed Landfill Pits 1 and 7, Annual Report for 2001*, Lawrence Livermore National Laboratory, Livermore, CA (UCAR-10191-01-4).
- Christofferson, E., and M. J. Taffet (2001), *LLNL Experimental Test Site 300 Compliance Monitoring Program for the CERCLA-Closed Pit 6 Landfill, First Quarter Report, January–March 2001*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-132057-01-1).
- Christofferson, E., M. J. Taffet, W. A. McConachie, and S. P. Vonder Haar (2001a), *LLNL Experimental Test Site 300 Compliance Monitoring Program for the CERCLA-Closed Pit 6 Landfill, Second Quarter Report, April–June 2001*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-132057-01-2).

- Christofferson, E., S. P. Vonder Haar, W. A. McConachie, and M. J. Taffet (2001b), *LLNL Experimental Test Site 300 Compliance Monitoring Program for the CERCLA-Closed Pit 6 Landfill, Third Quarter Report, July–September 2001*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-132057-01-3).
- Christofferson, E., S. P. Vonder Haar, and W. A. McConachie (2002), *LLNL Experimental Test Site 300 Compliance Monitoring Program for the CERCLA-Closed Pit 6 Landfill, Annual Report for 2001*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-132057-01-4).
- Ciba-Geigy Ltd. (1981), “Units of Measurement, Body Fluids, Composition of the Body, Nutrition.” In *Geigy Scientific Tables*, Vol. 1, Eighth Edition, Basel, Switzerland.
- Clough, R. E. (2000), *Integrated Safety Management System Description*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-132791 Rev. 3).
- Cooperrider, A. Y., B. J. Boyd, and H. R. Stuart, eds. (1986), *Inventory and Monitoring of Wildlife Habitat*, U. S. Department of Interior, Bureau of Land Management, Service Center, Denver, CO.
- CVRWQCB (1993), *Order No. 93-100, Waste Discharge Requirements for University of California Lawrence Livermore National Laboratory Site 300 and U.S. Department of Energy, Landfill Pits 1 and 7, San Joaquin County*, Central Valley Regional Water Quality Control Board (June 25, 1993).
- CVRWQCB (1998), *Revised Monitoring and Reporting Programs No. 93-100 and 96-248, Lawrence Livermore National Laboratory Site 300 and U.S. Department of Energy, Landfill Pits 1 and 7, San Joaquin County*, Central Valley Regional Water Quality Control Board.
- Dibblee, T. W., Jr. (1980), *Preliminary Geologic Map of the Midway Quadrangle, Alameda and San Joaquin Counties, California*, USGS Open File Report 80-535.
- Dibley, V., and R. Depue (2000), *LLNL Livermore Site and Site 300 Environmental Restoration Project Standard Operating Procedures (SOPs)*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-MA-109115 Rev. 7).
- Dibley, V., M. Dresen, L. Berg, R. Bainer, E. Folsom, R. Blake, J. Coty, Z. Demir, K. Folks, S. Gregory, B. Heffner, G. Howard, J. Karachewski, P. Krauter, W. McConachie, C. Noyes, R. Ruiz, and R. Ward (2002), *LLNL Ground Water Project 2001 Annual Report*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-126020-01).
- Diersch, H.J.G. (1998), *FEFLOW: Interactive, Graphics-Based Finite-Element Simulation System for Modeling Groundwater Flow, Contaminant Mass and Heat Transport Processes, User_s Manual, Release 4.7*, WASY Institute for Water Resources Planning and Systems Research Ltd., Berlin, Germany.
- Dresen, M. D., L. Ferry, R. Ferry, and W. Isherwood (2000), *Final Proposed Plan for Environmental Cleanup at Lawrence Livermore National Laboratory Site 300*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-136376).
- Eadie, G. G., and D. E. Bernhardt (1976), *Sampling and Data Reporting Considerations for Airborne Particulate Radioactivity*, U.S. Environmental Protection Agency, Office of Radiation Programs, Las Vegas, Nevada (ORP/LV-76-9).
- Eccher, B., K. Folks, R. Goluba, M. Gonzalez, D. Hieb, W. Isherwood, M. Kelly, S. Mathews, V. Mode, B. Schumacher, T. Schmiegel, and S. Thomson (1994a), *Storm Water Pollution Prevention Plan (SWPPP) Livermore Site*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-110573-94).
- Eccher, B., K. Folks, R. Goluba, M. Gonzalez, D. Hieb, W. Isherwood, M. Kelly, S. Mathews, V. Mode, B. Schumacher, T. Schmiegel, and S. Thomson (1994b), *Storm Water Pollution Prevention Plan (SWPPP), Experimental Test Site (Site 300)*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-110572-94).

- Eckerman, K. F., and J. C. Ryman (1993), *External Exposure to Radionuclides in Air, Water and Soil*, U.S. Environmental Protection Agency, Washington, DC (Federal Guidance Report No. 12, EPA 402-R-93-081).
- Environmental Laboratory (1987), *U.S. Army Corps of Engineers Wetlands Delineation Manual*, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi (Technical Report Y-87-1).
- EPD (1997), *Transition Plan: Transfer of Existing Waste Treatment Units to the Decontamination and Waste Treatment Facility*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-126352).
- Ferry, L., T. Berry, and D. MacQueen (1998), *Post-Closure Plan for the Pit 6 Landfill Operable Unit, Lawrence Livermore National Laboratory, Site 300*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-128638).
- Ferry, R., L. Ferry, S. Gregory, V. Madrid, J. Valett, R. Depue, and K. Heyward (2001a), *Draft Five-Year Review Report for the Building 834 Operable Unit at Lawrence Livermore National Laboratory Site 300*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-144744DR).
- Ferry, R., W. Daily, L. Ferry, G. Aarons, V. Madrid, J. Valett, Z. Demir, R. Depue, and K. Heyward (2001b), *Five-Year Review Report for the General Services Area Operable Unit at Lawrence Livermore National Laboratory Site 300*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-144104).
- Ferry, R., M. Dresen, L. Ferry, W. Isherwood, J. Ziagos, W. Daily, R. Depue, E. Folsom, R. Halden, B. Heffner, K. Heyward, M. Taffet, and S. Vonder Haar (2001c), *Remedial Design Work Plan for Interm Remedies at Lawrence Livermore National Laboratory Site 300*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-143563).
- Folks, K. (1997), *LLNL Report of Waste Discharge for Beneficial Reuse of Soil at the Livermore Site*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-126943).
- Gallegos, G. M. (1991), *Assessment of Sediment Monitoring at LLNL*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-ID-121236).
- Gallegos, G. M. (1993), "Surveillance Monitoring of Soils for Radioactivity: Lawrence Livermore National Laboratory 1976 to 1992," *Health Physics* 69(4), 487-493.
- Gallegos, G. M., A. H. Biermann, R. J. Harrach, N. A. Bertoldo, R. L. Berger, and K. A. Surano (2000), *LLNL NESHAPs 1999 Annual Report*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-ID-113867-00).
- Gallegos, G. M., R. J. Harrach, R. L. Berger, N. A. Bertoldo, P. J. Tate, and S-R. Peterson (2001), *LLNL NESHAPs 2000 Annual Report*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-ID-113867-01).
- Gallegos, G. M., B. K. Balke, K. A. Surano, W. G. Hoppes, P. J. Tate, J. C. Steenhoven, B. C. Fields, L. M. Garcia, K. C. Lamson (1992), *Environmental Report 1991*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-50027-91).
- Gallegos, G. M., D. MacQueen, and K. Surano (1999), *Livermore Big Trees Park: 1998 Summary Results*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-ID-134581).
- Gallegos, G. M., P. J. Tate, B. K. Balke, E. Christofferson, R. J. Harrach, W. G. Hoppes, R. A. Failor, S. Wander, B. C. Fields, L. M. Garcia, and A. R. Grayson (1994), *Environmental Report for 1993*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-50027-93).
- Galles, H. L. (1997), Letter to J. Cho re: Lawrence Livermore National Laboratory Drainage Retention Basin Monitoring Plan Amendment (WGMG97-439, December 9, 1997).

- Games, P. A., and J. F. Howell (1976), "Pairwise Multiple Comparison Procedures with Unequal n's and/or Variances. A Monte Carlo Study," *Journal of Educational Statistics* **1**:113–125.
- Gibbs, J. P. (1998), Amphibian movement in response to forest edges, roads, and streambeds in southern New England. *Journal of Wildlife Management* **65**:584–589.
- Gouveia, F., and K. R. Chapman (1989), *Climatology of Lawrence Livermore National Laboratory*, Lawrence Livermore National Laboratory, Livermore, CA (UCID-21686).
- Grandfield, C. H. (1989), *Guidelines for Discharges to the Sanitary-Sewer System*, Lawrence Livermore National Laboratory, Livermore, CA (UCAR-10235).
- Gregory, S., V. Madrid, L. Ferry, R. Halden, Z. Demir, S. Bilir, R. Depue, R. Ferry, K. Heyward, and J. Valett (2001), *Draft Final Interim Remedial Design for the Building 834 Operable Unit Treatment Facility at Lawrence Livermore National Laboratory Site 300*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-144919DR).
- Gudiksen, P. H., C. L. Lindeken, C. Gatrousis, and L. R. Anspaugh (1972), *Environmental Levels of Radioactivity in the Vicinity of the Lawrence Livermore Laboratory, January through December 1971*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-51242).
- Gudiksen, P. H., C. L. Lindeken, J. W. Meadows, and K. O. Hamby (1973), *Environmental Levels of Radioactivity in the Vicinity of the Lawrence Livermore Laboratory, 1972 Annual Report*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-51333).
- Guthrie, E. B., N. C. Shen, and B. B. Bandong (2001), *Isotope Exchange and fractionation Corrections for Extraction of Tritiated Water in Silica Gel by Freeze-drying Techniques*. Draft. September 24, 2001.
- Hall, H. L., and W. L. Edwards (1994a), *Radiation Analytical Sciences Quality Assurance Plan, Quality Implementing Procedures and Quality Assurance Project Plans*, Vol. 1, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-MA-116560, Vol. 1).
- Hall, H. L., and W. L. Edwards (1994b), *Radiation Analytical Sciences Integrated Software Documentation*, Vol 3, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-MA-116560, Vol. 3).
- Hall, H. L., and W. L. Edwards (1994c), *Radiation Analytical Sciences Technical Implementing Procedures*, Vol. 2A, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-MA-116560, Vols. 2A and 2B).
- Harrach, R. J., S-R. Peterson, G. M. Gallegos, P. J. Tate, N. A. Bertoldo, and Paris E. Althouse (2002), *LLNL NESHAPs 2001 Annual Report*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-ID-113867-02).
- Harrach, R. J. (1998), *Guidance for Radiological Dose Assessment*, Operations and Regulatory Affairs Division, Lawrence Livermore National Laboratory, Livermore, CA (EMP-R-DA).
- Harrach, R. J., G. M. Gallegos, R. A. Failor, E. Christofferson, P. J. Tate, E. R. Brandstetter, J. M. Larson, J. McIntyre, B. C. Fields, R. A. Brown, L. M. Garcia, and A. R. Grayson (1995), *Environmental Report 1994*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-50027-94), <http://www.llnl.gov/saer/>.
- Harrach, R. J., R. A. Failor, G. M. Gallegos, P. J. Tate, E. Christofferson, E. R. Brandstetter, J. M. Larson, A. H. Biermann, R. A. Brown, B. C. Fields, L. M. Garcia, and A. R. Grayson (1996), *Environmental Report 1995*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-50027-95), <http://www.llnl.gov/saer/>.
- Harrach, R. J., G. M. Gallegos, P. J. Tate, E. Christofferson, E. R. Brandstetter, J. M. Larson, A. H. Biermann, B. C. Fields, L. M. Garcia, and K. A. Surano (1997), *Environmental Report 1996*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-50027-96), <http://www.llnl.gov/saer/>.

- Hoffman, J., M. Maley, B. Qualheim, R. Bainer, E. Folsom, and M. Dresen (1998), *LLNL Ground Water Project 1997 Annual Report*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-126020-97).
- Homann, S. G. (1994), *HOTSPOT Health Physics Codes for the PC*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-MA-10615).
- Holland, R.F., and S.K. Jain (1978), Vernal Pools. Pages 515-533 in: M.G. Barbour and J. Mayor (Editors). *Terrestrial Vegetation of California*. Wiley -Interscience, New York, NY.
- Huey, A. S. (1948), "Geology of the Tesla Quadrangle, California," *California Division of Mines and Geology*, Bulletin 140.
- ICRP (1977), *Recommendations of the International Commission on Radiological Protection*, International Commission on Radiological Protection, Publication 26, Pergamon Press, New York, NY.
- ICRP (1979 et seq.), *Limits for Intakes of Radionuclides by Workers*, International Commission on Radiological Protection, Publication 30, Pergamon Press, New York, NY.
- ICRP (1995), Age dependent doses to members of the public from intake of radionuclides, Part 4, Inhalation Dose Coefficients. Publication 71; Ann. ICRP 25(3&4), Pergamon Press, Oxford.
- ICRP (1996), "Compilation of Ingestion and Inhalation Dose Coefficients." In *Age-dependent Doses to Members of the Public from Intake of Radionuclides: Part 5*. Annals of the ICRP Vol. 26 No. 1. ICRP No. 72 ISSN 0146-6453, Pergamon Press, Oxford.
- Isherwood, W. F., C. H. Hall, M. D. Dresen, and A. J. Boegel (1991), *CERCLA Feasibility Study Report for the LLNL Livermore Site*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-104040).
- Jack Faucett Associates, Inc. and SC % A, Inc. (1987), *Comparison of AIRDOS-EPA Predictions of Ground-Level Airborne Radionuclide Concentrations to Measured Values*. Jack Faucett Associates, Bethesda, MD, (JACKFAU-341/12-87).
- Jackson, C. S. (1997), Letter to the San Francisco Bay Regional Water Quality Control Board re: Lawrence Livermore National Laboratory Building 253 Catch Basin Mercury Residue, May 23, 1997.
- Lamarre, A. L., and M. J. Taffet (1989), *Firing Table Gravel Cleanup at Lawrence Livermore National Laboratory Site 300*, Lawrence Livermore National Laboratory, Livermore, CA (UCAR-10282).
- Lamarre, A. L. (2001a), *Compliance Report for the Building 832 Canyon and Building 854 Ground Water Treatment Systems, 4th Quarter 2000*, Lawrence Livermore National Laboratory Site 300, Livermore, California, March 30, 2001.
- Lamarre, A. L. (2001b), *Compliance Report for the Building 832 Canyon and Building 854 Ground Water Treatment Systems, 1st Quarter 2001*, Lawrence Livermore National Laboratory Site 300, Livermore, California, June 30, 2001.
- Lamarre, A. L. (2001c), *Compliance Report for the Building 832 Canyon and Building 854 Ground Water Treatment Systems, 2nd Quarter 2001*, Lawrence Livermore National Laboratory Site 300, Livermore, California, September 30, 2001.
- Lamarre, A. L. (2001d), *Compliance Report for the Building 832 Canyon and Building 854 Ground Water Treatment Systems, 3rd Quarter 2001*, Lawrence Livermore National Laboratory Site 300, Livermore, California, December 30, 2001.
- Lamarre, A. L. (2001e), *Quarterly Compliance Report for the Building 834 Ground Water Treatment System, 4th Quarter 2000*, Lawrence Livermore National Laboratory Site 300, Livermore, California, March 30, 2001.

- Lamarre, A. L. (2001f), *Quarterly Compliance Report for the Building 834 Ground Water Treatment System, 1st Quarter 2001*, Lawrence Livermore National Laboratory Site 300, Livermore, California, June 30, 2001.
- Lamarre, A. L. (2001g), *Quarterly Compliance Report for the Building 834 Ground Water Treatment System, 2nd Quarter 2001*, Lawrence Livermore National Laboratory Site 300, Livermore, California, September 30, 2001.
- Lamarre, A. L. (2001h), *Quarterly Compliance Report for the Building 834 Ground Water Treatment System, 3rd Quarter 2001*, Lawrence Livermore National Laboratory Site 300, Livermore, California, December 30, 2001.
- Lamarre, A. L. (2001i), *Quarterly Compliance Report for the Eastern and Central General Services Area Soil Vapor and Ground Water Treatment Systems, 4th Quarter 2000*, Lawrence Livermore National Laboratory Site 300, Livermore, California, January 30, 2001.
- Lamarre, A. L. (2001j), *Quarterly Compliance Report for the Eastern and Central General Services Area Soil Vapor and Ground Water Treatment Systems, 1st Quarter 2001*, Lawrence Livermore National Laboratory Site 300, Livermore, California, April 30, 2001.
- Lamarre, A. L. (2001k), *Quarterly Compliance Report for the Eastern and Central General Services Area Soil Vapor and Ground Water Treatment Systems, 2nd Quarter 2001*, Lawrence Livermore National Laboratory Site 300, Livermore, California, July 30, 2001.
- Lamarre, A. L. (2001l), *Quarterly Compliance Report for the Eastern and Central General Services Area Soil Vapor and Ground Water Treatment Systems, 3rd Quarter 2001*, Lawrence Livermore National Laboratory Site 300, Livermore, California, October 30, 2001.
- Larson, J. M., R. J. Harrach, P. E. Althouse, N. A. Bertoldo, A. H. Biermann, R. G. Blake, E. R. Brandstetter, S. L. Brigdon, R. A. Brown, E. Christofferson, K. J. Folks, G. M. Gallegos, L. M. Garcia, T. A. Giesing, A. R. Grayson, L. C. Hall, D. H. MacQueen, S. Mathews, S. R. Peterson, M. J. Taffet, P. J. Tate, R. J. Vellinger, and R. J. Ward (1999), *Environmental Report 1998*, Lawrence Livermore National Laboratory, Livermore, CA, (UCRL-50027-98), <http://www.llnl.gov/saer>.
- Larson, J. M., A. H. Biermann, R. J. Harrach, P. E. Althouse, N. A. Bertoldo, R. G. Blake, E. R. Brandstetter, S. L. Brigdon, R. A. Brown, E. Christofferson, K. J. Folks, G. M. Gallegos, L. M. Garcia, T. A. Giesing, A. R. Grayson, L. C. Hall, D. H. MacQueen, S. Mathews, S. R. Peterson, M. J. Taffet, P. J. Tate, R. J. Vellinger, R. J. Ward, and R. A. Williams (2000), *Environmental Report 1999*, Lawrence Livermore National Laboratory, Livermore, CA, (UCRL-50027-99), <http://www.llnl.gov/saer>.
- LLNL (2000), *Post-Closure Permit Application for the Building 829 HE Open Burn Facility—Volume 1*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-139697).
- Limnion Corporation, The (1991), *The Drainage Retention Basin Management Plan*, Lawrence Livermore National Laboratory, Livermore, CA.
- Longley, K. E., H. V. Johns, and H. Abraham (1994), *The Water Quality Control Plan (Basin Plan) for the California Regional Water Quality Control Board, Central Valley Region, Sacramento and San Joaquin River Basins*, Central Valley Regional Water Control Board, Sacramento, CA.
- Loredo, I., D. Van Vuren, A. J. Kuenzi, and M. L. Morrison (1994), California ground squirrel control strategies at Concord Naval Weapons Station: alternatives for control and the ecological consequences. *Proc. Vertebr. Pest Conf.* **16**:72-77.
- Loredo, I., and D. Van Vuren (1996), Reproductive ecology of a population of the California tiger salamander. *Copeia*. 1996:895-901.
- Loredo, I., D. Van Vuren, and M.L. Morrison (1996), Habitat use and migration behavior of the California tiger salamander. *Journal of Herpetology* **30**:282-285.

- MacQueen, D. H. (1995), *Livermore Big Trees Park January 1995 Soil Survey Results*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-ID-121045).
- Madrid, V. M., R. Halden, S. Gregory, Z. Demir, and J. Valett (2001), *3-D Geospatial Modeling of a DNAPL Source Area*, Geological Society of America, Cordilleran Section 97th Annual Meeting, Los Angeles, CA, April 9-11, 2001.
- Madrid, V., L. Ferry, A. Ritcey, J. Valett, and M. Verce (2002), *Draft Interim Remedial Design for the High Explosives Process Area Operable Unit at Lawrence Livermore National Laboratory Site 300*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-147095DR).
- Marshack, J.B. (2000), *A Compilation of Water Quality Goals*, California Environmental Protection Agency Regional Water Quality Control Board, Central Valley Region, August 2000.
- Mathews, S. (2000), *Lawrence Livermore National Laboratory Site 300 Water Suppliers' Pollution Prevention and Monitoring and Reporting Program*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-139704).
- Mathew, S. (2001), *National Ignition Facility Construction Storm Water Pollution Prevention Plan, Revision 6*, Lawrence Livermore National Laboratory, Livermore, CA, September 2001, (UCRL-AR-132601-09-01).
- Mathews, S., and M. Taffet (1997), *Final Closure Plan for the High-Explosives Open Burn Facility at Lawrence Livermore National Laboratory Experimental Test Site 300*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-ID-111753 Rev. 1).
- McFarlane, J.C., R. D. Rogers, and D. V. Bradley (1978), Environmental tritium oxidation in surface soil. *Environmental Science and Technology*, **12**, no. 5: 590-593.
- McNab, W. W., Jr., J. A. Karachewski, and G. A. Weissman (2001), *Field Measurements of Electro-osmotic Transport of Ground Water Contaminants in a Lithologically Heterogeneous Alluvial-Fan Setting*, Lawrence Livermore National Laboratory, Livermore CA (UCRL-ID-144879).
- Moore, R. E., C. F. Baes, III, L. M. McDowell-Boyer, A. P. Watson, F. A. Hoffman, J. C. Pleasant, and C. W. Miller (1979), *AIRDOS-EPA: A Computerized Methodology for Estimating Environmental Concentrations and Dose to Man from Airborne Releases of Radionuclides*. Oak Ridge National Laboratory, Oak Ridge, TN (ORNL-5532).
- Morey, S.R. (1998), Pool duration influences age and body mass at metamorphosis in the western spadefoot toad: Implications for vernal pool conservation. Pp. 86-91 In Witham, C. W., E.T Bauder, D. Belk, W.R. Ferren Jr., and R. Ornduff (Editors). *Ecology, Conservation, and Management of Vernal Pool Ecosystems – Proceedings from a 1996 Conference*. California Native Plant Society, Sacramento, CA 1998.
- NCRP (1987a), *Recommendations on Limits of Exposure to Ionizing Radiation*, Report No. 91, National Council on Radiation Protection and Measurements, Washington, DC.
- NCRP (1987b), *Ionizing Radiation Exposure of the Population of the United States*, Report No. 93, National Council on Radiation Protection and Measurements, Washington, DC.
- NCRP (1999), *Recommended Screening Limits for Contaminated Surface Soil and Review of Factors Relevant to Site-Specific Studies*, Report No. 129, National Council on Radiation Protection and Measurements, Bethesda, MD.
- Oak Ridge Institute for Science and Education (1995), *Atmospheric Dispersion Modeling Resources*, Second Edition.
- Osborne, R. V. (1968), "Intake of Tritium When Skin Is Splashed with Tritiated Water." *Health Physics*, **15**:155–156.
- Parks, B. S. (1992), *User's Guide for CAP88-PC, Version 1.0*, U.S. Environmental Protection Agency, Office of Radiation Programs, Las Vegas, NV (EPA 402-B-92-001).

- Pendleton, B., A. Giron, B. A. Millsap, K. W. Cline, and D. M. Bird, eds. (1987), *Raptor Management Techniques Manual*, National Wildlife Federation, Washington, DC.
- Peterson, S-R., and P. A. Davis (2002), "Tritium Doses from Chronic Atmospheric Releases: A New Model Proposed for Regulatory Compliance". *Health Physics*. (UCRL-JC-141535).
- Peterson, W. B., and L. G. Lavdas (1986), "INPUFF 2.0—A Multiple Source Gaussian Puff Dispersion Algorithm," In *User's Guide*, U.S. Environmental Protection Agency, Research Triangle, NC.
- Petranka, J. W. (1998), *Salamanders of the United States and Canada*. Smithsonian Institute Press, Washington, DC.
- Raber, E., and Gilbert, K. V. (2001a), *Annual Hazardous Waste Report—Mainsite*, Lawrence Livermore National Laboratory, Livermore, CA.
- Raber, E., and Gilbert, K. V. (2001b), *Annual Hazardous Waste Report—Site 300*, Lawrence Livermore National Laboratory, Livermore, CA.
- Regional Water Quality Control Board (RWQCB) (1996), Letter from Loretta Barsamian and Richard McMurtry, RWQCB Executive Officer and Ground Water Protection and Waste Containment Division Chief, respectively, to Paul Ko, DOE Project Manager, stating that no further remedial action related to the fuel hydrocarbons is required, dated October 30, 1996.
- Revelli, M. A. (2002), *Lawrence Livermore National Laboratory Site 300—Compliance Monitoring Program for the Closed Building 829 Facility—Annual Report 2001*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-143121-01).
- Rice, D. W., Jr., and G. J. Cannon, eds. (1999), *Health and Environmental Assessment of the Use of Ethanol as a Fuel Oxygenate*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-135949), <http://www-erd.llnl.gov/ethanol/>.
- Rice, D. W., and Depue (2001) *Environmental Assessment of the Use of Ethanol as a Fuel Oxygenate: Subsurface Fate and Transport of Gasoline Containing Ethanol*,
- Rogers/Pacific Corporation (1990), *Lawrence Livermore National Laboratory Site 300 Resource Conservation and Recovery Act Closure and Post-Closure Plans—Landfill Pits 1 and 7*, Vols. I and II, Van Nuys, CA (California EPA No. CA2890090002).
- Rosson, R., R. Jakiel, and B. Kahn (1998), "Isotopic exchange and the vapor pressure isotope effect in tritium oxide adsorption on silica gel." *J. Phys. Chem.* B102:10342–10346.
- Rosson, R., R. Jakiel, S. Klima, B. Kahn, and P. Fledderman (2000), "Correcting triium concentrations in water vapor monitored with silica gel." *Health Physics* 78 (1):68-73.
- Rueth, L. S., R. A. Ferry, L. K. Green-Horner, and T. H. DeLorenzo (1998), *Remedial Design Document for the General Services Area Operable Unit Treatment Facilities Lawrence Livermore National Laboratory, Site 300*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-127465).
- SFBRWQCB (1982a), *Water Quality Control Plan, San Francisco Bay Basin*, State of California, San Francisco Bay Regional Water Quality Control Board, Oakland, CA.
- SFBRWQCB (1982b), *Waste Discharge Requirements and National Pollutant Discharge Elimination System (NPDES) Storm Water Permit for: U.S. Department of Energy and Lawrence Livermore National Laboratory*, San Francisco Bay Regional Water Quality Control Board, Oakland, CA. (Order No. 95-174, NPDES No. CA030023).
- SFBRWQCB (1995), *Water Quality Control Plan, San Francisco Bay Basin*, State of California, San Francisco Bay Regional Water Quality Control Board, Oakland, CA.

- SFBRWQCB (1996), Letter from Loretta Barsamian and Richard McMurtry, SFRWQCB Executive Officer and Ground Water Protection and Waste Containment Division Chief, respectively, to Paul Ko, DOE Project Manager, stating that no further remedial action related to the fuel hydrocarbons is required, dated October 30, 1996.
- Scheffé, H. (1953), "A Method for Judging All Contrasts in the Analysis of Variance," *Biometrika*, **40**: 87-104.
- Schemnitz, S. D., ed. (1980), *Wildlife Management Techniques Manual*, The Wildlife Society, Washington, DC.
- Shaffer, H.B., and S.E. Stanley (1991), *Final report to California Department of Fish and Game; California tiger salamander surveys, 1991*. Unpublished report.
- Shaffer, H. B., and M.L. McKnight (1996), The polytypic species revisited; genetic differentiation and molecular phylogenetics of the tiger salamander *Ambystoma tigrinum* (Amphibia: Caudata) complex. *Evolution* **50**:417-433.
- Shaffer, H. B., R.N. Fisher, and S.E. Stanley (1993), Status report; The California tiger salamander (*Ambystoma californiense*). Final report for the California Department of Fish and Games.
- Shleien, B., and M. S. Terpilak (1984), *The Health Physics and Radiological Health Handbook*, Nucleon Lectern Associates, Inc., Olney, MD.
- Silver, W. J., C. L. Lindeken, J. W. Meadows, W. H. Hutchin, and D. R. McIntyre (1974), *Environmental Levels of Radioactivity in the Vicinity of the Lawrence Livermore Laboratory, 1973 Annual Report*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-51547).
- Silver, W. J., C. L. Lindeken, J. W. Meadows, W. H. Hutchin, and D. R. McIntyre (1975), *Environmental Monitoring at the Lawrence Livermore Laboratory, 1974 Annual Report*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-50027-74).
- Silver, W. J., C. L. Lindeken, K. M. Wong, E. H. Willes, and J. H. White (1978), *Environmental Monitoring at the Lawrence Livermore Laboratory, 1977 Annual Report*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-50027-77).
- Silver, W. J., C. L. Lindeken, J. H. White, and R. W. Buddemeir (1980), *Environmental Monitoring at the Lawrence Livermore Laboratory, 1979 Annual Report*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-50027-79).
- State of California (2001), *E-1 City/County Population Estimates, with Annual Percent Change, January 1, 2000 and 2001*, Department of Finance, Sacramento, California, May 2001.
- Sweet, C.W., and C. E. Murphy, Jr. (1984), Tritium deposition in pine trees and soil from atmospheric releases of molecular tritium. *Environmental Science and Technology*, **18**: 358.
- SWRCB (1999), *Waste Discharge Requirements for Discharges of Storm Water Runoff Associated with Construction Activity*. NPDES General Permit No. CAS000002 (Order No. 99-08-DWQ).
- SWRCB (2001), *Modification of Water Quality Order 99-08-DWQ State Water Resources Control Board (SWRCB) National Pollutant Discharge Elimination System (NPDES) General Permit for Storm Water Discharges Associated With Construction Activity*, State Water Resources Control Board Resolution No. 2001 - 046, April 26, 2001.
- Stone, R., and M. R. Ruggieri (1983), *Ground-Water Quality and Movement at Lawrence Livermore National Laboratory*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-53474).
- Struckmeyer, R. (1994), *NRC TLD Direct Radiation Monitoring Network, Progress Report, July-September, 1994*, Nuclear Regulatory Commission, Washington, DC (NUREG-0837, Vol. 14, No. 3).

- Surano, K.A., G. B. Hudson, R. A. Failor, J. M. Sims, R. C. Holland, S. C. MacLean, and J. C. Garrison (1992), Helium-3 mass spectrometry for low-level tritium analysis of environmental samples. *J. of Radioanalytical and Nuclear Chemistry*, **161**, no. 2: 443-453.
- Taffet, M. J., L. Green-Horner, L. C. Hall, T. M. Carlsen, and J. A. Orberdorfer (1996), *Addendum to Site-Wide Remedial Investigation Report, Building 850/Pit 7 Complex Operable Unit, Lawrence Livermore National Laboratory Site 300*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-108131, Add. 1).
- Tate, P., S. Mathews, G. Gallegos, L. M Garcia, J. M. Larson, A. H. Biermann, E. R. Brandstetter, E. Christofferson, R. J. Harrach, D. Rueppel, F. Gouveia, P. Althouse, B. C. Fields, D. MacQueen, R. A. Brown, R. Vellingner, K. A. Surano, K. J. Folks, S. L. Brigdon, A. L. Grayson, W. G. Hoppes, R. L. Welsh, N. A. Bertoldo, G. J. Cannon, R. L. Berger, R. G. Blake, M. J. Taffet, R. A. Failor, and C. Choate (1999), *Environmental Monitoring Plan*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-ID-106132 Rev. 2).
- Thorpe, R. K., W. F. Isherwood, M. D. Dresen, and C. P. Webster-Scholten (1990), *CERCLA Remedial Investigation Report for the LLNL Livermore Site*, Vols. 1-5, Lawrence Livermore National Laboratory, Livermore, CA (UCAR-10299).
- Tibor, D. P. (2001), *Inventory of Rare and Endangered Plants of California*, 6th ed. California Native Plant Society, Sacramento, California.
- Toy, A. J., C. L. Lindeken, K. S. Griggs, and R. W. Buddemeier (1981), *Environmental Monitoring at the Lawrence Livermore National Laboratory, 1980 Annual Report*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-50027-80).
- U.S. Department of Health and Human Services (1999), Health Consultation: "Plutonium Contamination in Big Trees Park," Lawrence Livermore National Laboratory, Public Service, Agency for Toxic Substances and Disease Registry, CERCLIS No. CA28900125584, pp. 7-8.
- U.S. Department of Health and Human Services (2001), *Environmental Evaluations at SRS and LLNL with Emphasis on the Monitoring and Dosemetry of Organically-Bound Tritium*, Final report of an expert panel convened by the Agency for Toxic Substances and Disease Registry, Atlanta, Georgia, July 2001.
- U.S. DOE (1988), *External Dose-Rate Conversion Factors for Calculation of Dose to the Public*, U.S. Department of Energy, Washington, DC (DOE/EH-0070).
- U.S. DOE (1991), *Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance*, U.S. Department of Energy, Washington, DC (DOE/EH-0173T).
- U.S. DOE (1993), *Record of Decision for the Lawrence Livermore National Laboratory Livermore Site*, U.S. Department of Energy, Washington, DC (UCRL-AR-109105).
- U.S. DOE (1999), *Supplement Analysis for Continued Operation of Lawrence Livermore National Laboratory and Sandia National Laboratories, Livermore*, Volumes I and II, Oakland Operations Office, Oakland, California (DOE/EIS-0157-SA-01).
- U.S. DOE (2001), *Interim Site-Wide Record of Decision for Lawrence Livermore National Laboratory Site 300*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-138470).
- U.S. DOE (2002), *A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota*, U.S. Department of Energy, Washington, DC, (DOE-STD-1153-2002).
- U.S. DOE and UC (1992a), *Final Environmental Impact Statement and Environmental Impact Report for Continued Operation of Lawrence Livermore National Laboratory and Sandia National Laboratories, Livermore*, Lawrence Livermore National Laboratory, Livermore, CA (DOE/EIS-0157, SCH90030847).

- U.S. DOE and UC (1992b), *Final Environmental Impact Statement and Environmental Impact Report Executive Summary*, Lawrence Livermore National Laboratory, Livermore, CA (DOE/EIS-0157).
- U.S. EPA (1987), *Data Quality Objectives for Remedial Response Activities: Development Process*, U.S. Environmental Protection Agency, Office of Emergency and Remedial Response, Washington, DC (EPA 540/G-87/003, OSWER Directive 9355-0).
- U.S. EPA (1993), *Supplement B to the Guideline on Air Quality Models (Revised)*, U.S. Environmental Protection Agency, Office of Emergency and Remedial Response, Washington, DC (EPA Report No. EPA-450/2-78-027R Supplement B).
- U.S. EPA (2000), "Notice: Final Reissuance of National Pollutant Discharge Elimination System (NPDES) Storm Water Multi-Sector General Permit for Industrial Activities," Environmental Protection Agency, Federal Register, Volume 65, No. 210 (October 30, 2000).
- U.S. NRC (1977), *Calculation of Annual Doses to Man from Routine Releases of Reactor Effluent for the Purpose of Evaluation Compliance with 10 Code of Federal Regulations, Part 50, Appendix I*, U.S. Nuclear Regulatory Commission, Washington, DC (Regulatory Guide 1.109).
- Webster-Scholten, C. P., and C. H. Hall (1988), *Work Plan, Lawrence Livermore National Laboratory, Livermore Site: CERCLA/SARA Remedial Investigations/ Feasibility Studies*, Lawrence Livermore National Laboratory, Livermore, CA (UCAR-10225).
- Webster-Scholten, C. P., ed. (1994), *Final Site-Wide Remedial Investigation Report, Lawrence Livermore National Laboratory Site 300*, Lawrence Livermore National Laboratory, Livermore, CA (UCRL-AR-108131).
- Ziagos and Ko (1997), *Treatability Study Report for the Building 832 Canyon Operable Unit at Lawrence Livermore National Laboratory Site 300*, Livermore, CA, March, 1997.
- Ziagos, J., and E. Reber-Cox (1998), *Ground Water Tritium Plume Characterization Summary Report for the Building 850/Pits 3 and 5 Operable Unit, Lawrence Livermore National Laboratory Site 300*, Livermore, CA, October 30, 1998.

ACRONYMS AND ABBREVIATIONS

	%RSD	Percent relative standard deviation	
A	ACDEH	Alameda County Department of Environmental Health	
	ACHCS	Alameda County Health Care Services	
	ACL	Ambient concentration limit	
	ACOE	Army Corps of Engineers	
	ALARA	As low as reasonably achievable	
	ANSI	American National Standards Institute	
	ARO	Assurance Review Office at LLNL	
	ATSDR	Agency for Toxic Substances and Disease Registry	
	AVLIS	Advanced Vapor Laser Isotope Separation	
	AWQC	Ambient water quality criteria	
B	BAAQMD	Bay Area Air Quality Management District	
	BCG	Biota concentration guide	
	BETX (or BTEX)	Benzene, ethyl benzene, toluene, and xylene	
	BIT Report	Biennial inspection of terminals report	
	BMP	Best management practice	
	Bq	Becquerel	
	BSA	Blanket Service Agreement	
	BTU	Biotreatment unit	
	C	CAM	Continuous air monitor
		CAREs	(Tri-Valley) Communities Against a Radioactive Environment
CCR		California Code of Regulations	
CDFG		California Department of Fish and Game	
CEPRC		Chemical Emergency Planning and Response Commission	
CEQA		California Environmental Quality Act of 1970	
CERCLA		Comprehensive Environmental Response, Compensation and Liability Act of 1980	

	CERCLA/SARA	Superfund Amendments and Reauthorization Act (SARA)
	CES	Chemistry and Materials Science Environmental Services
	CFF	Contained Firing Facility
	CFR	Code of Federal Regulations
	CGSA	Central General Service Area
	CHP	California Highway Patrol
	Ci	Curie
	COC	Constituent of concern
	COD	Chemical oxygen demand
	CRD	Catalytic reductive dehalogenation
	CVRWQCB	Central Valley Regional Water Quality Control Board
	CWA	Federal Clean Water Act
	CWG	Community Work Group
D	DAP	Discipline action plan
	DC	Direct current
	DCG	Derived Concentration Guide
	DHS	Department of Health Services
	DLM	Designated level methodology
	DNT	Defense and Nuclear Technologies
	DOE	U.S. Department of Energy
	DOE/OAK	DOE Oakland Operations Office
	DOT	U.S. Department of Transportation
	DRB	Drainage Retention Basin
	DTSC	(California Environmental Protection Agency), Department of Toxic Substances Control
	DWTF	Decontamination and Waste Treatment Facility
	DU	Depleted uranium
E	E2	Energy efficiency
	EA	Environmental assessment
	EDE	Effective dose equivalent
	EDO	Environmental Duty Officer
	EIR	Environmental impact report
	EIS	Environmental impact statement
	EML	Environmental Monitoring Laboratory

	EMRL	Environmental Monitoring Radiation Laboratory
	EO	Electroosmosis
	EOG	Environmental Operations Group
	EPA	U.S. Environmental Protection Agency
	EPCRA	Emergency Planning and Community Right-to-Know Act of 1986
	EPD	Environmental Protection Department (LLNL)
	EPL	Effluent pollutant limit
	EPTP	Environmental Protection Training Department (LLNL)
	ERD	Environmental Restoration Division (of the Environmental Protection Department at LLNL)
	ES&H	Environment, Safety, and Health
	EST	Environmental support team
	EWSE	Explosives Waste Storage Facility
	EWTF	Explosives Waste Treatment Facility
F	FFA	Federal facility agreement
	FHC	Fuel hydrocarbon
	FONSI	Finding of no significant impact
	FSP	Facility safety plan
	FY	fiscal year
G	GAB	Gross alpha and gross beta
	GAC	Granulated activated carbon
	GBq	Gigabecquerel. (10^9 Bq)
	GFI	Ground fault interrupter
	GPS	Global positioning system
	GSA	General Services Area (LLNL Site 300)
	GTU	GAC treatment unit
	GWP	Ground Water Project
	GWMP	Ground Water Project Management Program
	GWTF	Groundwater treatment facility
	GWTS	Groundwater treatment system
	Gy	Gray
H	HCAL	Hazards Control Department's Analytical Laboratory
	HE	High explosives
	HEPA	High-efficiency particulate air (filter)

	HMX	Cyclotetramethyltetramine. Also referred to as octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine.
	HPGe	High-purity germanium
	HSU	Hydrostratigraphic unit
	HT	Tritiated hydrogen gas (See also tritium in Glossary.)
	HTO	Tritiated water and water vapor (See also tritium in Glossary.)
	HWCA	(California) Hazardous Waste Control Act
	HWM	Hazardous Waste Management Division (of the Environmental Protection Department at LLNL)
I	ICRP	International Commission on Radiological Protection
	IMS	Instrumented membrane system
	IQR	Interquartile range
	ISMS	Integrated Safety Management System
	IWS	Integration work sheet
L	LEPC	Local Emergency Planning Committee
	LLNL	Lawrence Livermore National Laboratory
	LOEC	Lowest observed effect concentration
	LOS	Limit of sensitivity
	LWRP	Livermore Water Reclamation Plant
M	MAPEP	Mixed Analyte Performance Evaluation Program
	mCi	Millicurie (10^{-3} Ci)
	MCL	Maximum contaminant level
	MDC	Minimum detectable concentration
	MEI	Maximally exposed individual
	ML	Million liters
	MOU	Memorandum of understanding
	MRP	Monitoring and Reporting Program
	MSDS	Material safety data sheet
	mSv	Millisievert (10^{-3} Sv)
N	NCR	Nonconformance report
	NCRP	National Council on Radiation Protection and Measurements
	NEPA	National Environmental Policy Act
	NESHAPs	National Emissions Standards for Hazardous Air Pollutants
	NHPA	National Historical Preservation Act

	NIF	National Ignition Facility
	NOD	Notice of deficiency
	NOEC	No observed effect concentration
	NOV	Notice of Violation
	NPDES	National Pollutant Discharge Elimination System
	NPL	National Priorities List
	NRC	Nuclear Regulatory Commission
	nSv	Nanosievert (10^{-9} Sv)
	NWP	nationwide permit
O	OBT	Organically bound tritium
	ORAD	Operations and Regulatory Affairs Division (of the Environmental Protection Department at LLNL)
	OSP	Operational safety plan
	OU	Operable unit
P	P2	Pollution prevention
	P2/E2	Pollution prevention/energy efficiency
	PA	Programmatic agreement
	PCB	Polychlorinated biphenyl
	PCE	Perchloroethylene (or perchloroethene). Also called tetrachloroethylene (or tetrachloroethene).
	PHA	Public health assessment
	pHMS	pH Monitoring Station
	PM	Performance measure
	PMCL	Primary maximum contaminant level
	POTW	Publicly owned treatment works
	ppb	Parts per billion
	ppm	Parts per million
	ppmv	Parts per million by volume
	PPOA	Pollution prevention opportunity assessment
	PQL	Practical quantitation limit
	PTU	Portable treatment unit
Q	QA	Quality assurance
	QC	Quality control

R	RAIP	Remedial Action Implementation Plan	
	RCRA	Resource Conservation and Recovery Act of 1976	
	RDWP	Remedial Design Work Plan	
	RD	Remedial Design	
	RDX	Hexahydro-1,3,5-trinitro-1,3,5-triazine	
	RI/FS	Remedial investigation/feasibility study	
	RL	Reporting limit	
	ROD	Record of Decision	
	ROI	Return on investment	
	RWQCB	Regional Water Quality Control Board	
	S	SAA	Streambed alteration agreement
		SAER	Site Annual Environmental Report
		Sandia/California	Sandia National Laboratories/California
		SAR	Safety analysis report
SARA		Superfund Amendment and Reauthorization Act of 1986 (see also CERCLA/SARA)	
SAT		Space Action Team	
SDF		Sewer Diversion Facility	
SE		Standard error	
SERC		State Emergency Response Commission	
SFBRWQCB		San Francisco Bay Regional Water Quality Control Board	
SI		Système International d'Unités	
Site 300		LLNL's Experimental Test Site, located approximately 24 km east of the Livermore site	
SJVUAPCD		San Joaquin Valley Unified Air Pollution Control District	
SME		Subject matter expert	
		Safety Management Evaluation	
SMS		Sewer Monitoring Station	
SOP		Standard operating procedures	
SOV		Summary of violations	
SPCC	Spill Prevention Control and Countermeasure		
STP	Site treatment plan		
STU	Solar treatment unit		
Sv	Sievert		

	SVE	Soil vapor extraction
	SW-MEI	Sitewide maximally exposed individual member (of the public)
	SWPPP	Storm Water Pollution Prevention Plan
	SWRCB	(California) State Water Resources Control Board
T	TBOS	Tetrabutyl orthosilicate
	TBq	Terabecquerel (10^{12} Bq)
	TCE	Trichloroethene (or trichloroethylene)
	TCLP	Toxicity characteristic leaching procedure
	TDS	Total dissolved solids
	TKEBS	Tetrakis (2-ethylbutyl) silane
	TLD	Thermoluminescent dosimeter
	TNT	Trinitrotoluene
	TOC	Total organic carbon
	TOX	Total organic halides
	TRU	Transuranic (waste)
	TSCA	Toxic Substances Control Act
	TSS	Total suspended solids
	TTO	Total toxic organics
	TWMS	Total Waste Management System
U	UC	University of California
	USC	U.S. Code
	UV/H₂O₂	Ultraviolet/hydrogen peroxide
V	VOC	Volatile organic compound
	VTF	Vapor treatment facility
W	WAA	Waste accumulation area
	WDR	Waste Discharge Requirements
	WSS	Work Smart Standards
Z	Zone 7	Alameda County Flood Control and Conservation District, Zone 7

GLOSSARY

- A** **Absorbed dose:** the amount of energy imparted to matter by ionizing radiation per unit mass of irradiated material, in which the absorbed dose is expressed in units of rad or gray (1 rad = 0.01 gray)
- Accuracy:** the closeness of the result of a measurement to the true value of the quantity measured
- Action level:** defined by regulatory agencies, the level of pollutants which, if exceeded, requires regulatory action
- Aerosol:** a gaseous suspension of very small particles of liquid or solid
- Ag:** silver
- Alameda County Flood Control and Water Conservation District:** also known as Zone 7, the water management agency for the Livermore-Amador Valley with responsibility for water treatment and distribution, and responsible for management of agricultural and surface water and the ground water basin
- Alluvium:** sediment deposited by flowing water
- Alpha particle:** a positively charged particle emitted from the nucleus of an atom, having mass and charge equal to those of a helium nucleus (two protons and two neutrons)
- Ambient air:** the surrounding atmosphere, usually the outside air, as it exists around people, plants, and structures; not considered in monitoring purposes when immediately adjacent to emission sources
- Analysis of variance (ANOVA):** a test of whether two or more sample means are statistically different
- Analyte:** the specific component measured in a chemical analysis
- Anion:** a negatively charged ion, such as Cl⁻
- Aquifer:** a saturated layer of rock or soil below the ground surface that can supply usable quantities of ground water to wells and springs, and be a source of water for domestic, agricultural, and industrial uses
- Aquitard:** low-permeability geologic formation that bounds an aquifer
- As:** arsenic
- Atom:** the smallest particle of an element capable of entering into a chemical reaction

Atomic absorption (AA) spectroscopy: a method used to determine the elemental composition of a sample, where the sample is vaporized and its light absorbance measured

B Barcad: device that samples water in a well in which water, collected in a discrete water-bearing zone, is forced to the surface by pressurized nitrogen

Bay Area Air Quality Management District (BAAQMD): the local agency responsible for regulating stationary air emission sources (including the LLNL Livermore site) in the San Francisco Bay Area

Becquerel (Bq): the SI unit of activity of a radionuclide, equal to the activity of a radionuclide having one spontaneous nuclear transition per second

Beta particle: a negatively charged particle emitted from the nucleus of an atom, having charge, mass, and other properties of an electron

Biochemical (biological) oxygen demand (BOD): a measure of the amount of dissolved oxygen that microorganisms need to break down organic matter in water, used as an indicator of water quality

Blowdown: water discharged from cooling towers in order to control total dissolved solids concentrations by allowing make-up water to replenish cooling apparatuses

C CaCO₃: calcium carbonate

California Code of Regulations (CCR): codification of regulations promulgated by the State of California

California Environmental Quality Act of 1970 (CEQA): statute that requires that all California state, local, and regional agencies document, consider, and disclose to the public the environmental implications of their actions

CAP88-PC: computer code required by the EPA for modeling air emissions of radionuclides

Categorical discharge: discharge from a process regulated by EPA rules for specific industrial categories

Cd: cadmium

Chain-of-custody: a method for documenting the history and possession of a sample from the time of its collection, through its analysis and data reporting, to its final disposition

Chemistry and Materials Science Environmental Services (CES): an LLNL laboratory that analyzes environmental samples

Chlorofluorocarbon (CFC): a compound that has fluorine and chlorine atoms on a carbon backbone, such as Freons

Chlorocarbon: a compound of carbon and chlorine, or carbon, hydrogen, and chlorine, such as carbon tetrachloride, chloroform, and tetrachloroethene

Code of Federal Regulations (CFR): a codification of all regulations promulgated by federal government agencies

Collective dose equivalent and collective effective dose equivalent: the sums of the dose equivalents or effective dose equivalents to all individuals in an exposed population within 80 km (50 miles) of the radiation source. These are evaluated by multiplying the dose received by an individual at each location by the number of individuals receiving that dose, and summing over all such products for locations within 80 km of the source. They are expressed in units of person-rem or person-sievert. The collective EDE is also referred to as the “population dose.”

Committed dose equivalent: the predicted total dose equivalent to a tissue or organ over a 50-year period after an intake of a radionuclide into the body. It does not include contributions from external dose. Committed dose equivalent is expressed in units of rem (or sievert; 100 rem equals one sievert).

Committed effective dose equivalent: the sum of the committed dose equivalents to various tissues in the body, each multiplied by an appropriate weighting factor representing the relative vulnerability of different parts of the body to radiation. Committed effective dose equivalent is expressed in units of rem or sievert.

Comprehensive Environmental Response, Compensation and Liability Act of 1980

(CERCLA): administered by EPA, this program, also known as Superfund, requires private parties to notify the EPA after the release of hazardous substances or conditions that threaten to release hazardous substances, and undertake short-term removal and long-term remediation.

Cosmic radiation: radiation with very high energies originating outside the earth’s atmosphere; it is one source contributing to natural background radiation

Cr: chromium

Cu: copper

Curie (Ci): a unit of measurement of radioactivity, defined as the amount of radioactive material in which the decay rate is 3.7×10^{10} disintegrations per second or 2.22×10^{12} disintegrations per minute; one Ci is approximately equal to the decay rate of one gram of pure radium

D Daughter nuclide: a nuclide formed by the radioactive decay of another nuclide, which is called the parent

De minimis: shortened form of “de minimis non curat lex,” which means, “The law does not care for, or take notice of, very small or trifling matters,” meaning a level that is so inconsequential that it cannot be cause for concern

Depleted uranium: uranium having a lower proportion of the isotope ^{235}U than is found in naturally occurring uranium. The masses of the three uranium isotopes with atomic weights 238, 235, and 234 occur in depleted uranium in the weight-percentages 99.8, 0.2, and 5×10^{-4} , respectively. Depleted uranium is sometimes referred to as D-38.

Derived Concentration Guide (DCG): concentrations of radionuclides in water and air that could be continuously consumed or inhaled for one year and not exceed the DOE primary radiation standard to the public (100 mrem/y EDE)

Dose: the energy imparted to matter by ionizing radiation; the unit of absorbed dose is the rad, equal to 0.01 joules per kilogram for irradiated material in any medium

Dose commitment: the dose that an organ or tissue would receive during a specified period of time (e.g., 50 or 70 years) as a result of one year's intake of one or more radionuclides

Dose equivalent: the product of absorbed dose in rad (or gray) in tissue and a quality factor representing the relative damage caused to living tissue by different kinds of radiation, and perhaps other modifying factors representing the distribution of radiation, etc. expressed in units of rem or sievert (1 rem = 0.01 sievert)

Dosimeter: a portable detection device for measuring the total accumulated exposure to ionizing radiation

Dosimetry: the theory and application of the principles and techniques of measuring and recording radiation doses

Downgradient: in the direction of groundwater flow from a designated area; analogous to downstream

Drainage Retention Basin (DRB): man-made, lined pond used to capture storm water runoff and treated water at the LLNL Livermore site

E Effective dose equivalent (EDE): an estimate of the total risk of potential effects from radiation exposure, it is the summation of the products of the dose equivalent and weighting factor for each tissue. The weighting factor is the decimal fraction of the risk arising from irradiation of a selected tissue to the total risk when the whole body is irradiated uniformly to the same dose equivalent. These factors permit dose equivalents from nonuniform exposure of the body to be expressed in terms of an effective dose equivalent that is numerically equal to the dose from a uniform exposure of the whole body that entails the same risk as the internal exposure (ICRP 1980). The effective dose equivalent includes the committed effective dose equivalent from internal deposition of radionuclides and the effective dose equivalent caused by penetrating radiation from sources external to the body, and is expressed in units of rem (or sievert).

Effluent: a liquid or gaseous waste discharged to the environment

Emergency Planning and Community Right-to-Know Act of 1986 (EPCRA): act that requires facilities that produce, use, or store hazardous substances to report releases of reportable quantities or hazardous substances to the environment

Environmental impact report (EIR): a detailed report prepared pursuant to CEQA on the environmental impacts from any action carried out, approved, or funded by a California state, regional, or local agency

Environmental impact statement (EIS): a detailed report, required by the National Environmental Policy Act, on the environmental impacts from a federally approved or funded project. An EIS must be prepared by a federal agency when a "major" federal action that will have "significant" environmental impacts is planned.

Evapotranspiration: a process by which water is transferred from the soil to the air by plants that take the water up through their roots and release it through their leaves and other aboveground tissue

F Federal facility: a facility that is owned or operated by the federal government, subject to the same requirements as other responsible parties when placed on the Superfund National Priorities List

Federal facility agreement (FFA): a negotiated agreement that specifies required actions at a federal facility as agreed upon by various agencies (e.g., EPA, RWQCB, and DOE).

Federal Register: a document published daily by the federal government containing notification of government agency actions, including notification of EPA and DOE decisions concerning permit applications and rule-making

Fiscal year: LLNL's fiscal year is from October 1 through September 30.

Freon 11: trichlorofluoromethane

Freon 113: 1,1,2-trichloro-1,2,2-trifluoroethane; also known as CFC 113

G Gamma ray: high-energy, short-wavelength, electromagnetic radiation emitted from the nucleus of an atom, frequently accompanying the emission of alpha or beta particles

Gram (g): the standard metric measure of weight approximately equal to 0.035 ounce

Gray (Gy): the SI unit of measure for absorbed dose; the quantity of energy imparted by ionizing radiation to a unit mass of matter, such as tissue. One gray equals 100 rads, or 1 joule per kilogram.

Groundwater: all subsurface water

H Half-life (radiological): the time required for one-half the radioactive atoms in a given amount of material to decay; for example, after one half-life, half of the atoms will have decayed; after two half-lives, three-fourths; after three half-lives, seven-eighths; and so on, exponentially

Hazardous waste: hazardous wastes exhibit any of the following characteristics: ignitability, corrosivity, reactivity, or EP-toxicity (yielding toxic constituents in a leaching test), but other wastes that do not necessarily exhibit these characteristics have been determined to be hazardous by EPA. Although the legal definition of hazardous waste is complex, according to EPA the term generally refers to any waste that, if managed improperly, could pose a threat to human health and the environment.

(California) Hazardous Waste Control Act (HWCA): legislation specifying requirements for hazardous waste management in California

Hg: mercury

High-efficiency particulate air filter (HEPA): a throwaway, extended-media, dry type filter used to capture particulates in an air stream; HEPA collection efficiencies are at least 99.97% for 0.3 micrometer diameter particles

Hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX): a high-explosive compound

High explosives (HE): materials that release large amounts of chemical energy when detonated

Hydraulic gradient: in an aquifer, the rate of change of total head (water-level elevation) per unit distance of flow at a given point and in a given direction

Hydrology: the science dealing with the properties, distribution, and circulation of natural water systems

I Inorganic compounds: compounds that either do not contain carbon or do not contain hydrogen along with carbon, including metals, salts, and various carbon oxides (e.g., carbon monoxide and carbon dioxide).

In situ: refers to the treatment of contaminated areas in place without excavation or removal, as in the in situ treatment of on-site soils through biodegradation of contaminants

Interim status: a legal classification allowing hazardous waste incinerators or other hazardous waste management facilities to operate while EPA considers their permit applications, provided that they were under construction or in operation by November 19, 1980 and can meet other interim status requirements

International Commission on Radiological Protection (ICRP): an international organization that studies radiation, including its measurement and effects

Interquartile range (IQR): the distance between the top of the lower quartile and the bottom of the upper quartile, which provides a measure of the spread of data

Isotopes: forms of an element having the same number of protons in their nuclei, but differing numbers of neutrons

- L Less than detection limits:** a phrase indicating that a chemical constituent was either not present in a sample, or is present in such a small concentration that it cannot be measured by a laboratory's analytical procedure, and therefore is not identified or not quantified at the lowest level of sensitivity.

Liter (L): the SI measure of capacity approximately equal to 1.057 quart

Livermore Water Reclamation Plant (LWRP): the City of Livermore's municipal wastewater treatment plant, which accepts discharges from the LLNL Livermore site

Low-level waste: waste defined by DOE Order 5820.2A, which contains transuranic nuclide concentrations less than 100 nCi/g

Lower limit of detection: the smallest concentration or amount of analyte that can be detected in a sample at a 95% confidence level

Lysimeter: an instrument for measuring the water percolating through soils and determining the dissolved materials

- M Maximally exposed individual (MEI):** a hypothetical member of the public at a fixed location who, over an entire year, receives the maximum effective dose equivalent (summed over all pathways) from a given source of radionuclide releases to air. Generally, the MEI is different for each source at a site.

Maximum Contaminant Level (MCL): the highest level of a contaminant in drinking water that is allowed by the U.S. Environmental Protection Agency regulation

Multiple completion: a borehole with water surveillance monitoring devices (Barcads) placed at various levels and separated by impermeable layers of material such as grout. Usually referred to as a well, the uppermost "completion" is accessible from the surface, making physical sample-taking possible (as opposed to Barcads).

Metric units: Metric system and U.S. customary units and their respective equivalents are shown in Table GL-1. Except for temperature for which specific equations apply, U.S. customary units can be determined from metric units by multiplying the metric units by the U.S. customary equivalent. Similarly, metric units can be determined from U.S. customary equivalent units by multiplying the U.S. customary units by the metric equivalent.

Mixed waste: waste that has the properties of both hazardous and radioactive waste

Table GL-1. Metric and U.S. customary unit equivalents

Metric unit	U.S. customary equivalent unit	U.S. customary unit	Metric equivalent unit
Length			
1 centimeter (cm)	0.39 inches (in)	1 inch (in)	2.54 centimeters (cm)
1 millimeter (mm)	0.039 inches (in)		25.4 millimeters (mm)
1 meter (m)	3.28 feet (ft)	1 foot (ft)	0.3048 meters (m)
	1.09 yards (yd)	1 yard (yd)	0.9144 meters (m)
1 kilometer (km)	0.62 miles (mi)	1 mile (mi)	1.6093 kilometers (km)
Volume			
1 liter (L)	0.26 gallons (gal)	1 gallon (gal)	3.7853 liters (L)
1 cubic meter (m ³)	35.32 cubic feet (ft ³)	1 cubic foot (ft ³)	0.028 cubic meters (m ³)
	1.35 cubic yards (yd ³)	1 cubic yard (yd ³)	0.765 cubic meters (m ³)
Weight			
1 gram (g)	0.035 ounces (oz)	1 ounce (oz)	28.6 gram (g)
1 kilogram (kg)	2.21 pounds (lb)	1 pound (lb)	0.373 kilograms (kg)
1 metric ton (MT)	1.10 short ton (2000 pounds)	1 short ton (2000 pounds)	0.90718 metric ton (MT)
Geographic area			
1 hectare	2.47 acres	1 acre	0.40 hectares
Radioactivity			
1 becquerel (Bq)	2.7×10^{-11} curie (Ci)	1 curie (Ci)	3.7×10^{10} becquerel (Bq)
Radiation dose			
1 rem	0.01 sievert (Sv)	1 sievert (Sv)	100 rem
Temperature			
$^{\circ}\text{C} = (^{\circ}\text{F} - 32) / 1.8$		$^{\circ}\text{F} = (^{\circ}\text{C} \times 1.8) + 32$	

N National Emission Standards for Hazardous Air Pollutants (NESHAPs): standards found in the Clean Air Act that set limits for hazardous air pollutants

National Environmental Policy Act (NEPA): federal legislation enacted in 1969 that requires all federal agencies to document and consider environmental impacts for federally funded or approved projects and the legislation under which DOE is responsible for NEPA compliance at LLNL

National Institute for Standards and Technology (NIST): the federal agency, formerly known as the National Bureau of Standards, responsible for reference materials against which laboratory materials are calibrated

National Pollutant Discharge Elimination System (NPDES): federal regulation under the Clean Water Act that requires permits for discharges into surface waterways

NEWTRIT: model used to calculate doses from environmental measurements

Ni: nickel

Nonpoint source: any nonconfined area from which pollutants are discharged into a body of water (e.g., agricultural runoff, construction runoff, and parking lot drainage), or into air (e.g., a pile of uranium tailings)

Nuclear Regulatory Commission (NRC): the federal agency charged with oversight of nuclear power and nuclear machinery and applications not regulated by DOE or the Department of Defense

Nuclide: a species of atom characterized by the constitution of its nucleus. The nuclear constitution is specified by the number of protons, number of neutrons, and energy content; or, alternatively, by the atomic number, mass number, and atomic mass. To be regarded as a distinct nuclide, the atom must be capable of existing for a measurable length of time.

O Off-site: outside the boundaries of the LLNL Livermore site and Site 300 properties

On-site: within the boundaries of the LLNL Livermore site or Site 300 properties

P Part B permit: the second, narrative section submitted by generators in the RCRA permitting process that covers in detail the procedures followed at a facility to protect human health and the environment

Parts per billion (ppb): a unit of measure for the concentration of a substance in its surrounding medium; for example, one billion grams of water containing one gram of salt has a salt concentration of one part per billion

Parts per million (ppm): a unit of measure for the concentration of a substance in its surrounding medium; for example, one million grams of water containing one gram of salt has a salt concentration of one part per million

Pb: lead

Perched aquifer: aquifer that is separated from another water-bearing stratum by an impermeable layer

Performance standards (incinerators): specific regulatory requirements established by EPA limiting the concentrations of designated organic compounds, particulate matter, and hydrogen chloride in incinerator emissions

pH: a measure of hydrogen ion concentration in an aqueous solution. Acidic solutions have a pH from 0 to 6; basic solutions have a pH greater than 7; and neutral solutions have a pH of 7.

Piezometer: instrument for measuring fluid pressure used to measure the elevation of the water table in a small, nonpumping well

Pliocene: geological epoch of the Tertiary period, starting about 12 million years ago

PM-10: fine particulate matter with an aerodynamic diameter equal to or less than 10 microns

Point source: any confined and discrete conveyance (e.g., pipe, ditch, well, or stack)

Pretreatment: any process used to reduce a pollutant load before it enters the sewer system

Pretreatment regulations: national wastewater pretreatment regulations, adopted by EPA in compliance with the 1977 amendments to the Clean Water Act, which required that EPA establish pretreatment standards for existing and new industrial sources

Priority pollutants: a set of organic and inorganic chemicals identified by EPA as indicators of environmental contamination

- Q Quality assurance (QA):** a system of activities whose purpose is to provide the assurance that standards of quality are attained with a stated level of confidence
- Quality control (QC):** procedures used to verify that prescribed standards of performance are attained
- Quality factor:** the factor by which the absorbed dose (rad) is multiplied to obtain a quantity that expresses (on a common scale for all ionizing radiation) the biological damage to exposed persons, usually used because some types of radiation, such as alpha particles, are biologically more damaging than others. Quality factors for alpha, beta, and gamma radiation are in the ratio 20:1:1.
- Quaternary:** the geologic era encompassing the last 2–3 million years
- R Rad:** the unit of absorbed dose and the quantity of energy imparted by ionizing radiation to a unit mass of matter such as tissue, and equal to 0.01 joule per kilogram, or 0.01 gray.
- Radioactive decay:** the spontaneous transformation of one radionuclide into a different nuclide (which may or may not be radioactive), or de-excitation to a lower energy state of the nucleus by emission of nuclear radiation, primarily alpha or beta particles, or gamma rays (photons)
- Radioactivity:** the spontaneous emission of nuclear radiation, generally alpha or beta particles, or gamma rays, from the nucleus of an unstable isotope
- Radionuclide:** an unstable nuclide. See nuclide and radioactivity.
- Regional Water Quality Control Board (RWQCB):** the California regional agency responsible for water quality standards and the enforcement of state water quality laws within its jurisdiction. California is divided into a number of RWQCBs; the Livermore site is regulated by the San Francisco Bay Region, and Site 300 is regulated by the Central Valley Region.
- Rem:** a unit of radiation dose equivalent and effective dose equivalent describing the effectiveness of a type of radiation to produce biological effects; coined from the phrase “roentgen equivalent man,” and the product of the absorbed dose (rad), a quality factor (Q), a distribution factor, and other necessary modifying factors. One rem equals 0.01-sievert.
- Resource Conservation and Recovery Act of 1976 (RCRA):** a program of federal laws and regulations that govern the management of hazardous wastes, and applicable to all entities that manage hazardous wastes
- Risk assessment:** the use of established methods to measure the risks posed by an activity or exposure by evaluating the relationship between exposure to radioactive substances and the subsequent occurrence of health effects and the likelihood for that exposure to occur
- Roentgen (R):** a unit of measurement used to express radiation exposure in terms of the amount of ionization produced in a volume of air
- S Sampling and Analysis Plan:** a detailed document that describes the procedures used to collect, handle, and analyze groundwater samples, and details quality control measures that are implemented to ensure that sample-collection, analysis, and data-presentation activities meet the prescribed requirements
- San Francisco Bay Regional Water Quality Control Board (SFBRWCB):** the local agency responsible for regulating stationary air emission sources (including the Livermore site) in the San Francisco Bay Area

San Joaquin County Health District (SJCHD): the local agency that enforces underground-tank regulations in San Joaquin County, including Site 300

San Joaquin Valley Unified Air Pollution Control District (SVUAPCD): the local agency responsible for regulating stationary air emission sources (including Site 300) in San Joaquin County

Sanitary waste: most simply, waste generated by routine operations that is not regulated as hazardous or radioactive by state or federal agencies

Saturated zone: a subsurface zone below which all rock pore-space is filled with water; also called the phreatic zone

Sensitivity: the capability of methodology or instrumentation to discriminate between samples having differing concentrations or containing varying amounts of analyte

Sewerage: the system of sewers

Sievert (Sv): the SI unit of radiation dose equivalent and effective dose equivalent, that is the product of the absorbed dose (gray), quality factor (Q), distribution factor, and other necessary modifying factors. 1 Sv equals 100 rem.

Sitewide Maximally Exposed Individual (SW-MEI): a hypothetical person who receives, at the location of a given publicly accessible facility (such as a church, school, business, or residence), the greatest LLNL-induced effective dose equivalent (summed over all pathways) from all sources of radionuclide releases to air at a site. Doses at this receptor location caused by each emission source are summed, and yield a larger value than for the location of any other similar public facility. This individual is assumed to continuously reside at this location 24 hours per day, 365 days per year.

Specific conductance: measure of the ability of a material to conduct electricity; also called conductivity

Superfund: the common name used for the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA). California has also established a "State Superfund" under provisions of the California Hazardous Waste Control Act.

Superfund Amendments and Reauthorization Act (SARA): act enacted in 1986, which amended and reauthorized CERCLA for five years at a total funding level of \$8.5 billion

Surface impoundment: a facility or part of a facility that is a natural topographic depression, man-made excavation, or diked area formed primarily of earthen materials, although it may be lined with man-made materials. The impoundment is designed to hold an accumulation of liquid wastes, or wastes containing free liquids, and is not an injection well. Examples of surface impoundments are holding, storage, settling and aeration pits, ponds, and lagoons.

Système International d'Unités (SI): an international system of physical units which include meter (length), kilogram (mass), kelvin (temperature), becquerel (radioactivity), gray (radioactive dose), and sievert (dose equivalent)

T Thermoluminescent dosimeter (TLD): a device used to measure external beta or gamma radiation levels, and which contains a material that, after exposure to beta or gamma radiation, emits light when processed and heated

Total dissolved solids (TDS): the portion of solid material in a waste stream that is dissolved and passed through a filter

Total organic carbon (TOC): the sum of the organic material present in a sample

Total organic halides (TOX): the sum of the organic halides present in a sample

Total suspended solids (TSS): the total mass of particulate matter per unit volume suspended in water and wastewater discharges that is large enough to be collected by a 0.45 micron filter

Tritium: the radioactive isotope of hydrogen, containing one proton and two neutrons in its nucleus, which decays at a half-life of 12.3 years by emitting a low-energy beta particle

Transuranic waste (TRU): material contaminated with alpha-emitting transuranium nuclides, which have an atomic number greater than 92 (e.g. ^{239}Pu), half-lives longer than 20 years, and are present in concentrations greater than 100 nCi/g of waste

U Unsaturated zone: that portion of the subsurface in which the pores are only partially filled with water and the direction of water flow is vertical; is also referred to as the vadose zone.

U.S. Department of Energy (DOE): the federal agency responsible for conducting energy research and regulating nuclear materials used for weapons production

U.S. Environmental Protection Agency (EPA): the federal agency responsible for enforcing federal environmental laws. Although some of this responsibility may be delegated to state and local regulatory agencies, EPA retains oversight authority to ensure protection of human health and the environment.

V Vadose zone: the partially saturated or unsaturated region above the water table that does not yield water to wells

Volatile organic compound (VOC): liquid or solid organic compounds that have a high vapor pressure at normal pressures and temperatures and thus tend to spontaneously pass into the vapor state

W Waste accumulation area (WAA): an officially designated area that meets current environmental standards and guidelines for temporary (less than 90 days) storage of hazardous waste before pickup by the Hazardous Waste Management Division for off-site disposal

Wastewater treatment system: a collection of treatment processes and facilities designed and built to reduce the amount of suspended solids, bacteria, oxygen-demanding materials, and chemical constituents in wastewater

Water table: the water-level surface below the ground at which the unsaturated zone ends and the saturated zone begins, and the level to which a well that is screened in the unconfined aquifer would fill with water

Weighting factor: a tissue-specific value used to calculate dose equivalents which represents the fraction of the total health risk resulting from uniform, whole-body irradiation that could be contributed to that particular tissue. The weighting factors used in this report are recommended by the International Commission on Radiological Protection (ICRP 1980).

Wind rose: a diagram that shows the frequency and intensity of wind from different directions at a specific location

Z Zn: zinc

Zone 7: the common name for the Alameda County Flood Control and Water Conservation District

EXTERNAL DISTRIBUTION

Air Resources Board
J. Morgester
Compliance Division
P.O. Box 2815
Sacramento, CA 95812

A.K.T.
Eleni Tsakopoulos
770 College Town Drive
Suite 101
Sacramento, CA 95826-2303

Alameda County Department of
Environmental Health
Robert Weston
Environmental Protection Division
1131 Harbor Bay Parkway, 2nd Floor
Alameda, CA 94502

Alameda County Flood Control and
Water Conservation District, Zone 7
David Lunn
5997 Parkside Drive
Pleasanton, CA 94588-5127

Alameda County Water District
E. L. Lenahan
43885 S. Grimmer Blvd.
Fremont, CA 94537

Argonne National Laboratory
Norbert Golchert
9700 S. Cass Avenue
Building 200, Room B-117
Argonne, IL 60439

Argonne National Laboratory
Michael Lazaro
9700 S. Cass Avenue
Building 200, Room B-900
Argonne, IL 60439

Assistant Administrator for Air Radiation (ANR-443)
U.S. Environmental Protection Agency
401 "M" Street, SW
Washington, DC 20460

Bay Area Air Quality
Management District
Ellen Garvey
939 Ellis Street
San Francisco, CA 94109

Bay Area Air Quality
Management District
Dick Duker
939 Ellis Street
San Francisco, CA 94109

Biomedical & Environmental
Sciences Lab
O. R. Lunt, Director
University of California
900 Veteran Avenue
Los Angeles, CA 90024

Brookhaven National Laboratory
Robert Miltenberger
G. L. Schroeder
Bldg. 535A
Upton, NY 11973

Brookhaven National Laboratory
J. Naidu
Safety & Environmental Protection
Bldg. 535A
Upton, NY 11973

California Department of Energy
Barbara J. Byron
Executive Office
1515 - 9th Street/MS-36
Sacramento, CA 95814

California Department of Health Services
Dorice Bailey
Edgar D. Bailey
K. Jackson
DHS/EMB, MS-396
601 N. 7th Street, Box 942732
Sacramento, CA 95814

California Environmental
Protection Agency
Mark Piros
Northern California Coastal Cleanup
Operations Branch
700 Heinz Avenue, Suite 200
Berkeley, CA 94710-2737

California Environmental
Protection Agency
Ted Park
Department of Toxic Substances Control
700 Heinz Avenue, Suite 300
Berkeley, CA 94710-2737

California Environmental
Protection Agency
M. Sandhu
Department of Toxic Substances Control
700 Heinz Avenue, Suite 300
Berkeley, CA 94710-2737

California Environmental
Protection Agency
C. Williams
Department of Toxic Substances Control
700 Heinz Avenue, Bldg. F
Berkeley, CA 94710-2737

California Regional Water Quality Control Board
S. Timm
Central Valley Region
3443 Routier Road
Sacramento, CA 95827-3098

California Regional Water Quality Control Board
Naomi Feger
San Francisco Bay Region
1515 Clay Street, Suite 1400
Oakland, CA 94612

California State Water Resources Control Board
Stan Martinson
Division of Water Quality
901 "P" Street
Sacramento, CA 95814

Continuous Electron Beam
Accelerator Facility
Bob May
Radiation Control
12000 Jefferson Avenue
Newport News, VA 23606

Chow Engineering
Sam Kreitem
770 Edgewater Dr., #729
Oakland, CA 94621

Ernest Orlando Lawrence
Berkeley National Laboratory
Ron Pauer
Environmental Monitoring Group
MS75B-101
One Cyclotron Road
Berkeley, CA 94720

Ernest Orlando Lawrence
Berkeley National Laboratory
Henry Tran
MS75B-101
One Cyclotron Road
Berkeley, CA 94720

Environmental Measurements Lab
Edward P. Hardy, Jr., Director
Environmental Studies Division
U.S. Department of Energy
376 Hudson Street
New York, NY 10014-3621

FERMCO
P. A. Kraps
Allan Lydic
Xenos J. Sroka
Site Restoration Services
P.O. Box 538704
Cincinnati, OH 45253-8704

FERMCO
Caran Siefert
Environmental Protection
P.O. Box 538704
Cincinnati, OH 45253-8704

Fermilab
Sam Baker
Paul Kesich
P.O. Box 500, MS-119
Batavia, IL 60510

Hanford Environmental Health Foundation
Joseph K. Samuels
Environmental Health Services
P.O. Box 100, H1-78
Richland, WA 99352

Livermore Water Reclamation Plant
Darren Greenwood
Water Resources Manager
101 West Jack London Blvd.
Livermore, CA 94551

Lockheed Idaho Technologies Co.
Leah Street
Environmental Protection
P.O. Box 1625
Idaho Falls, ID 83415-4110

Los Alamos National Laboratory
Tom Buhl
Doris Garvey
Environmental Assessments and Resource Evaluation
Section HSE-8, MS-K490
P.O. Box 1663
Los Alamos, NM 87545

Los Alamos National Laboratory
Bruce Gallahar
Steven Rae
Environment, Safety, & Health Division
MS-K497, ESH-18
P.O. Box 1663
Los Alamos, NM 87545

Los Alamos National Laboratory
Keith Jacobson
Air Quality Division
ESH-17, MS-J978
P.O. Box 1663
Los Alamos, NM 87545

Los Alamos National Laboratory
Julie Johnston
Environment, Safety, & Health Division
ESH-20, MS-M887
P.O. Box 1663
Los Alamos, NM 87545

Los Alamos National Laboratory
John M. Puckett, Division Leader
Safeguards Systems
NIS-7
P.O. Box 1663
Los Alamos, NM 87545

Los Alamos National Laboratory
David B. Rogers (3 sets)
Water Quality & Hydrology Group
ESH-18 MS-K497
P.O. Box 1663
Los Alamos, NM 87545

Los Alamos National Laboratory
Lars Sohlt
Environmental Surveillance Group
MS-M992E-ER
P.O. Box 1663
Los Alamos, NM 87545

Massachusetts Institute of Technology
Hugh Gusterson
STS Program
E51-296F
77 Massachusetts Avenue
Cambridge, MA 02139

Mountain Environmental
Katherine Hunninen
P.O. Box 1010
Silver Plume, CO 80476

Nevada Operations Office
Bruce W. Church
Asst. Manager for Environment,
Safety and Health
P.O. Box 98518
Las Vegas, NV 89193-8518

Oak Ridge National Laboratory
Laury Hamilton
Building 4500S, MS-6137
Oak Ridge, TN 37831-6137

Oak Ridge National Laboratory
John B. Murphy
Head, Environmental Surveillance
and Protection Section
Building 4500N, MS-6198
Oak Ridge, TN 37831-6198

Oak Ridge National Laboratory
Frank O'Donnell
Building 4500S, MS-6102
Oak Ridge, TN 37831-6102

Oak Ridge National Laboratory
Mark Tardiff
Office of Environmental Compliance and
Documentation
Building 4500N, MS-6198
Oak Ridge, TN 37831-6198

Pacific Northwest National Laboratory
P. Evan Dresel
Stuart Luttrell
Earth and Environmental Sciences
P.O. Box 999
Richland, WA 99352

Pacific Northwest National Laboratory
W. W. Laity, General Manager
Environmental Management Operations
Battelle Blvd.
P.O. Box 999
Richland, WA 99352

Questa Engineering Corporation
Jeff Peters
1220 Brickyard Cove Road
Point Richmond, CA 94807

Radiobiology & Environmental Health Laboratory
Sheldon Wolff, Director
University of California
Medical Center
San Francisco, CA 94143

REECO
Stuart C. Black
Health Physics Department
P.O. Box 98521, MS-708
Las Vegas, NV 89193-8521

REECO
Wayne M. Glines
Alan Latham
Analytical Services Department
P.O. Box 98521
Las Vegas, NV 89193-8521

San Francisco Public Utilities Commission
Water Quality Bureau
David Quinones
1000 El Camino Real
Millbrae, CA 94030

San Francisco Public Utilities Commission
Water Quality Bureau – Engineering
Raymond Mah
1000 El Camino Real
Millbrae, CA 94030

San Joaquin County Public Health Services
Doug Wilson
Environmental Health Division
P.O. Box 388
Stockton, CA 95201

San Joaquin Local Health District
V. V. Williams
P.O. Box 388
Stockton, CA 95201

San Joaquin Valley Unified Air Pollution Control
District
Jim Swaney
Permit Services Manager
4230 Kiernan Avenue, Suite 130
Modesto, CA 95356

Sandia National Laboratories/California
Robert Holland
P.O. Box 969, MS-9221
Livermore, CA 94551-0969

Sandia National Laboratories/California
Tricia Larson
P.O. Box 969, MS-9014
Livermore, CA 94551-0969

Sandia National Laboratories
H. S. Hwang
F. Ghanbari
Lih-Jenn Shyr
Dept. 7575
P.O. Box 5800, MS-0174
Albuquerque, NM 87185

Sandia National Laboratories
Marion McDonald
Dept. 6500, MS-1141
P.O. Box 5800
Albuquerque, NM 87185

Savannah River Plant
Tim Jannik
WSRC-Env. Analysis Section
Building 733-42A, Room 226
Aiken, SC 29808

Robert L. Schlegel
12321 Tampico Way
Silver Spring, MD 20904

Stanford Linear Accelerator Center
Michael P. Grissom
Environment, Safety, & Health, MS-84
2575 Sand Hill Road
Menlo Park, CA 94025-7015

William N. Taber
4211 S. Yuron Way
Lakewood, CO 80235

TetraTech, Inc.
John Nash
5203 Leesburg Pike, Suite 900
Falls Church, VA 22041

Tri-Valley CARES
Marylia Kelly
2582 Old First Street
Livermore, CA 94550

U.S. Department of Energy
Brookhaven Area Office
Gerald Granzen
Environmental Programs Division
Bldg. 464
Upton, NY 11973-5000

U.S. Department of Energy
B. Sue Lantz
Idaho Operations Office
850 Energy Drive, MS-1146
Idaho Falls, ID 83401-1563

U.S. Department of Energy
Stephen Chase
Office of Env. & Tech. Support
Defense Programs, DP-45
1000 Independence Avenue S.W.
Washington, DC 20585

U.S. Department of Energy
Office of Scientific & Technical Information
P.O. Box 62
Oak Ridge, TN 37831

U.S. Department of Energy
Rocky Flats Area Office
James K. Hartmen
Environmental Program Branch
P.O. Box 928
Golden, CO 80402-0928

U.S. Environmental Protection Agency
Federal Facilities Cleanup Office SFD8-1
Kathy Setian
Region IX
75 Hawthorne Street
San Francisco, CA 94195-3901

U.S. Environmental Protection Agency
S. Rosenblum, AIR-6
P. Wood, AIR-6
Region IX
75 Hawthorne Street
San Francisco, CA 94195-3901

U.S. Environmental Protection Agency
K. Silva, WTR-7
M. Gill, SFD-8
Region IX
75 Hawthorne Street
San Francisco, CA 94195-3901

University of California Berkeley
James Hunt
Department of Civil and Environmental Engineering
631 Davis Hall, MS-1710
Berkeley, CA 94720

West Valley Nuclear Services Co., Inc.
Anthony Nagel
Environmental, Safety, Health
and Quality Assurance
10282 Rock Springs Road
P.O. Box 191
West Valley, NY 14171-0191

Westinghouse Hanford Co.
Austin R. Johnson
P.O. Box 1970, H6-30
Richland, WA 99352

Westinghouse Savannah River Co.
James Heffner
Pete Fledderman
Environmental Protection
P.O. Box 616, Bldg. 735A
Aiken, SC 29802

**Environmental Protection Department • Lawrence Livermore National Laboratory
University of California • P.O. Box 808 • Livermore, California 94551**