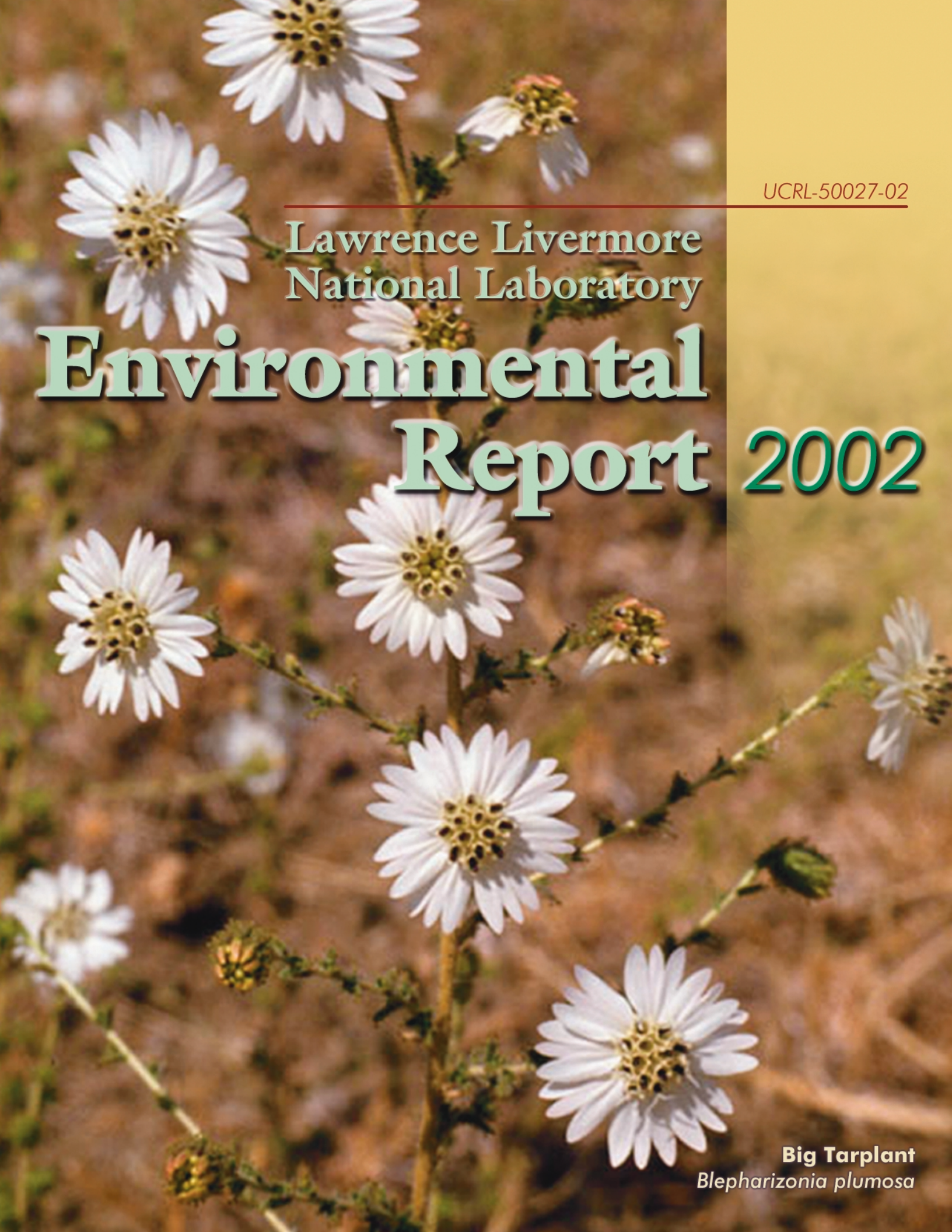
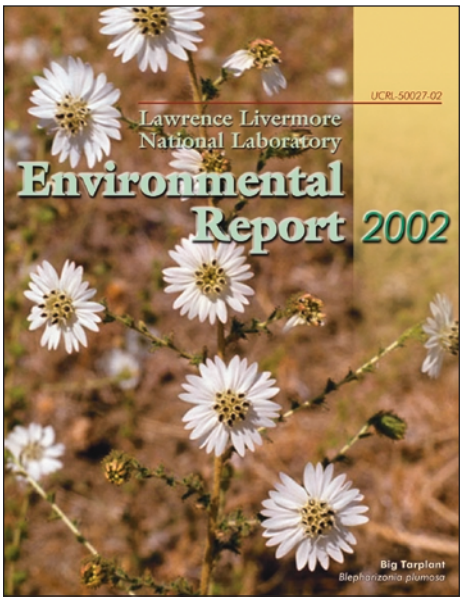
UCRL-50027-02

Lawrence Livermore
National Laboratory

Environmental Report 2002



Big Tarplant
Blepharizonia plumosa



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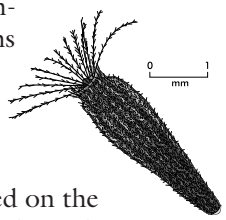
Cover
The big tarplant (*Blepharizonia plumosa*) is an annual plant that flowers in the late summer and early fall, several months after most Site 300 annual plants are done flowering. This species is a member of the sunflower family (Asteraceae). As is common in many members of the sunflower family, the big tarplant has tiny glands on the stems and leaves that give this plant a distinctive smell. Its inner seeds have tiny feather-like appendages, called pappus, that help the seeds be disbursed by the wind.



The big tarplant is an extremely rare annual plant included on the California Native Plant Society's List 1B, which includes plants that are rare, threatened, or endangered. The big tarplant's range includes Alameda, Contra Costa, San Joaquin, Stanislaus, and Solano Counties. In these areas, it is found in dry grasslands at elevations less than 505 meters (CNPS 2001). This species often occurs in disturbed areas, such as along the edges of roads or in areas were there have been grassfires. Although several populations of big tarplant occur at Site 300, this species is extremely rare elsewhere and may be limited to as few as three general areas outside of Site 300 (California Natural Diversity Database 2003).

This work was performed under the auspices of the U.S. Department of Energy by University of California Lawrence Livermore National Laboratory under contract W-7405-Eng-48.

Environmental Report 2002

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Subject: 2002 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) Livermore Site Office, provides a comprehensive summary of the environmental program activities at LLNL for calendar year 2002. 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. The data in this report shows that there is a continuing trend of reduction for specific emissions, ambient concentrations of radiological and non-radiological substances, and contaminants on-site and off-site as the cleanup process continues. LLNL's environmental programs have been implemented to reinforce our commitment toward the protection of 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,

Daniel N. Nakahara

Daniel Nakahara, Assistant Manager
for Environmental Stewardship Division

Preface

The *Environmental Report 2002* 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 2002* 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 2002, and corrections to them, can be accessed at this same Internet address.

In the *Environmental Report 2002*, 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). 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, Karl Brunckhorst, David J. Castro, Steven Hall, David Macedo, Renee Needens, Terrance W. Poole, Donald G. Ramsey, Sterling Sawyer, and Robert Williams—and to the data management personnel— Kimberly A. Swanson, Beth Schad, Hildy Kiefer, Suzanne Chamberlain, Della Burruss, Susan Lambaren, Nancy Montez, and Lisa Graves. Marla Carpenter provided secretarial support and collated and distributed drafts.

Special thanks go to William Hoppes and Art Biermann for their support of the project and reviews of the drafts; and Sandra Mathews and Paul McGuff for their comments and coordination efforts. In addition, the following people contributed significantly to this report: Stephanie Goodwin, C. Susi Jackson, Charlene Grandfield, Albert L. Lamarre, Duane W. Rueppel, Tom Smith, 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, Site Overview, 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 (CERCLA) the Resource Conservation and Recovery Act (RCRA) 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. This chapter also describes LLNL's activities and progress in waste minimization and pollution prevention.

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, Ambient Air Monitoring, describes the purpose of the air particulate and tritium ambient air monitoring programs and provides analyses of

the measurements taken in calendar year 2002. The chapter provides dose estimates from exposure to radiological materials in the ambient air.

Chapter 6, Sewerable Water 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 and allowed discharges to 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 Investigation and Remediation, summarizes CERCLA activities undertaken at the Livermore site and Site 300 during calendar year 2002. It 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 Monitoring, describes the direct environmental radiation measurements obtained for the Livermore site and Site 300. The measurement method and results are explained.

Chapter 13, Radiological 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 2002. 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 are reported and summarized in this report.

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Executive Summary

Lawrence Livermore National Laboratory (LLNL) is a U.S. Department of Energy (DOE) 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, soil, vegetation and foodstuff, and air and liquid effluents for numerous radiological and nonradiological 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 2002.

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 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 the decline in 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 trends.

The 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/m^3 (100,000 pCi/m^3). All measurements of HTO in air in 2002 were less than 7 Bq/m^3 (189 pCi/m^3), 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 2002 is 2.9 Bq/L (78 pCi/L), less than 0.4% of the drinking water standard. Tritium concentrations in all wines collected in 2002 are on average less than 0.2% 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 responsions 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. The measurements in other parts of the United States 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

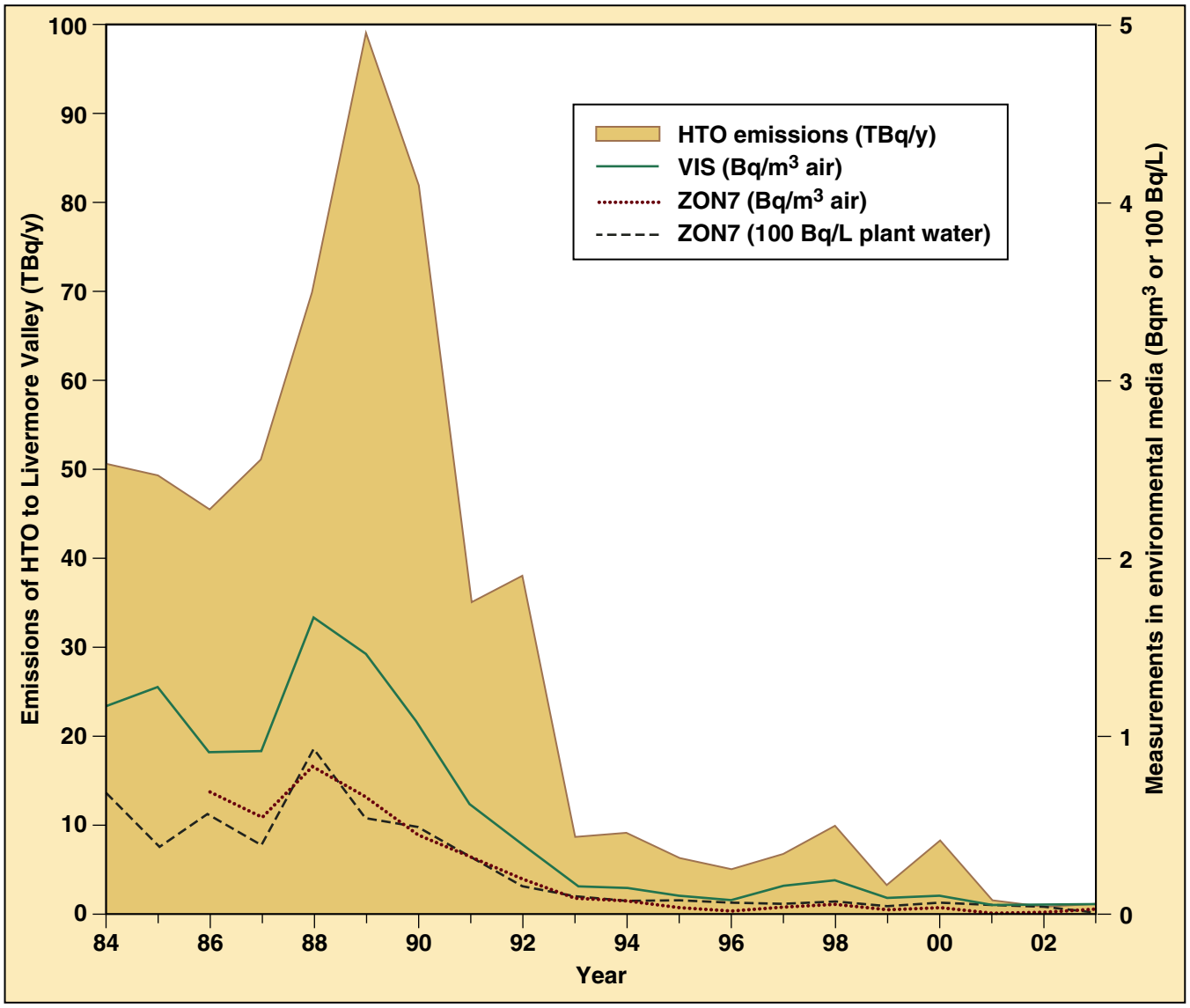
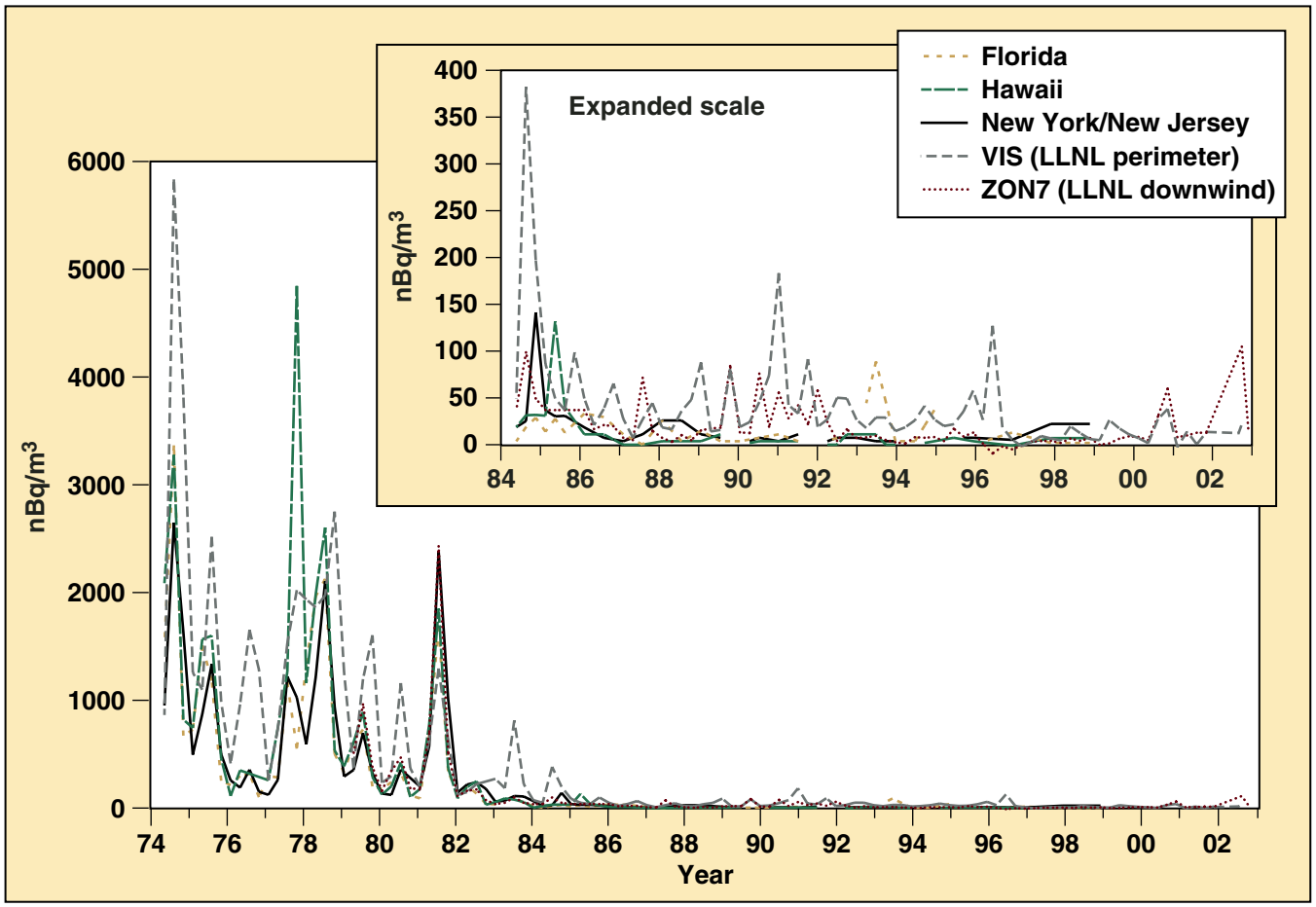


Figure EX-1. Annual median tritium (HTO) concentrations for samples of ambient air and vegetation decline with the declining emissions of HTO

measurements at sampling location VIS show the contributions of resuspension of plutonium-contaminated soil.

The Derived Concentration Guide for plutonium in air is 7.4×10^{-4} Bq/m^3 (0.02 pCi/m^3); the highest measured value in 2002 for LLNL sampling locations for plutonium is 2.5×10^{-7} Bq/m^3 (6.6×10^{-6} pCi/m^3), only 0.03% of the Derived Concentration Guide.

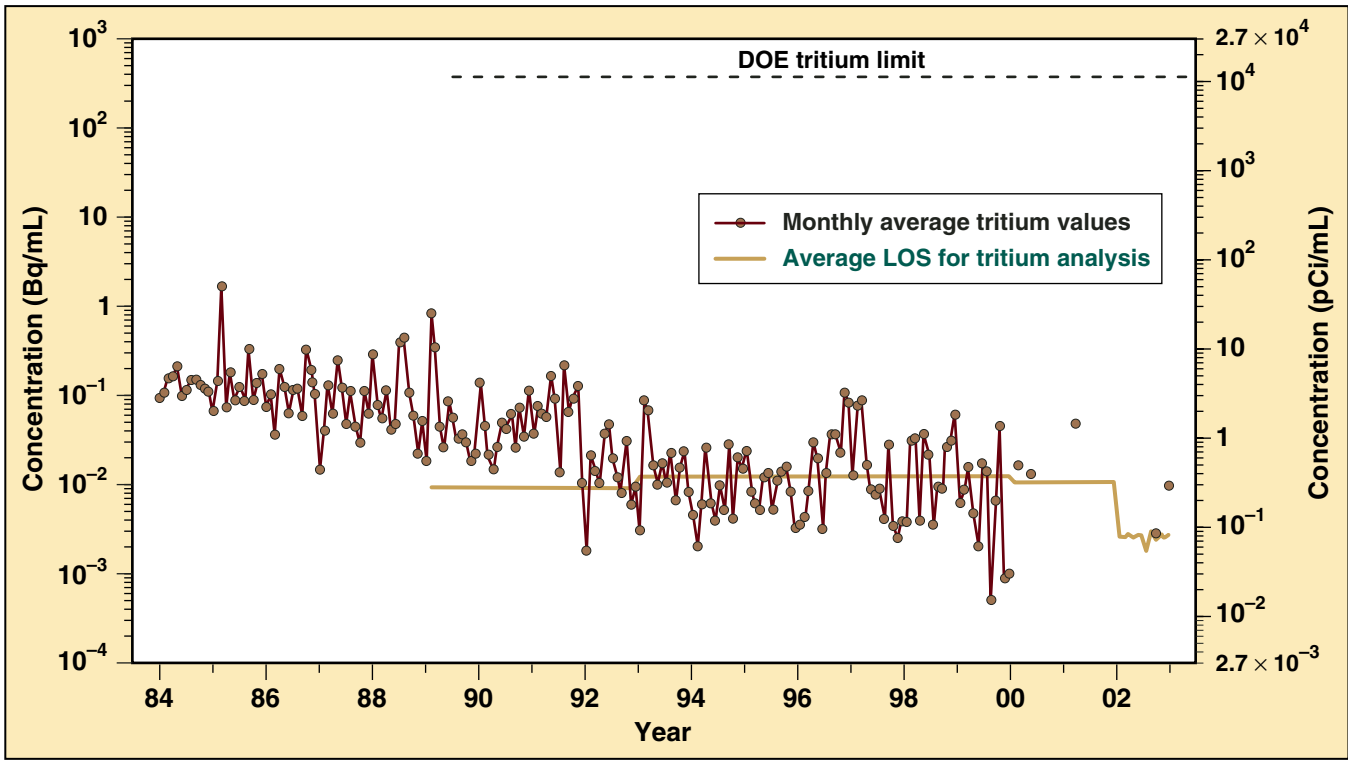
Substantial efforts are also undertaken by LLNL to characterize the contribution of operations to the sewer effluent leaving the Livermore site. During 2002, no permitted discharge limit for radioactive materials was exceeded in the sewer effluent. The



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/m^3) at three locations throughout the United States, and a perimeter and downwind LLNL Livermore site location

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 Livermore site sewer effluent since 1982. As can be seen in this figure, the amount of tritium released has declined significantly. During 2002, the monthly tritium activity averages were mostly below the limit of sensitivity of the analytical method used. The maximum monthly tritium release was 0.010 Bq/mL (0.27 pCi/mL), or 0.003% 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, 0.0023% and 0.00034%, respectively, of their Derived Concentrations Guides.



Note: Only values above the LOS are plotted for 2000–2002.

Figure EX-3. Historical trend in tritium concentration in the Livermore site sanitary sewer effluent

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 2002, 6.9 mBq/dry g (0.19 pCi/dry g), is 1.5% 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 7.9 µg/dry g and was from a sample collected at Site 300, in an area where depleted uranium was used in explosives experiments; the measured value is well below the NCRP screening level of 313 µg/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 2002 yielded an annual dose of 0.65 mSv (65 mrem), a value consistent with local measured averages.

Nonradiological Monitoring

Most nonradiological monitoring is performed on samples of groundwater, sanitary sewer water, 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 the Livermore site sanitary sewer monitoring station as well as wells, springs, ponds, streams, and drinking water reservoirs. With the exception of metal compounds and minor pH fluctuations in sanitary sewer effluent, all nonradiological constituents of samples collected in 2002 were within regulatory or permit limits. Even with the sanitary sewer discharges, no corrective action was required by the regulatory agency and none of the discharges represented a threat to the environment.

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 7.4 billion liters (2.0 billion gallons) of groundwater and over 1.1 million cubic meters (38 million cubic feet) of vapor have been treated, removing more than 1380 kilograms (3049 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 km^2 (11.8 mi^2), 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 km^2 (1.3 mi^2) is effectively one operable unit. Site 300 has additional contaminants, including organosilicate oil, nitrate, high explosives, perchlorate, 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.

LLNL has made substantial progress in cleanup at Site 300. For example, before treatment commenced at the General Services Area (GSA) in 1991, the contaminant plume as shown by monitoring of groundwater wells at the eastern 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

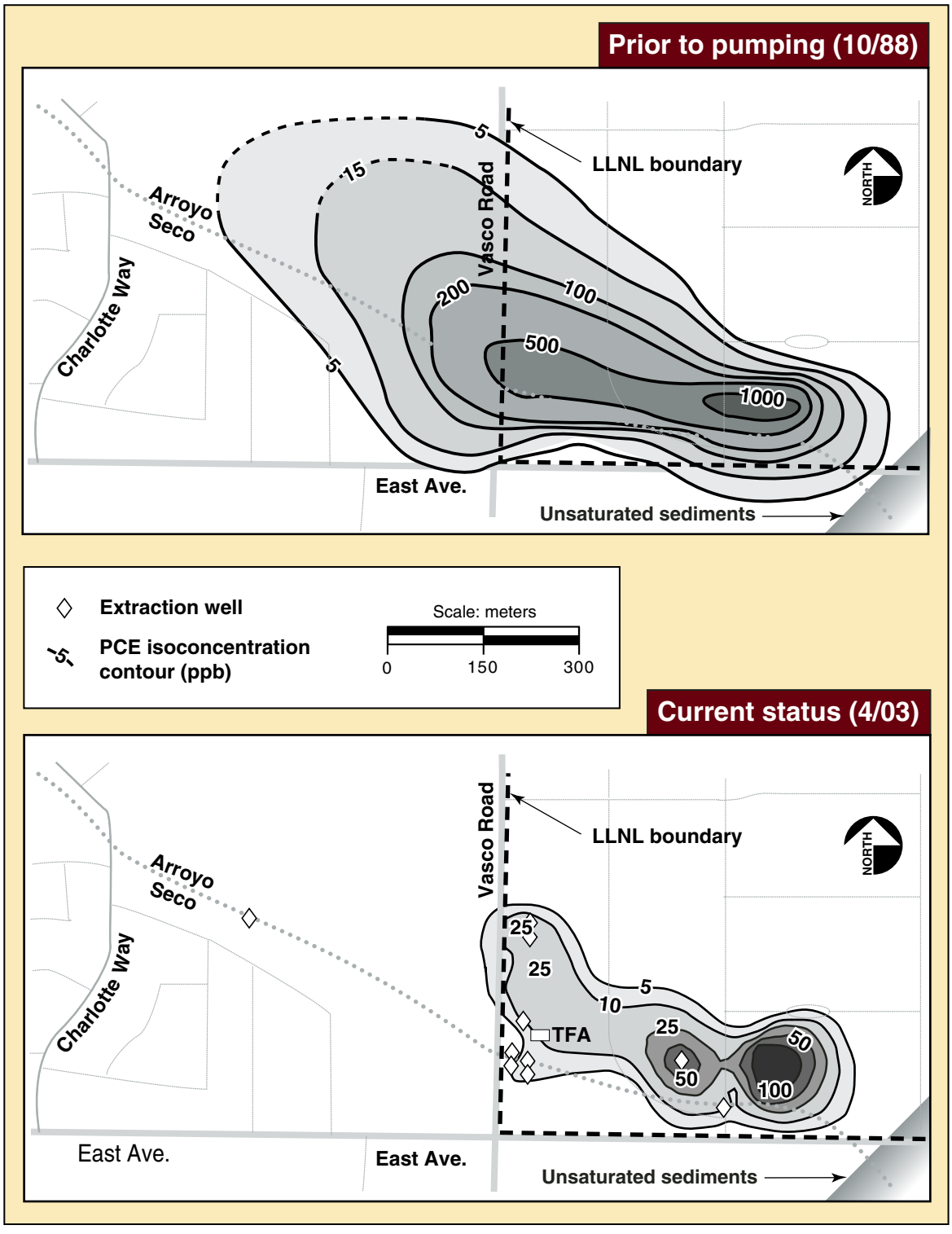


Figure EX-4. Successful reduction of the PCE plume at the western and southern boundaries of the Livermore site

wells. The reduction in this plume is illustrated in Figure EX-5. Overall, since remediation efforts began at Site 300 in 1990, more than 865 million liters (224 million gallons) of groundwater and approximately 3.9 million cubic meters (137 million cubic feet) of vapor have been treated, yielding about 231 kilograms (510 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 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

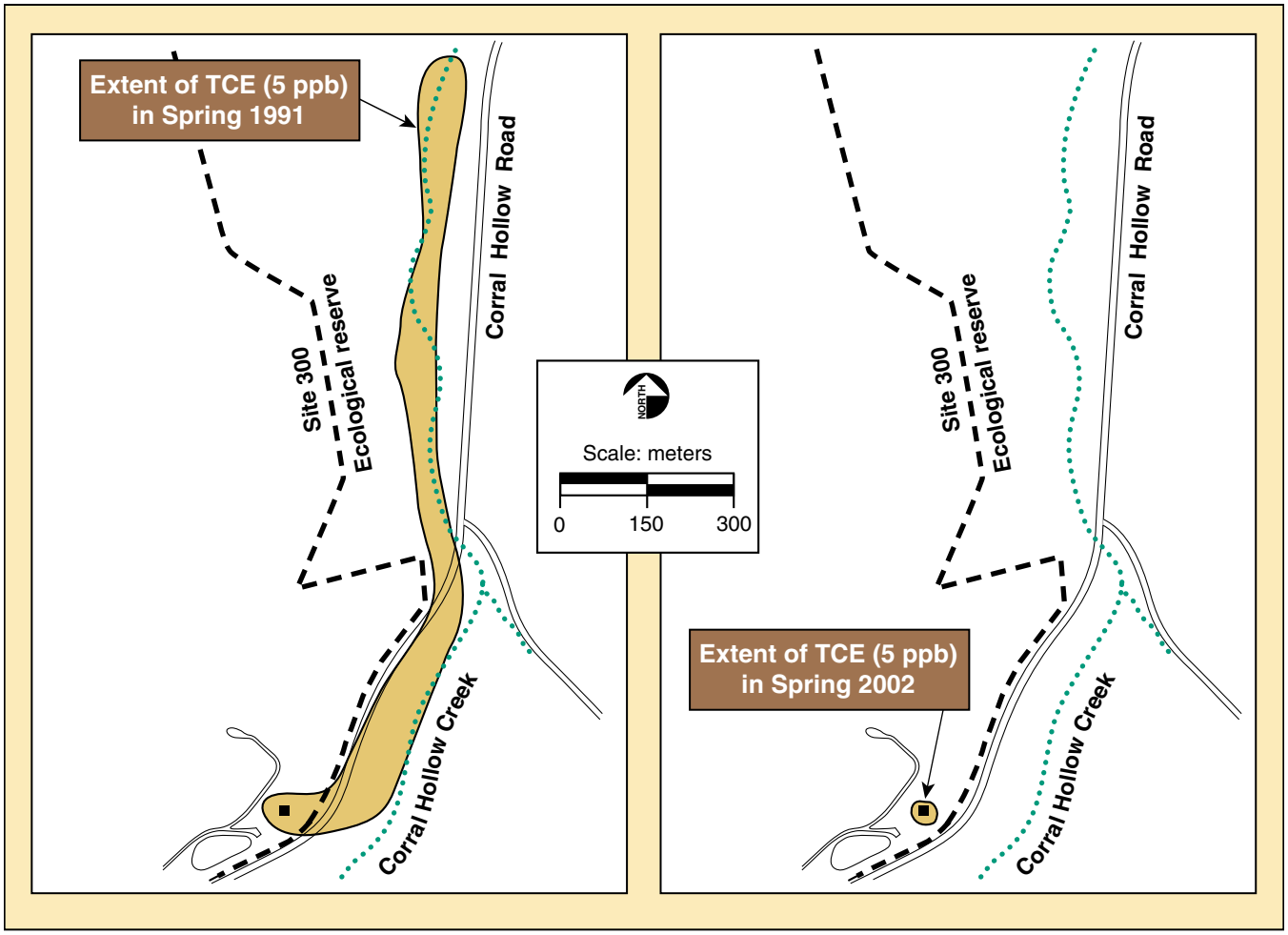


Figure EX-5. Successful reduction of the TCE plume at the southeastern boundary of LLNL's Site 300

Act (CEQA); the Endangered Species Act; the National Historic Preservation Act; the Antiquities Act; and the Comprehensive Environmental Response, Compensation and Liability Act (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 2002, LLNL obtained 150 to 250 air permits each year, depending on operations, while the number of permitted underground tanks steadily declined from 80 to 16 as the tanks were 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, organic compounds, 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.

No air emission violations were identified in 2002. However, an inspection in 2003 identified a record keeping violation from September 2002 to February 2003, for which LLNL paid a $2650 penalty. Tank inspections resulted in a violation notice consisting of three violations categorized as minor by the regulatory agency. Hazardous waste permit inspections resulted in a violation notice consisting of two violations for exceeding storage time limits. None of the violations in 2002 resulted in a release or posed a threat to the public or the environment.

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 (such as the sanitary sewer reports), or annually (such as 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 radiological dose to a hypothetical maximally exposed individual member of the public arising from releases of radioactive material to air. This annual report is submitted to the U.S. Environmental Protection Agency (EPA) to demonstrate compliance with the National Emissions Standards for Hazardous Air Pollutants (NESHAPs) section of the federal Clean Air Act. NESHAPs limits the annual dose to members of the public caused by DOE facility 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 inventories of radionuclides from unmonitored sources as required by the U.S. EPA, as well as stack monitoring and ambient air monitoring, where available. The total dose to the maximally exposed public individual for 2002 was 0.23 μSv (0.023 mrem) for the Livermore site and 0.21 μSv (0.021 mrem) for Site 300. These doses are well below the 100 μSv (10 mrem) standard. LLNL also calculates potential doses to aquatic and terrestrial biota from LLNL operations. These potential doses are found to be well below DOE allowable dose limits. All these dose assessments confirm that the impacts of LLNL operations on the public and the environment 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. Biological assessment surveys were also performed for special-status species at Site 300 project construction areas.

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 the 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 commitment of LLNL to control pollutants.

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

In summary, the results of the 2002 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. Environmental monitoring of LLNL operations does not indicate an adverse impact to public health or the environment.

Site Overview

Introduction

Lawrence Livermore National Laboratory is a premier applied-science national security laboratory. LLNL's primary mission is to ensure that the nation's nuclear weapons remain safe, secure, and reliable, and to prevent the spread and use of nuclear weapons worldwide. This mission enables LLNL programs in advanced defense technologies, energy, environment, biosciences, and basic science to apply LLNL's unique capabilities and to enhance the competencies needed for our national security mission. LLNL serves as a resource to the U.S. government and a partner with industry and academia.

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.

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 LLNL might have on the surrounding environment. Some history and a description of these characteristics help us understand the importance of LLNL's meteorological and geographic setting.

Location

LLNL consists of two sites—the Livermore site located in Livermore, California 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.

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 LLNL began to its present population, which is about 76,700 (State of California 2002). 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.

The Livermore site occupies an area of 3.28 km^2 (1.3 mi^2), 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 U.S. 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 components of their missions are similar, LLNL and Sandia/California are separate entities, each with its own management.

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 Site, 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 km^2 (11.8 mi^2). 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

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

the town of Tracy, population 65,600 (State of California 2002), 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 daily maximum, minimum, and average temperatures for the Livermore site in 2002 were 20.4°C (68.7°F), 9.0°C (48.7°F), and 14.7°C (58.4°F), respectively. The mean daily maximum, minimum, and average temperatures for Site 300 in 2002 were 20.2°C (68.3°F), 13.1°C (55.5°F), and 16.2°C (61.9°F), respectively. The nighttime temperatures are typically higher (and diurnal temperature ranger smaller) at Site 300 compared to the Livermore site; stronger winds at a higher elevation prevent formation of strong radiational inversions near the ground. Temperatures range from –4°C (25°F) during the coldest winter mornings to 40°C (104°F) during the warmest summer afternoons. The coldest weather during 2002 occurred during the last week of January when the temperature dipped to –2°C (27 to 28°F) on three mornings at LLNL and –1°C (30°F) at Site 300 on one morning. The warmest day was July 10 when the temperature reached 40.1°C (104.2°F) at the Livermore site and 39.0°C (102.2°F) at Site 300.

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 during the warm season, increasing in intensity as the valley heats up. During the winter, the wind blows from the northeast more frequently as cold, dense air spills out of the San Joaquin Valley. 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 blows more often from the northeast. However, the peak wind gust of 23.2 m/s (52 mph) from the SSW occurred early on December 16, as a strong cold front swept the area.

Based on a 45-year record, the highest and lowest annual rainfalls were 541 and 211 mm (21.31 and 8.31 in.), and the normal annual rainfall is 350 mm (13.78 in.). In 2002, the Livermore site received 271 mm (10.66 in.) of rain, or 77% of normal. Most of the rain fell during the last two months of the year, including 102 mm (4.00 in.) in the 8 days ending on December 20. The December total rainfall of 132 mm (5.21 in.) was the greatest ever recorded for the month of December at the Livermore site since records have been kept (1958). The maximum daily rainfall of 36.8 mm (1.45 in.) fell on December 16.

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 1-2**. The data show that winds are stronger and show less directional distribution than at the Livermore site. Winds from the west-southwest through west and northwest through north occurred 40% and 30% of the time during 2002. The cold front passage early on December 16 caused even stronger winds at Site 300, briefly reaching hurricane force. The peak gust reached 33 m/s (83 mph) from the south, the highest ever recorded at Site 300 since measurements have been taken (1990). As is the case for the Livermore site, precipitation at Site 300 is seasonal, with most rainfall occurring between October and April. Since Site 300 is situated downwind (north) of more significant terrain (winds are typically southerly during storms) than at LLNL, rainfall amounts are typically 15% or so lower than

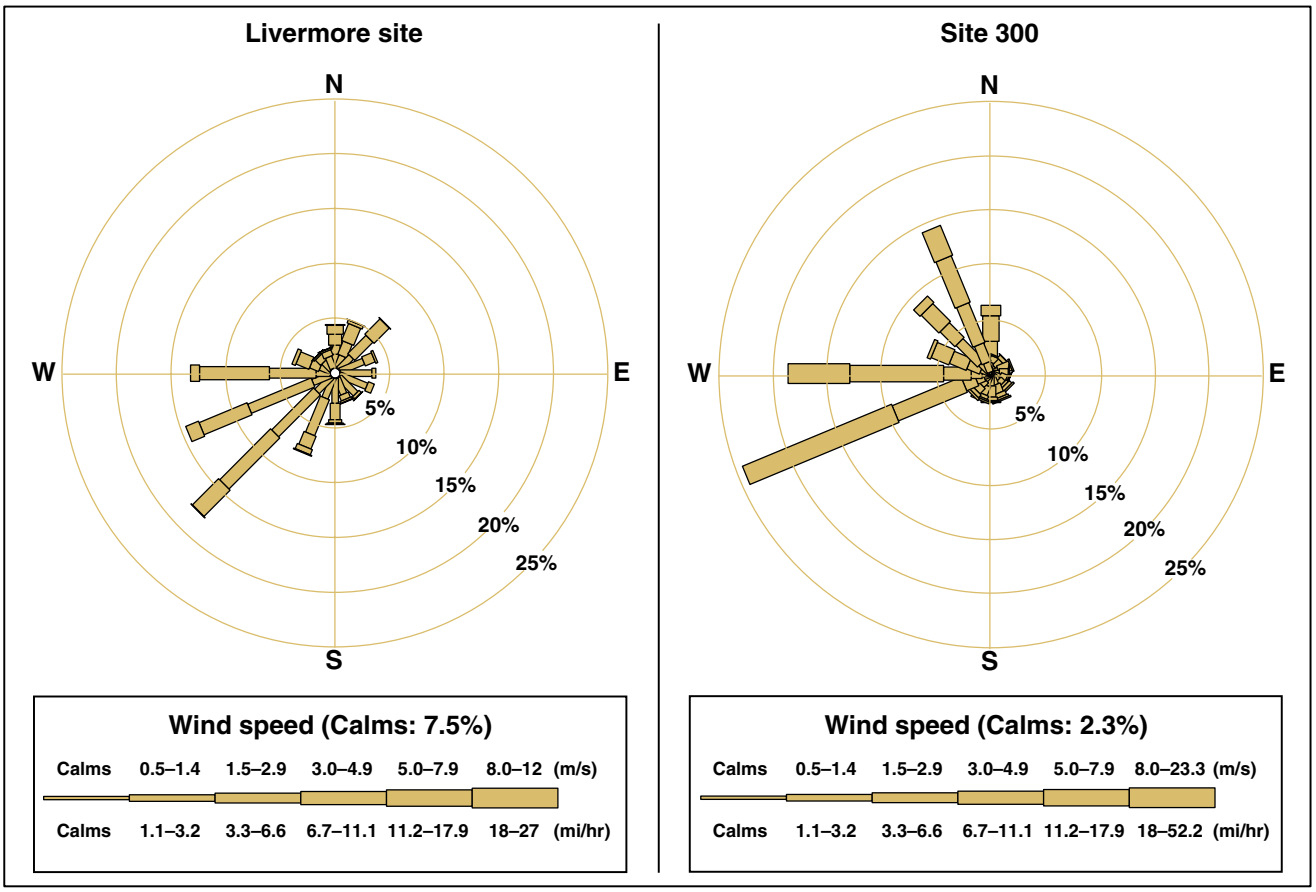


Figure 1-2. Wind rose showing wind direction and speed frequency at the Livermore site, 2002. The length of each spoke is proportional to the frequency at which the wind blows from the indicated direction. Different line widths of each spoke represent wind speed classes. The average wind speed in 2002 at the Livermore site was 2.4 m/s (5.3 mph); at Site 300 it was 5.5 m/s (12.4 mph).

at the Livermore site. Similar to the Livermore site, Site 300 received most of its rainfall during November and December, including 88.1 mm (3.47 in.) during the 8 days ending on December 20. The maximum daily rainfall of 27.4 mm (1.08 in.) occurred on November 8. Rainfall for 2002 was about 25% below normal, or 220 mm (8.65 in.) at Site 300.

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 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. Surface waterways in the vicinity of the Livermore site are the Arroyo Seco (along the southwest corner of the site), the Arroyo Las Positas (along the northern perimeter of the site), and the Arroyo Mocho (southwest of the site). These arroyos are shown in **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 northwest-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 is a summary of 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 1-3** shows a contour map of water table elevations 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 1-3** 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

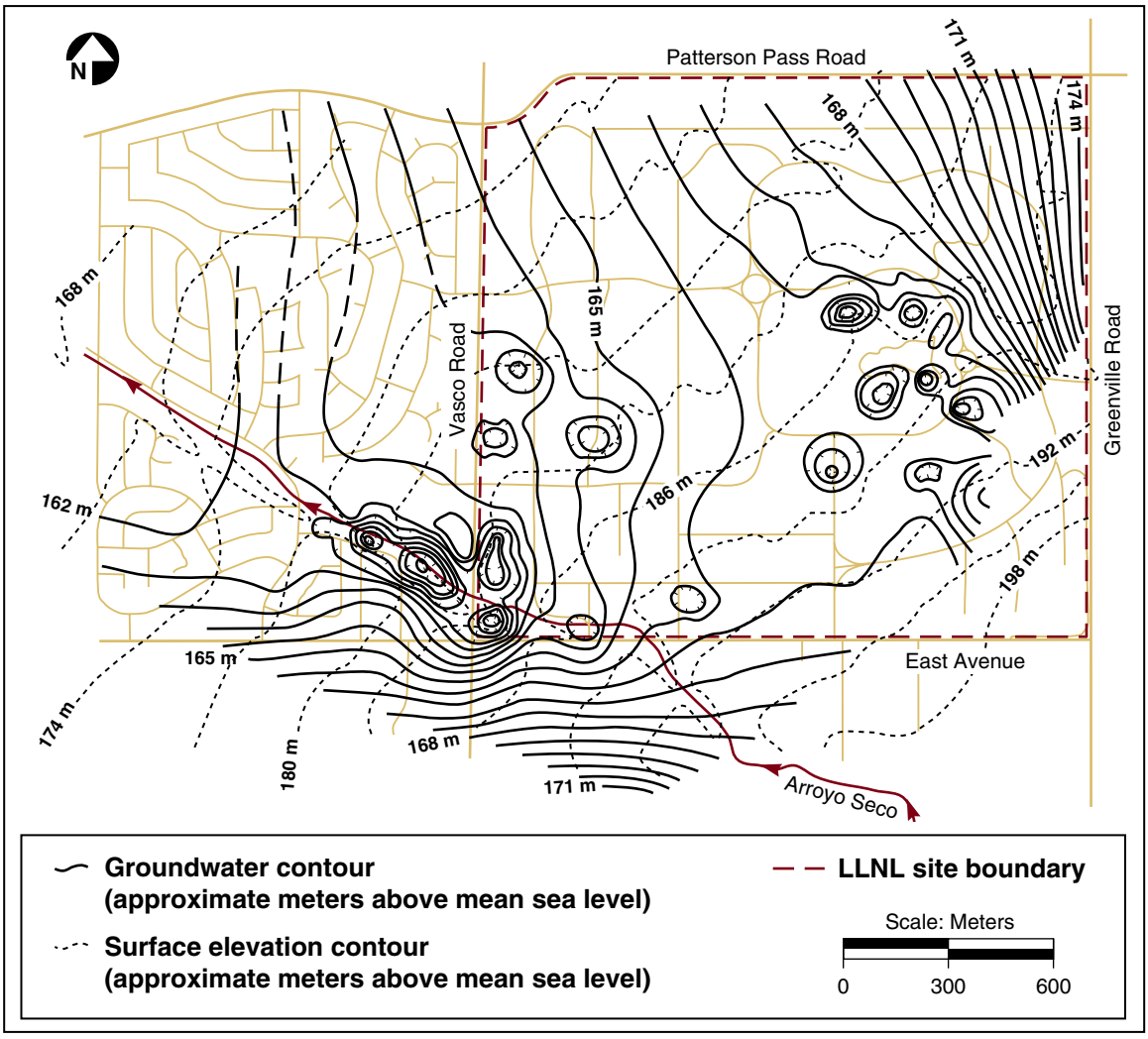


Figure 1-3. 2002 approximate groundwater and surface elevation contours, Livermore site and vicinity

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 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 pump water from this aquifer and are used to supply drinking and process water.

Figure 1-4 shows the elevation contours for groundwater in the regional aquifer at Site 300. This map of the groundwater elevations 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 Chapter 8.

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.

Contributing Authors Acknowledgement

We acknowledge the work of Richard Blake, Brent Bowen, Donald MacQueen, Lily Sanchez, and Michael Taffet in preparing this chapter.

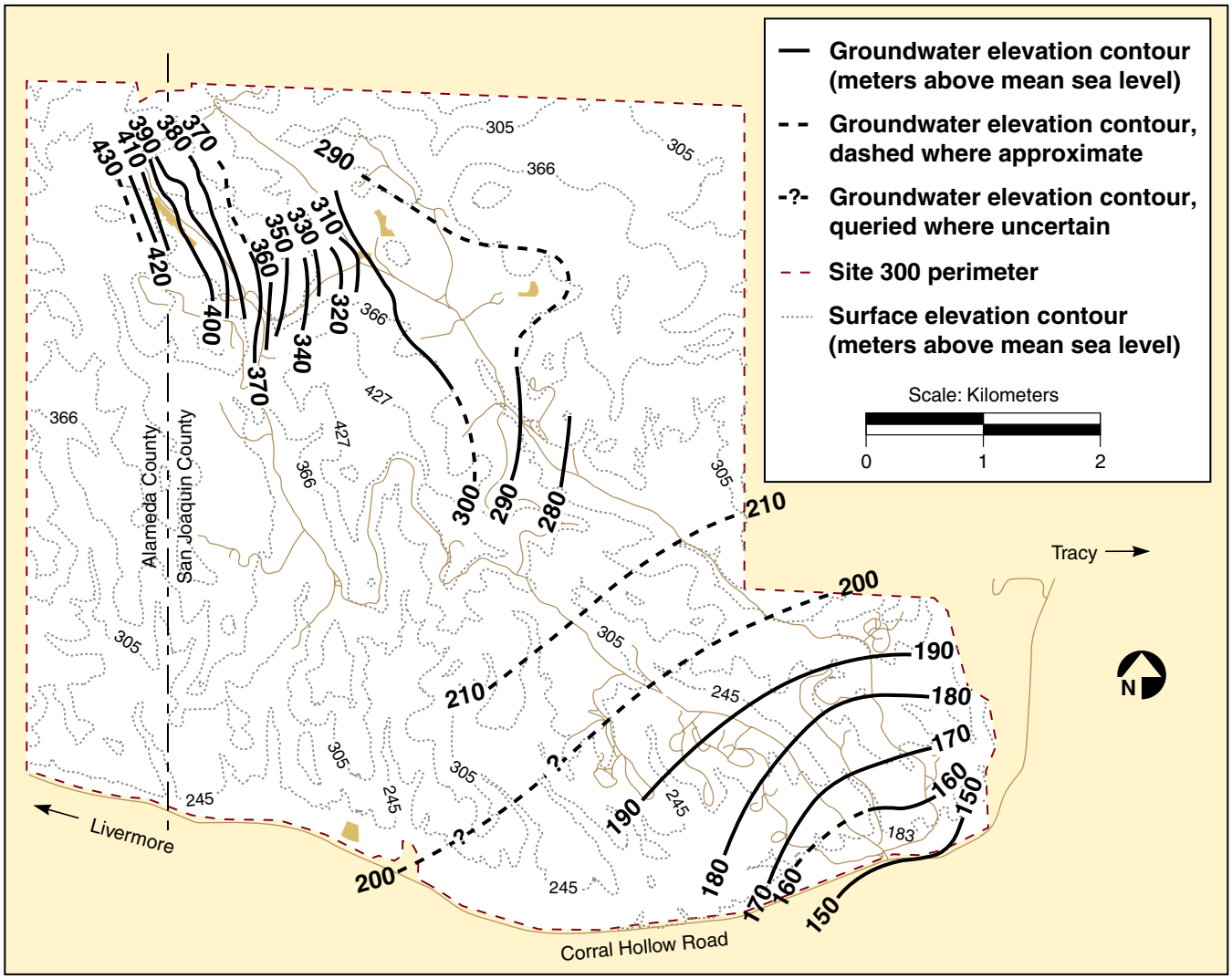


Figure 1-4. Approximate 2002 groundwater elevations for the principal continuous water-bearing zone at Site 300

2

Compliance Summary

Introduction

During 2002, Lawrence Livermore National Laboratory participated in numerous activities to comply with federal, state, and local environmental regulations as well as internal requirements and applicable U.S. 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 LLNL 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 LLNL that are discussed in 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 concerning 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

Ongoing groundwater investigations and remedial activities at the Livermore site and Site 300 are called the Livermore Site Ground Water Project (GWP) and the Site 300 CERCLA Project, respectively. These activities fall under the jurisdiction of the Comprehensive Environmental Response,

Compensation and Liability Act (CERCLA), Title I of the Superfund Amendments and Reauthorization Act (SARA). As part of work on these projects, DOE and LLNL also continued community relations activities. These projects and activities are described in the following sections.

Livermore Site Ground Water Project

The Livermore site became a CERCLA site in 1987 when it was placed on the National Priorities List. 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), through continuous monitoring and by the 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 also present to some extent beyond the boundary, mainly to the west and south of the site (see **Figures 8-3** to **8-8**).

In 2002, 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 2002 Annual Report* (Dibley et al. 2003) on schedule on March 31, 2003. 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 2002; Bainer and Joma 2002a, 2002b, 2003a).

Milestones and Activities

In 2002, DOE/LLNL completed all 2002 Remedial Action Implementation Plan (RAIP) milestones (Dresen et al. 1993). One milestone (Treatment Facility C-East remediation) was delayed with regulatory concurrence because new work was not authorized under the terms and provisions of a Federal Budget Continuing Resolution at the beginning of Fiscal Year 2002.

Milestones in 2002 for the GWP included constructing Treatment Facility C East (TFC-E) and Treatment Facility 406 Northwest (TF406-NW), expanding soil vapor treatment facility 5475 (VTF5475), and preparing a five-year review. Other 2002 GWP activities included operating 27 groundwater treatment facilities and 1 soil vapor treatment facility, operating 82 groundwater extraction wells, installing 10 new wells, and conducting 7 hydraulic tests. In addition to the extraction wells, the Livermore site currently has 512 monitor wells.

Treatment Facilities

DOE and LLNL operated treatment facilities TFA, TFB, TFC, TFD, TFE, TFG, TF406, TF518, and TF5475 in 2002. A total of 82 groundwater extraction wells operated at an average flow rate of 2,572,000 L/day. Vapor treatment facility VTF5475 operated at an average flow of 393 m^3/day from 1 soil vapor extraction well. Together, the groundwater and vapor treatment facilities removed approximately 146 kg of VOC

mass in 2002 compared to 215 kg in 2001. Since remediation began in 1989, approximately 7.4 billion L of groundwater and more than 1,076,000 m^3 of vapor have been treated, removing more than 1,380 kg of VOCs. See Chapter 8 for further information.

Community Relations

The Community Work Group (CWG) met once in 2002 to discuss the DOE budget, the Consensus Statement, and progress of the Livermore site cleanup. Correspondence and communication continued with CWG members throughout the year. DOE and LLNL met three times 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 (TAG).

Other Livermore site community relations activities in 2002 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 http://www-envirinfo.llnl.gov.

Site 300 CERCLA Project

Investigations and remedial activities are ongoing at Site 300, which became a CERCLA site in 1990, 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 2002, 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) and *Final Site-Wide Feasibility Study for Lawrence Livermore National Laboratory Site 300* (Ferry et al. 2000).

Documentation

LLNL submitted all required documentation to oversight agencies on time in 2002. The *Final Interim Remedial Design Report for the Building 834 Operable Unit Treatment Facility at Lawrence Livermore National Laboratory Site 300* (Gregory et al. 2002), the *Final 5-Year Review Report for the Building 834 Operable Unit at Lawrence Livermore National Laboratory Site 300* (Ferry et al. 2002), the *Characterization Summary Report for the Building 854 Operable Unit at Lawrence Livermore National Laboratory Site 300* (Ferry and Kearns 2002), the *Final Interim Remedial Design Report for the High Explosives Process Area Operable Unit at Lawrence Livermore National Laboratory Site 300* (Madrid et al. 2002), the *Final Compliance Monitoring Plan/Contingency Plan for Interim Remedies at Lawrence Livermore National Laboratory Site 300* (Ferry et al. 2002), quarterly reports, and work plans were among the documents submitted.

Milestones and Activities

LLNL completed all the 2002 FFA milestones for Site 300 on or ahead of schedule. These included construction of the Building 815-PRX

groundwater and soil vapor extraction and treatment facility and initiation of build-out and upgrade of the Building 834-SRC groundwater and soil vapor treatment facility in the Building 834 Operable Unit.

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 the groundwater. Eleven treatment facilities operated during 2002. Twenty-one wells that extract groundwater only, 7 wells that extract soil vapor only, and 24 wells that extract both groundwater and soil vapor operated during 2002, treating about 93.1 million L of groundwater. The 24 wells that extract both vapor and groundwater and the 7 wells that extract only vapor together removed 795,960 m^3 of vapor. In 2002, the Site 300 treatment facilities removed approximately 9.5 kg of VOCs. Since remediation efforts began in 1990, more than 895 million L of groundwater and approximately 3.93 million m^3 of vapor have been treated, to yield about 231 kg of removed VOCs. See Chapter 8 for further information.

Community Relations

The Site 300 CERCLA project maintains continuing communications with the surrounding communities of Tracy and Livermore. Community relations activities in 2002 included maintenance of the information repositories and administrative records; off-site, private well-sampling activities; mailings to stakeholders; and interviews with the news media.

On April 16, 2002, LLNL held a public workshop to present to the community the overall plan for implementation of, and to respond to comments on, the *Final Compliance Monitoring Plan/ Contingency Plan for Interim Remedies at Lawrence Livermore National Laboratory Site 300* (Ferry et al. 2002).

LLNL hosted TAG meetings with the community and Tri-Valley CAREs on January 11, June 10, and October 29, 2002. These meetings provided a forum for focused discussions on CERCLA activities at the various operable units at Site 300. Tri-Valley CARES receives the annual TAG grant from EPA to support an environmental consultant to review Site 300 CERCLA activities.

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 2002, soil and rubble were evaluated at 67 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 of the U.S. Department of Health and Human Services. The ATSDR's mission is to serve the public by using the best science, taking responsive public health actions, and providing trusted health information to prevent harmful exposures and disease related to toxic substances.

The ATSDR is mandated by Congress to conduct public health assessments (PHAs) of communities that are adjacent to DOE sites undergoing CERCLA cleanup. A PHA is an evaluation of whether exposures to hazardous substances from a site might be harmful to site neighbors. The

ATSDR conducts PHAs of Livermore communities in response to its Congressional mandate. These assessments began almost ten years ago and are now drawing to conclusion.

One PHA addresses community concerns about the health impacts of releases of tritium from LLNL. An ATSDR report, *Health Consultation on Tritium Releases and Potential Offsite Exposures (*March 11, 2002) was based on the ATSDR's findings and those of a panel of five tritium experts. In the report, the 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.

As part of an effort to address concerns about the 1965 and 1970 releases that account for about 80% of all the tritium released by LLNL, the ATSDR issued a draft report in May 2002, titled *Focused Public Health Assessment of 1965 and 1970 Accidental Tritium Releases at the Lawrence Livermore National Laboratory.* LLNL provided comments on this draft before the original public comment period ended in August 2002. The public comment period was subsequently extended until March 31, 2003. In this document, the ATSDR presented doses predicted by modeling both releases based on the best available information, including meteorological conditions. Preliminary conclusions indicate that, though some public exposure to tritium probably did occur as the result of the accidental releases, the maximum exposures predicted were below levels that might cause adverse health effects.

The ATSDR also issued a PHA in early 2003, *Plutonium 239 in Sewage Sludge Used as a Soil or Soil Amendment in the Livermore Community.* A release, well within regulatory limits, of about 32 grams of plutonium over several weeks in 1967 raised community concerns. The plutonium was found in sewage sludge that was available to the community and public organizations. Both the California Department of Health Services (DHS) and the Atomic Energy Commission found no public health concern at the time. Public sludge distribution ended in the mid-1970s.

The ATSDR PHA determined there was no apparent public health hazard from the sludge. ATSDR stated that, while exposure may have occurred or may still be occurring, the resulting doses will not cause sickness or death. The ATSDR determined that any potential radiological doses are below levels of health concern. It stated it had no recommendations concerning additional soil sampling in areas of known or unknown sludge distribution. The agency found that available data and evaluations provide an adequate basis for these public health conclusions. It added that any additional sampling data would be subject to the same types of uncertainties as existing historical data. The agency recommended public outreach on this topic, which it conducted in February 2003. It also recommended that LLNL continue required routine regulatory monitoring of released plutonium.

Both ATSDR PHAs are expected to become final in late 2003 or early 2004. Additional information concerning these ATSDR findings may be read in the environmental repositories or at LLNL's environmental information website http://www-envirinfo.llnl.gov/.

Emergency Planning and Community Right-to-Know Act and Toxics Release Inventory Report

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 these chemicals to organizations responsible for emergency response planning. Executive Order 13148 directs all federal agencies to comply with the requirements of the EPCRA, including SARA Section 313, "Toxics Release Inventory (TRI) Program."

As a result of greatly reduced TRI reporting thresholds, LLNL submitted for Site 300 the TRI Form R report for lead to the Department of Energy on June 25, 2002, for reporting year 2001. Monitoring and other pollution prevention options are being evaluated to help minimize environmental releases.

EPCRA requirements and LLNL compliance are summarized in **Table 2-1**.

Clean Air Act—Air Quality Management Activities

All activities at LLNL are evaluated to determine the need for air permits. 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) and/or BAAQMD for Site 300.

In 2002, LLNL operated 199 air emission sources for the Livermore site. BAAQMD inspectors found no deficiencies at the Livermore site in 2002 (see **Table 2-2**). However, during an inspection in April 2003, the BAAQMD issued a notice of violation (NOV) for a record keeping violation during the time period September 2002 to February 2003. LLNL was subsequently assessed a $2650 penalty.

The BAAQMD finalized LLNL's Synthetic Minor Operating Permit in November 2002 and forwarded the draft to EPA. The Synthetic Minor Operating Permit conditions require LLNL to ensure that the emissions of regulated air pollutants are below the permitted threshold values. These values limit emissions from combustion sources to less than 50 tons per year for oxides of nitrogen and emissions from solvent evaporating sources to less than 50 tons per year for precursor organic compounds and to less than 23 tons per year for all hazardous air pollutants. Permit conditions also require LLNL to prepare an annual emissions report for each year ending on June 30. In 2002, the SJVUAPCD issued or renewed air permits for 44 air emission sources for Site 300 (see **Table 2-3**).

National Emission Standards for Hazardous Air Pollutants, Radionuclides

To demonstrate compliance with the National Emission Standards for Hazardous Air Pollutants (NESHAPs) for radiological emissions, LLNL is required to monitor certain air release points and evaluate all potential sources of radionuclide air emissions to determine the maximum possible dose to the public. These evaluations include modeling (using EPA-sanctioned computer codes) based on radionuclide inventory data, air effluent (source emission) monitoring, and air surveillance monitoring.

The *LLNL NESHAPs 2002 Annual Report* (Harrach et al. 2003), submitted to DOE and EPA, reported that the estimated maximum

Table 2-1. Summary of LLNL compliance with EPCRA

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 26, 2002.
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 in 2002.
311 MSDS/Chemical Inventory	Operator must submit MSDSs or chemical list to SERC, LEPC, and Fire Department.	Update submitted April 26, 2002.
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 11, 2002) and Alameda County (April 15, 2002).
313 Toxic Release Inventory	Operator must submit Form R to U.S. EPA and California EPA for toxic chemicals released.	Form R for lead (Site 300 only) was submitted to DOE June 25, 2002; DOE forwarded it to U.S. EPA and California EPA June 28, 2002.

a See Acronyms and Abbreviations for list of acronyms.

radiological doses to the public were 0.23 µSv (0.023 mrem) for the Livermore site and 0.21 µSv (0.021 mrem) for Site 300 in 2002.

The reported doses include contributions from both point and diffuse sources. The totals were well below the 100 µSv/y (10 mrem/y) dose limits defined by the NESHAPs regulations. The details of these data are described in Chapter 13.

In 2002, 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 2002.

Clean Water Act and Related State Programs

Preserving clean water is an 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 Waste Discharge Requirements (WDRs), for any waste discharges affecting the beneficial uses of waters of the state. The local regional water quality control boards (RWQCBs) are responsible for issuing and enforcing both types of permits as well as water quality certifications for discharges authorized under Section 401 of the CWA.

Table 2-2. Inspections and tours of the Livermore site and Site 300 by external agencies in 2002

Medium	Description	Agency[a]	Date	Finding[a]
Livermore Site				
Air	Emission sources	BAAQMD	2/8 3/13 6/6 9/6 10/24	No violations[b]
Sanitary sewer	Annual compliance sampling	LWRP	10/7–10/8	No violations
	Categorical sampling		10/21	No violations
Waste	Hazardous waste facilities	DTSC	5/22–5/24, 5/30, 6/4	Received an inspection report and summary of violations on 8/21/02. See **Table 2-8** for description and resolution.
	Medical waste	ACDEH	9/25	No violations
Storage tanks	Compliance with underground storage tank requirements and operating permits	ACDEH	10/15 10/16	No violations
Site 300				
Air	Emission sources Startup inspection of Contained Firing Facility and CGSA air stripper	SJVUAPCD	6/4	No violations
Water	Permitted operations	CVRWQCB	11/11	No violations
Waste	Permitted hazardous waste operational facilities (EWTF, EWSF, B883 CSA), hazardous waste-related documentation, and hazardous waste transporter registration inspection	DTSC	11/20-11/21	No violations
Storage tanks	Compliance with underground storage tank requirements and operating permits	SJCEHD	10/17, 11/25-11/27, 12/13	Received notification of three minor violations on 10/17. See **Table 2-8** for description and resolution.

a See Acronyms and Abbreviations for list of acronyms.

b LLNL is currently working with BAAQMD on an NOV issued in April 2003 for an alleged recordkeeping violation during September 2002 through February 2003.

Several agencies issue other water-related permits. The Livermore Water Reclamation Plant (LWRP) requires permits for discharges to the city's sanitary sewer system. The Army Corps of Engineers (ACOE) issues permits for work in navigable waterways and for controlling fill operations in waters of the United States below the ordinary high water mark. The State Water Resources Control Board (SWRCB) can issue statewide NPDES permits/WDRs. The California Department of Fish and Game (CDFG), under the Fish and Game Code, requires streambed alteration agreements (SAAs)

Table 2-3. Summary of permits active in 2002[a,b]

Type of permit	Livermore site	Site 300
Air	BAAQMD issued 199 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, material-handling equipment, sewer diversion system, oil and water separator, fire test cells, gasoline-dispensing operation, paper-pulverizer system, and firing tanks.	SJVUAPCD issued 44 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.
Water	WDR Order No. 88-075 for discharges of treated groundwater from Treatment Facility A to percolation pits and recharge basin. 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. WDR Order No. 99-08-DWQ, NPDES California General Construction Activity Permit No. CAS000002; Terascale Simulation Facility, Site ID No. 201S317827; Sensitive Compartmented Information Facility, Site ID No. 201S317621; Soil Reuse Project, Site 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. WDR Order No. 99-086 for the Arroyo Las Positas Maintenance Project. Nationwide Permits 18 and 33 for the Arroyo Las Positas Maintenance Project. One off-site project (at Arroyo Mocho) completed under a streambed alteration agreement. FFA for groundwater investigation/remediation.	WDR Order No. 93-100 for post-closure monitoring requirements for two Class I landfills. WDR Order No. 96-248 for operation of two Class II surface impoundments, a domestic sewage lagoon, and percolation pits. WDR Order No. 97-03-DWQ, NPDES California General Industrial Activity General Permit No. CAS000001 for discharge of storm water associated with industrial activities WDR Order No. 97-242, NPDES Permit No. CA0082651 for discharges of treated groundwater from the eastern General Services Area treatment unit. WDR Order No. 5-00-175, NPDES Permit No. CAG995001 for large volume discharges from the drinking water system that reach surface waters. FFA for groundwater investigation/remediation. 57 registered Class V injection wells.

Table 2-3. Summary of permits active in 2002[a,b] (continued)

Type of permit	Livermore site	Site 300
Hazardous waste	EPA ID No. CA2890012584. Authorization to mix resin in Unit CE231-1 under conditional exemption tiered permitting. Final Closure Plan submitted to DTSC for the Building 419 interim status unit (February 2001). Authorizations to construct the permitted units of Building 280, Building 695, and additions to Building 693. Authorization under hazardous waste permit to operate 18 waste storage units and 14 waste treatment units. 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). 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.	EPA ID No. CA2890090002. Part B Permit—Container Storage Area (Building 883) and Explosives Waste Storage Facility (issued May 23, 1996). Part B Permit—Explosives Waste Treatment Facility (issued October 9, 1997). Docket HWCA 92/93-031. Closure and Post-Closure Plans for Landfill Pit 6 and the Building 829 Open Burn Facility.
Medical waste	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, Tissue Culture Lab, and Chemistry and Materials Science Department.	Limited Quantity Hauling Exemption for small quantity medical waste generator.
Sanitary sewer	Discharge Permit No. 1250 (2001/2002 and 2002/2003[c]) for discharges of wastewater to the sanitary sewer. Permit 1510G (2001/2002[d]) for discharges of groundwater from CERCLA restoration activities.	
Storage tanks	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[e]; 365-D1U2 Permit No. 6492; and 611-D1U1, 611-G1U1, 611-G2U1, and 611-O1U1 Permit No. 6505.	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

a Permit numbers are based on actual permitted units or activities maintained and renewed by LLNL during 2002.

b See Acronyms and Abbreviations for list of acronyms.

c The Discharge Permit No. 1250 period is from May 15 to May 14; therefore, two permits were active during the 2002 calendar year.

d Permit 1510G is a two-year (January to December) permit.

e LLNL received permit exemption in October 2002.

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 CWA and California Aboveground Petroleum Storage Act also require 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 Department of Environmental Health (ACDEH) and San Joaquin County Environmental Health Department (SJCEHD) 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 2-3** and discussed in detail in Chapters 6, 7, and 9.

Groundwater and Surface Water

In 2002, 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 five NPDES permits, four WDRs, and agreements developed under CERCLA (**Table 2-3**). 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 discharges going to ground. Previously, these discharges were permitted under WDR 94-131, which was rescinded by the CVRWQCB in August 2000. The CVRWQCB continues to work on the revision to WDR 96-248; during the revision process, they decided to split discharges in the existing permit into two separate permits. LLNL expects these two permits to be issued in 2003.

During 2002, LLNL continued construction of two projects that were covered by the California General Construction Activity permit and obtained coverage for two new projects (see **Table 2-3**). Continuing operations included construction of the Soil Reuse Project and the National Ignition Facility (NIF) at the Livermore site. Construction operations began in June 2002 at both the Terascale Simulation Facility and the Sensitive Compartmented Information Facility projects.

LLNL received no NOVs in 2002 from the RWQCB that issued the NPDES permits and WDRs; however, LLNL identified administrative nonconformances with one of the five NPDES permits (see **Table 2-4**). These events are documented in the annual compliance certification required by NPDES Permit No. CAS000002. In addition, LLNL was unable to comply with prohibitions in WDR 96-248 on two occasions. These discharges were reported to the applicable regional boards and are discussed further in Chapter 7 and in quarterly and annual compliance monitoring reports under WDR 96-248.

The CVRWQCB inspected the Site 300 permitted facilities in November 2002. No violations were found during this inspection (see **Table 2-2**).

Sewerable Water

The Livermore site's sanitary sewer discharges are sampled continuously to satisfy various permit requirements. The monitoring results for the LLNL effluent are reported monthly to the LWRP. In 2002, LLNL sanitary effluent monitoring identi-

Table 2-4. Summary of NPDES permit nonconformance

Permit No.	Outfall	Nonconformance	Date(s) of nonconformance[a]	Description–solution
CAS000002	Arroyo Las Positas (Livermore site)	Sensitive Compartmented Information Facility – Began construction prior to approval and certification of Storm Water Pollution Prevention Plan (SWPPP)	5/13/02–6/14/02	SWPPP was revised, approved, and certified. Incident was reported to the regional board.
CAS000002	Arroyo Las Positas (Livermore site)	National Ignition Facility—Failure to inspect one significant rain event.	12/21/01	Incident was identified to project management and noted in compliance certification.

a These dates reflect the construction reporting period of June 2001 through May 2002.

fied five events that were at or slightly above effluent limitations contained in Permit No. 1250. Two of these events resulted in a Letter of Warning from the LWRP (see **Table 2-5**). Daily effluent samples collected on August 3 and 6 contained lead at concentrations of 0.226 mg/L and 0.208 mg/L, respectively, exceeding the discharge limit of 0.2 mg/L. The LWRP issued a Letter of Warning dated October 10, 2002, for these discharges. The other three events were brief pH monitoring fluctuations, reported to the LWRP. Following LWRP's evaluation of each event, they decided formal enforcement action was not appropriate. Further details of these events are found in Chapter 6.

LLNL also conducts self-monitoring of federally regulated processes, called categorical processes, and reports results to the LWRP semiannually. The data show compliance with all categorical pretreatment discharge standards.

On October 7 and 8, 2002, LWRP and EPD personnel collected split samples of site effluent as part of routine annual compliance sampling. Sample results confirmed compliance with effluent discharge limits. LLNL and LWRP also inspected and sampled categorical processes and their waste streams on October 21, 2002. No facility deficiencies were noted during any of the inspections (**Table 2-2**).

Table 2-5. 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 August 3 and 6 daily effluent samples exceeded the permit limit. LWRP issued a warning letter dated October 10, 2002.	8/3/02 8/6/02	Effluent samples collected August 4 and 9, 2002, confirmed LLNL's return to compliance.

LLNL monitors discharges from groundwater treatment facilities to the sanitary sewer under Permit 1510G (2002) as they occur. Data are reported annually to the LWRP. In 2002, 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, Nationwide Permits, and Waste Discharge Requirements

CDFG, RWQCBs, and ACOE all issue permits for work in streams (**Table 2-6**). In 2001, CDFG Legal Counsel advised LLNL that, because LLNL is federal property, LLNL is exempt from SAA requirements for activities conducted in streams at the Livermore site and Site 300. To ensure ongoing protection of streams, LLNL and CDFG are developing a memorandum of understanding (MOU) regarding LLNL activities that affect streams. In the interim, LLNL provides copies of the ACOE and RWQCB permit applications for comment to CDFG and continues to follow the substantive requirements of previously issued SAAs.

During 2002, LLNL continued operations 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 2002. In 2002, LLNL obtained coverage under NWP 33 to use cofferdams for dewatering areas to be desilted as part of the Arroyo Las Positas Maintenance Project. Operations continued maintenance activities under an SAA issued for vegetation management in Arroyo Seco. No projects at Site 300 required permits from ACOE during 2002.

LLNL operates a drinking water pump station approximately twenty miles south of LLNL where drinking water is pumped from the Hetch Hetchy underground pipeline to provide water for Sandia National Laboratories/California (Sandia/California) and LLNL. To access this facility, LLNL maintains, through an easement, an access road and low-water crossing at Arroyo Mocho. In 2002, LLNL began a project to stabilize the banks of the Arroyo Mocho pump station. The first phase of the stabilization project was conducted under an SAA from CDFG.

Table 2-6. 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 project plan)	Arroyo Seco	CDFG/SAA	1999
Arroyo Las Positas Maintenance Project (five-year project plan)	Arroyo Las Positas	CDFG/SAA SFBRWQCB/WDR ACOE/NWP 18 ACOE/NWP 33	1998 1999 2000 2002
Arroyo Mocho bank stabilization	Arroyo Mocho	CDFG/SAA	2001

a See Acronyms and Abbreviations for list of acronyms.

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, permitted underground storage tanks contain diesel fuel, gasoline, and used oil; aboveground storage tanks contain diesel fuel, insulating oil, and process wastewater. Some nonpermitted wastewater tank systems are a combination of underground storage tanks and aboveground storage tanks. **Table 2-7** shows the status of tanks at the Livermore site and Site 300 as of December 31, 2002. All permitted underground storage tanks were inspected by the regulating agencies in 2002. See **Table 2-2** for summary of inspections and **Table 2-8** for a description of a violation notice recieved as a result of a November 5 inspection.

Resource Conservation and Recovery Act and Related State Laws

The Resource Conservation and Recovery Act (RCRA) provides 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 require-

Table 2-7. Summary of in-service tanks in 2002

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
Used oil	1	0	1	0	0	0
Process wastewater	1[a]	41	42	0	11	11
Subtotal	11	41	52	5	11	16
Aboveground storage tanks						
Diesel fuel	0	27	27	0	7	7
Insulating oil	0	1	1	0	4	4
Process wastewater	10[b]	63	73	0	13	13
Miscellaneous non-waste tanks	0	17	17	0	0	0
Subtotal	10	108	118	0	24	24
Total	**21**	**149**	**170**	**5**	**35**	**40**

a LLNL received permit exemption in October 2002.

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

Table 2-8. Environmental occurrences reported under the Occurrence Reporting (OR) System, 2002

Date[a]	Occurrence category	Description[b]
April 5	Off-Normal	LLNL was notified by a scrap metal company on April 4 that equipment (a pulse-electron beam generator) shipped to them by LLNL that day contained a large volume of liquid. Before shipping the equipment, LLNL removed approximately 3000 gallons of Shell Diala insulating oil from the equipment. Upon receiving the equipment, the scrap metal company discovered that additional liquid was contained in a separate reservoir. Representatives from LLNL were sent to the scrap metal facility with a container truck to remove the remaining liquid. LLNL removed 2766 gallons of Shell Diala insulating oil from the equipment and shipped the oil to an outside company for recycling. Equipment containing liquid violates the definition of "scrap metal" as defined in California Code of Regulations, Title 22. Shipping scrap metal containing Shell Diala insulating oil violated the off-site facility acceptance criteria and meets the definition of an Off-Normal Occurrence. OR 2002-0008
June 6	Off-Normal	LLNL received an SOV from DTSC for alleged violations observed during the 2002 CEI of permitted hazardous waste handling operations. The alleged violations and resolutions were as follows: • Storage of one container of waste for greater than 90 days in the B612-4 90-day generator area. This waste container was moved to a permitted storage location. • Storage of two waste containers for greater than one year in the B693 Container Storage Unit. This waste was transferred to an off-site TSDF. • Inadequate aisle spacing in the Area 514-3 portable tank area. LLNL maintained that adequate aisle spacing was provided. • Failure of an individual to take a required refresher training course. LLNL maintained that the individual met the training requirements until he was transferred to a different position where the training was no longer required. Later, LLNL received notice from DTSC that the agency had rescinded the last two alleged violations. Receiving an SOV meets the requirements of an Off-Normal Occurrence. OR 2002-0012.
November 5	Off-Normal	LLNL received a field inspection report from the SJCEHD listing three minor violations: • Lack of documentation for tank alarms at Buildings 871, 875, and 879. • Line leak detector at Building 879 was not functioning at the required rate. • Lack of documentation of line leak test or positive turbine pump shutdown due to lack of dispenser pan sensors at Building 879. To address the observations, LLNL has developed logbooks at the tank system alarm panels and instituted documentation requirements for documenting alarms. In addition, the B879 line leak detector was replaced and the unleaded line system was leak tested and the results submitted to the SJCEHD as requested. Receiving a notice of violation meets the requirements of an Off-Normal Occurrence. OR 2002-0033.

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.

ments 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 Decontamination and Waste Treatment Facility [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., wastewater filtration, blending, and size reduction). A final closure plan for the Building 419 Interim Status Facility has been submitted to DTSC for approval. See **Table 2-2** for a summary of inspections and **Table 2-8** for a description of a Summary of Violations (SOV) received as a result of a May inspection.

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 by 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 deliver all information requested by DTSC, on an ongoing basis, to support an evaluation to determine the need for additional permit conditions or modifications. DTSC submitted status reports to Tri-Valley CAREs et al. in December 2001 and on March 25, 2002, and finalized their determination in June 2003.

Site 300

On November 20 and 21, DTSC conducted the 2002 compliance evaluation inspection of the Building 883 Container Storage Area (B883 CSA), Explosives Waste Storage Facility (EWSF), and the Explosives Waste Treatment Facility (EWTF). In addition to physical inspections of the hazardous waste facilities, DTSC inspected facility personnel training records, facility inspection checklists, waste inventories, waste requisitions, hazardous waste manifests, hazardous waste transporter registration, and Land Disposal Restriction Notifications/Certifications. No violations were issued at the conclusion of the inspection.

Hazardous Waste Reports

LLNL completes two annual hazardous waste reports, one for the Livermore site and the other for Site 300, that address the 2002 transportation, storage, disposal, and recycling of hazardous wastes. LLNL received an extension past the April 1, 2003, deadline for the 2002 annual

reports, required under 22 CCR 66262.41. These reports, *2002 Hazardous Waste Report-Mainsite* and *2002 Hazardous Waste Report-Site 300* were submitted to the DTSC by the extended deadline of April 15, 2003.

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 2002.

Waste Accumulation Areas

In January 2002, there were 22 waste accumulation areas (WAAs) at the Livermore site. One temporary WAA was put into service, and one temporary WAA was 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 1170 prescribed WAA inspections were conducted at the Livermore site.

One WAA was in operation at Site 300 during 2002. 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. 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 DHS and is enforced by the ACDEH.

LLNL is registered with the ACDEH as a generator of medical waste and has a treatment permit. No violations were issued as a result of the September 2002 ACDEH inspection of buildings at LLNL Health Services, the Biology and Biotechnology Research Program, and the Medical Photonics Lab (see **Table 2-2**).

Federal Facility Compliance Act

LLNL continues to work with DOE to maintain compliance with the Federal Facilities Compliance Act Site Treatment Plan (STP) for LLNL that was signed in February 1997. All milestones for 2002 were completed on time. Reports and certification letters were submitted to DOE as required. 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) governs 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 2002, LLNL generated the following PCB-containing waste: PCB oil drained from electrical equipment and vacuum pumps, electrical equipment contaminated with PCBs, liquid PCBs used to calibrate analytical equipment, and animal bedding and personnel protective equipment from lab experiments using PCBs. TSCA-regulated asbestos waste was generated 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 is currently stored at one of LLNL's hazardous waste storage facilities until the Waste Isolation Pilot Plant, or other approved facility, accepts this waste for final disposal.

National Environmental Policy Act

The National Environmental Policy Act (NEPA) established federal policy for protecting environmental quality. The major method for achieving established NEPA goals is the requirement to prepare 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., from the preparation of either an EA or EIS). DOE NEPA implementing procedures 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 2002, two DOE EAs were prepared for LLNL projects. On September 25, 2002, DOE issued a FONSI as a result of the *Environmental Assessment for the East Avenue Security Upgrade at Lawrence Livermore National Laboratory/Sandia National Laboratories, California*. This project will provide increased security to LLNL and Sandia/California facilities in the area of the federally owned section of East Avenue (between Vasco and Greenville Roads) shared by both laboratories.

On December 16, 2002, DOE issued a FONSI as a result of the *Environmental Assessment for the Proposed Construction and Operation of a Biosafety Level 3 Facility at Lawrence Livermore National Laboratory, Livermore, California*. This project will provide an enhanced ability for LLNL to conduct research on detection, identification, and protection measures that relate to the potential terrorist use of biological agents against U.S. personnel or facilities.

Twenty-three 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 Code of Federal Regulations (CFR) 1022.

In 2002, DOE began the NEPA process of preparing a new sitewide EIS by seeking public involvement and comment on the scope for the EIS document. The new EIS will replace 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) and its March 1999 Supplement Analysis. The draft EIS is projected to be available for public review and comment in fall 2003; completion of a ROD is expected in late fall 2004.

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 the *1992 EIS/EIR*. The 1997 and 1998 mitigation monitoring reports were published in 2001. The 1999 mitigation monitoring report was published in 2002. The 2000 and 2001 mitigation monitoring reports will be published in 2003.

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 LLNL'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. LLNL, and UC as its contractor operator, supports DOE NHPA responsibilities. LLNL does so in a limited manner with direction from DOE. The two primary NHPA sections that apply to LLNL are 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 UC, and the State Historic Preservation Office (SHPO). As of July 2003, a signed Programmatic Agreement exists among DOE, the UC, and the SHPO related to Section 106 responsibilities and the operation of LLNL.

The second approach is to complete an inventory of places that meet a statutory threshold of historic importance. During 2001 and 2002, LLNL developed historic background information, a necessary precursor for the inventory, and funded an analysis to make recommendations for historic significance determinations at the Livermore site and Site 300.

To date, 50 buildings have been evaluated by DOE with SHPO concurrence that the buildings are not eligible for listing on the National Register of Historic Places.

Endangered Species Acts and Sensitive Natural Resources

LLNL meets the requirements of the U.S. Endangered Species Act, the California Endangered Species Act, the Eagle Protection Act, the Migratory Bird Treaty Act, and the California Native Plant Protection Act as they pertain to endangered or threatened species and other special status species, their habitats, and designated critical habitats that exist at the LLNL sites. For example, LLNL consults with the USFWS when activities will result in an impact to federally endangered or threatened species, surveys for the presence of species of special concern, and follows mitigation requirements in WDRs and biological opinions.

Four species, the California red-legged frog (*Rana aurora draytonii*), Alameda whipsnake (*Masticophus lateralis euryxanthus*), valley elderberry

long-horn beetle (*Desmocerus californicus dimorphus*), and the large flowered fiddleneck (*Amsinckia grandiflora*), that are listed under the federal or California endangered species acts are known to occur at Site 300. Although there are no recorded observations of the federally endangered San Joaquin kit fox (*Vulpes macrotis mutica*) at Site 300, this species is known to have occurred in the adjacent Carnegie and Tracy Hills areas (USFWS 1998). Because of the proximity of known observations of San Joaquin kit fox to Site 300, it is necessary to consider potential impacts to San Joaquin kit fox during activities at Site 300. State threatened Swainson's hawks (*Buteo swainsoni*) have been observed at Site 300, but Swainson's hawk breeding habitat does not occur at Site 300. The federally threatened California red-legged frog is also known to occur at the Livermore site.

Several other species that are considered rare or otherwise of special interest by the federal and state governments also occur at Site 300. These species in addition to state and federally listed species that occur at Site 300 and the Livermore site are described further in Appendix A. These species include California Species of Special Concern, California Fully Protected Species, federal Species of Concern, species with respect to the federal Migratory Bird Act, and those species included in the California Native Plant Society's Inventory of Rare and Endangered Plants (CNPS 2001).

In 2001, the U.S. Fish and Wildlife Service (USFWS) designated critical habitat for the California red-legged frog (USFWS 2001). The North Buffer Zone and eastern edge of the Livermore site in addition to approximately half of Site 300 were included in this 2001 critical habitat designation. Most of this critical habitat designation, including all LLNL areas, were rescinded in 2002 due to a recent court decision. The USFWS plans to issue a new critical habitat proposal for the California red-legged frog in 2004 (USFWS 2002).

Critical habitat for the Alameda whipsnake was designated in 2000 and includes the southwest quarter of Site 300 (USFWS 2000). Similar to the California red-legged frog critical habitat designation, the Alameda whipsnake critical habitat designation was rescinded in 2003 by a court decision. A portion of Site 300 has also been designated as a critical habitat area for the large flowered fiddleneck and as the *Amsinckia grandiflora* Reserve through a declaration by Secretary of the U.S. DOE. Activities within the reserve are conducted under a memorandum of agreement between the DOE and the USFWS.

During desilting activities in 2002, Livermore site populations of the California red-legged frog (*Rana aurora draytonii*) were monitored in accordance with the 1997 and 1998 amended USFWS Biological Opinion for the Arroyo Las Positas Maintenance Project. A checkerboard pattern of Arroyo sections, ranging in length from one-hundred feet to three-hundred feet, were managed for excess in-stream vegetation and 73 California red-legged frogs were protected from harm in project locations during the maintenance process.

In implementing the mitigation monitoring requirements of the *1992 EIS/EIR*, biological assessment surveys were performed in 2002 for specific special-status species at Site 300 project construction (ground-disturbing) areas. Presence data for the San Joaquin kit fox, 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. In addition, Site 300 populations of the federally threatened California red-legged frog and a federal species of concern, the California tiger salamander (*Ambystoma californiense*), were monitored at wetland locations sitewide.

As part of the preparation for the new site-wide EIS, several surveys of biological resources at Site 300 were initiated in 2002. The surveys or inventories that were completed in 2002 as part of the sitewide EIS effort are described further in Appendix A.

As a result of these studies, information was gained about the presence, distribution and abundance of wildlife and plant species at Site 300 and at the Livermore site. Several special status species that were not previously recognized at Site 300 were observed during these studies. This includes four plants that are in the California Native Plant Societies Inventory of Rare and Endangered plants of California (CNPS 2001) and sixteen birds that are federal or California species of concern. In addition, the first known observation of a California legless lizard (*Anniella pulchra*), a California Species of Special Concern, at Site 300 occurred during the special status reptile studies conducted in 2002, and the occurrence of the valley elderberry longhorn beetle, a federally threatened species, was also confirmed in 2002.

In all, eight species of rare plants are known to occur at Site 300. Restoration and/or monitoring activities were conducted for three of these species in 2002: the large-flowered fiddleneck (*Amsinckia grandiflora*), the big tarplant (*Blepharizonia plumosa*, also known as *Blepharizonia plumosa* ssp *plumosa*), and the diamond-petaled poppy (*Eschscholzia rhombipetala*). The results of this work are described in more detail in an annual progress report (Carlsen et al. 2003). Rare plant research and monitoring is further described in Appendix A.

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 the 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 2002.

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.

LLNL's response to environmental occurrences is part of the larger on-site emergency response organization that includes representatives from Hazards Control (including the LLNL Fire Department), Health Services, Plant Engineering, Public Affairs, Safeguards and Security, and Environmental Protection. In 2002, three environmental incidents, summarized in **Table 2-8**, were reportable under DOE Order 232.1 and were categorized as off-normal occurrences according to DOE Order 232.1. DOE was notified of these incidents. No other agencies required notification.

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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) supports this effort in the areas of environmental compliance and accountability. This chapter begins with a brief description of LLNL's Integrated Safety Management System (ISMS), 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 LLNL's environmental protection efforts are then summarized. The majority of the chapter then describes LLNL's activities and progress in waste minimization and pollution prevention in 2002. This chapter concludes with a brief discussion of spill response and other environmental programs at LLNL.

Integrated Safety 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) ES&H 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 and environmental aspects associated with the work; (3) develop and implement hazard and aspect 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 description of LLNL's ISMS was initially provided in *Integrated Safety Management System Description (*Clough 2000); the most recent version of the document dated April 9, 2003 (UCRL-AR-132791, Version 6) can be found at the following website: http://www.llnl.gov/es_and_h/ism/ism-descriptionv6.pdf .

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.

In June 2002, the DOE conducted an independent oversight inspection of safety and emergency management. LLNL's ES&H Program was characterized as a comprehensive Environmental Management System (EMS) program and the environmental element of the program was rated as "Effective Performance."

Work Smart Standards

Work Smart Standards (WSS) are an integral part of an ISMS, whereby ES&H professionals identify hazards and environmental aspects, 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 and the environmental aspects associated with the work, and the selection of standards from which hazard and aspect controls are developed. This process empowers LLNL 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 LLNL 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 LLNL. LLNL's existing ES&H methodologies and documentation have been modified to incorporate the 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. The change control process is managed by the Change Control Board (CCB) with representatives from DOE, UC, and LLNL. In addition, LLNL undertakes periodic review of all the requirements to assure that the WSS set is current and complete.

On January 15, 2003, the DOE issued Order 450.1, "Environmental Protection Program," which requires DOE sites to implement an EMS integrated into their ISMS. The purpose of Order 450.1 is to align the DOE's system for environmental protection with the requirements of Executive Order 13148, "Greening the Government Through Leadership in Environmental Management." In February 2003, the CCB constituted a Standards Identification Team for the purpose of considering the adoption of in whole or part the Contractor Requirements Document of Order 450.1. This process will result in the consideration of all or parts of Order 450.1 for incorporation into the contract as necessary and sufficient under LLNL's current integrated ES&H management system.

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.

The WSS approach, coupled with enhanced, integrated ES&H management, continues to promise further safety and environmental improvements at 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 waste management in support of LLNL'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 LLNL 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, Radioactive and Hazardous Waste Management, and Environmental Restoration.

EPD monitors air, sewerable water, groundwater, surface water, soil, sediment, 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 2002, 11,877 samples were taken, and 212,689 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 requirements. EPD helps LLNL programs manage and minimize hazardous, radioactive, and mixed wastes, as well as identify opportunities for pollution prevention, including minimization of nonhazardous waste; 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 the 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 Radioactive and Hazardous Waste Management (RHWM) 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 LLNL 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 environmental 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 (EDO). EDOs are on duty 24 hours a day,

7 days a week, and coordinate emergency response with LLNL's ES&H teams and other first responders and environmental specialists.

Radioactive and Hazardous Waste Management Division

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

As part of its waste management activities, RHWM tracks and documents the movement of hazardous, mixed, and radioactive wastes from waste accumulation areas, which are typically 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 and other regulatory agencies; responds to emergencies; and participates in the cleanup of potential hazardous and radioactive spills at LLNL facilities. RHWM prepares numerous reports, including the annual and biennial hazardous waste reports required by the state and federal environmental protection agencies. RHWM also prepares waste acceptance criteria documents, safety analysis reports, and various waste guidance and management plans.

RHWM 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.

RHWM 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 and soil vapor extraction and treatment, 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 regularly 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; 25 portable groundwater treatment units; 2 catalytic dehalogenation units; and 3 soil vapor extraction facilities (see Chapter 8). In 2002, ERD operated 27 groundwater treatment facilities and soil vapor treatment units. At Site 300, ERD has designed, constructed, and operated 11 extraction and treatment facilities; 8 of these extract and treat groundwater only and 3 extract and treat groundwater and soil vapor. In addition, ERD has capped and closed 4 landfills and the High Explosives Rinse Water Lagoons and Burn Pits, excavated and closed numerous wastewater 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 LLNL workers the appropriate training support to ensure 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 2002, EPTP provided nearly 12,000 hours of environmental protection training to LLNL workers involved in science related work at LLNL. EPTP also provided an additional 2000 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 LLNL workers during 2002 addressed the requirements of the NEPA, the Resource Conservation and Recovery Act, the Superfund Amendment and Reauthorization Act, the Occupational Safety and Health Administration and other federal and 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 consists of training professionals and technical and administrative personnel familiar with the various environmental regulations and requirements and cognizant in LLNL operations requiring environmental protection training. 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 LLNL 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.

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) have been used to evaluate LLNL's environmental protection activities, and four have been used to evaluate LLNL's environmental restoration and waste management activities.

For 2002, DOE gave LLNL an average score of excellent for its environmental protection performance and an average score of outstanding for its

environmental restoration and waste management performance. DOE scores for individual performance measures are shown in **Table 3-1**. New PMs are being implemented for FY 2003, which began October 1, 2002. These will be discussed in the 2003 environmental report.

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 pollution prevention (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.

The DOE P2/E2 Leadership Goals are set to establish a Department-wide achievement standard. DOE field offices, such as the Livermore Site Office, have the responsibility to adapt, develop, and incorporate these goals into annual performance agreements for their sites. For LLNL in FY 2002, DOE P2/E2 goals for routine hazardous, low-level radioactive and mixed waste are part of the UC Contract PM (1.2.f). The LLNL PM 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. In the case that a waste reduction goal had already been achieved at a specific DOE facility, guidance associated with the Secretary of Energy indicates that the DOE facility should pick a more progressive goal to encourage further development. Hence, the LLNL PM goal was set at achieving a diversion of 66.7% of sanitary wastes by 2005.

Pollution Prevention Reporting

UC contract PM 1.2.f requires LLNL to provide an annual review of its waste generation. The review focuses on P2 opportunities and proposes implementation projects. The Permits and Regulatory Affairs Group (PRAG) of ORAD provided PM data at the end of each of the first three quarters, which included projections for year-end waste generation totals. In October 2002, PRAG submitted the UC Performance Measure Report for 4th Quarter, 2002 to the LLNL UC/DOE Contract ES&H Compliance Manager, which included all cumulative waste generation data required for Reporting on Contract 48 PM 1.2.f. LLNL received an "Excellent" rating for progress towards meeting the waste reduction goals for 2005. Cumulative waste data for this report is found in **Table 3-3**.

In December 2002, LLNL submitted data for the *Fiscal Year (FY) 2002 Annual Report on Waste Generation and Pollution Prevention Progress*. The report outlined waste generation data for FY 2002 and provided a progress report for the ongoing P2 activities on site.

Table 3-1. UC Contract 48 environmental protection and environmental restoration and waste management performance measures, FY 2002[a]

PM designator	Performance measure synopsis	Location in *Environmental Report*	Score
Performance Area: Environmental Protection			
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 2002 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 LLNL 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 2-3** and **2-8**	Excellent
1.2.h	Environmental releases LLNL controls and reduces the number of occurrences of environmental releases and the number of releases that result in violations.	Chapter 2, Compliance Summary, **Table 2-8**	Outstanding
Performance Area: Environmental Restoration and Waste Management			
1.1.a	Waste management productivity LLNL will collect data on the volume of waste received and volume of waste shipped	Chapter 3, section on Radioactive and Hazardous Waste Management Division	Outstanding
1.1.b	Waste Management Treatment and Disposal LLNL will reduce low-level and mixed waste inventories through treatment and disposal activities.	Chapter 3, section on Radioactive and Hazardous Waste Management Division	Outstanding
1.2.a	Advancement of the Environmental Management Program LLNL will advance the state of the art technologies by implementing their usage at LLNL and other DOE sites.	Chapter 3, section on Environmental Protection Department Chapter 8, Groundwater Investigation and Remediation	Outstanding
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	Good

a FY 2002 is the DOE and LLNL fiscal year of October 1, 2001, to September 30, 2002.

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 LLNL 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

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, improving resource usage, and reducing inventories and releases of hazardous chemicals. These efforts also benefit LLNL by reducing compliance costs and minimizing potential civil and criminal liabilities under environmental laws. In accordance with Environmental Protection Agency (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 RHWM Division's Total Waste Management System (TWMS) database. By reviewing this database, directorate managers and the P2 staff can monitor waste streams for P2 purposes. With the purpose to track and report waste minimization/P2 efforts, LLNL compares current waste generation against the baseline year, 1993, waste generation quantities. The routine waste generation for the 1993 baseline year and for 2002 and the percent reductions in routine waste generation since 1993 are presented in **Table 3-3**. Routine waste described in this table includes waste from normal (ongoing) operations produced by any type of production, analytical, and/or research and development laboratory operations. Periodic laboratory or facility clean-outs and spill cleanups which occur as a result of these processes are also considered normal operations. Since 2001, LLNL has revised the method by which it calculates waste generated for the purposes of tracking and reporting on P2 efforts. The reason for this change is to include additional categories of wastes to better identify future P2 opportunities and to eliminate categories of wastes that would otherwise be counted twice under the new tracking system. The reported waste quantities for hazardous waste, low-level radioactive waste (LLW), and mixed low-level waste (MIXED) now include wastes that are shipped off site, waste treated and sewered on site, as well as 50% of wastes that are 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.

The FY 2002 totals reported in the UC Performance Measures report for both LLW and MIXED were smaller than the FY 2001 totals and are indicative of progress towards the 2005 goals. The LLW total for FY 2002 actually meets the 2005 goal, which is 80% less than the FY 1993 baseline. The MIXED waste total represents a 57% reduction which is still short of the 80% goal for FY 2005. The hazardous waste total for FY 2002 is higher than it was FY 2001 and shows an increase in hazardous waste generation over the past two years. This increase is presently being reviewed and evaluated.

Nonhazardous Solid Waste Minimization

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

Table 3-3. Routine waste reduction, FY 2002

Waste category	1993 (baseline)	FY 2002	Reduction 2002 since 1993 (%)
Low-level radioactive	346 m^3	70 m^3	80
Mixed	26 m^3	11 m^3	57
Hazardous	1054 MT[a]	421 MT	60
Sanitary (nonhazardous solid waste)	5873 MT	5819 MT	1

a MT = metric tons

LLNL's goal is to reduce the generation of routine nonhazardous solid waste by 75% of the 1993 baseline year by year 2005. Together, the Livermore site and Site 300 generated 5819 metric tons of routine nonhazardous solid waste in FY 2002, a 1% reduction since 1993. This volume includes diverted waste (for example, material diverted through recycling and reuse programs) and landfill wastes.

LLNL generated 21,832 metric tons of nonroutine nonhazardous solid waste in FY 2002. This volume includes waste that is reused as cover soil at Class II landfills and through the nonroutine metals recycling programs. Nonroutine nonhazardous solid wastes include wastes from construction, and decontamination and demolition activities.

In FY 2002, the portion of nonhazardous waste sent to landfill was 5287 metric tons. The routine portion was 1803 metric tons and the nonroutine portion was 3484 metric tons. The breakdown for routine and nonroutine nonhazardous waste that was sent to landfills in FY 2002 is shown in Table 3-4.

Table 3-4. Total nonhazardous waste sent to landfills, FY 2002

Nonhazardous waste	2002 total (metric tons)
Routine	
Compacted	1803
Nonroutine	
Construction demolition (noncompacted)	3282
Industrial (TWMS)[a]	202
Nonroutine subtotal	3484
LLNL total	**5287**

a TWMS = Total Waste Management System

Diverted Waste

According to its management contract with UC, LLNL's goal for annual routine nonhazardous waste generated is to divert 66.7% of the 1993 baseline amount. Together the Livermore site and Site 300 diverted 4012 metric tons of routine nonhazardous waste in 2002. This represents a diversion rate of 69% of routine nonhazardous waste in FY 2002. This diversion rate includes waste recycled by RHWM and waste diverted through the surplus sales and pipette box recycling programs. The total routine and nonroutine waste diverted from landfills in FY 2002 was 18,649 metric tons.

Table 3-5 shows a breakdown of waste diversion categories for FY 2002, reflecting the variety of diversion programs in place at LLNL. Soil, a major contributor to diversion totals, is reused both on site and at a landfill for daily cover. Asphalt and

concrete are reused as road base material at a landfill. No cost-effective on-site reuse strategy for wood waste (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 2002

Waste description	Cumulative 2002 total (metric tons)
Asphalt/concrete	1,865.9
Batteries	21.6
Beverage and food containers	8.2
Cardboard	146.5
Compost	704.4
Cooking grease/food	2.8
Diverted soil (includes Class II Cover)	11,987.6
Magazines, newspapers, and phone books	30.4
Metals	1,290.1
Miscellaneous	1.6
Nonroutine metals	778.9
Paper	302.7
Pipette box recycling	1.0
RHWM recycled	234.1
Surplus sales	699.4
Tires and scrap	27.1
Toner cartridges	1.5
Wood	545.5
LLNL diversion total	**18,649.3**

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 in two ways: by eliminating an organic waste stream and associated tipping fees (hauling costs) and by saving the purchase cost of new material. In another 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. This practice also reduces 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. LLNL 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 FY 2002. This program, which serves all three on-site cafeterias, collected 8.2 metric tons of aluminum, glass, and plastic containers and steel food cans. The collected material was 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 and

Nuclear Technologies Program's Contained Firing Facility at Site 300 that moves explosive tests inside a facility where the debris is contained; the National Ignition Facility Programs' efforts to design the National Ignition Facility (NIF) to have minimal environmental impact; and the Education Program's efforts to enhance environmental education.

In the case of the Contained Firing Facility (CFF), new waste streams are being managed because the detonations are completely contained within the firing chamber and not open to the atmosphere as in the past. CFF is in the process of developing new operational source reduction measures. The net result will be greater protection for the environment and greater programmatic flexibility.

Current Return-on-Investment Projects

DOE has traditionally funded P2 projects through the High-Return-on-Investment (ROI) P2 Program. However, in FY 2002, ROI funding was severely limited. One new ROI project, an electric vehicle pilot program, was funded in FY 2002 (see **Table 3-6**). Other ROI-related work occurring in FY 2002 was associated with projects carried over from FY 2001 (also described in **Table 3-6**). The Water Recovery/Drain Down System project, funded in FY 2001, was the recipient of both a FY 2002 Federal Energy and Water Management Award, and a 2002 DOE Departmental Energy Management Award.

Table 3-6. High return-on-investment projects, FY 2002

Operation	Project[a]
Global Electric Motorcars (GEM) Pilot Study (FY 2002)	This project funded the purchase of a limited number of Daimler-Chrysler GEMs for a pilot study by the Fleet Management Group. The study, scheduled for early 2003, will evaluate the integration of electric vehicles into the LLNL fleet.
Water Recovery/Drain Down System (begun in FY 2001)	This project funded the purchase and conversion of a water-tank trailer to facilitate removal, storage and replacement of chiller water during maintenance operations. It received two federal water conservation awards.
Aqueous Parts Washer at Building 611 (begun in FY 2001)	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 Wash Water Recycling System (begun in FY 2001)	This project installed a wash water reclamation system at the LLNL Fleet Maintenance vehicle wash facility. The reclamation system conserves water, reduces the quantity of chemicals used for cleaning, and improves the trapping of oils and greases.
Photovoltaic (PV) Demonstration Project (begun in FY 2001)	This demonstration project installed three types of photovoltaic arrays at the LLNL Discovery Center to demonstrate different PV technologies and deployment scenarios.

a See Acronyms and Abbreviations for list of acronyms

Review of New Processes, Programs, or Experiments

Whenever feasible, many organizations at LLNL will use a "front-end" review process for P2 opportunities of new programs, projects, or experiments that could have a significant impact on the environment. For small-scale activities, such a review includes an assessment of the hazardous materials to be used and estimate of the associated wastes. This allows possibilities for chemical substitution, process changes, and recycling to be addressed.

Once P2 opportunities are identified, researchers and project managers are encouraged to implement them to the extent practicable.

For large processes or new programs, a more extensive review using a tool such as Design for Environment (DfE) may be carried out. A DfE review involves developing an understanding of potential environmental impacts throughout the lifetime of a project (including construction, operations, and decommissioning life-cycle stages), with the goal of minimizing or mitigating those impacts by modifying the project design. The NIF is an example of a program that has successfully implemented a variety of options identified during a DfE review. Examples of these options include implementation of recycling programs during NIF construction, the design and use of aqueous cleaning systems for parts and optics used during NIF operations, and the implementation of a number of facility design features that will help minimize wastes when NIF is decommissioned.

Green building is another "front-end" concept that can be applied to new construction at LLNL. It emphasizes the design of buildings that are efficient in their use of materials, energy, and other natural resources throughout their life cycle, and incorporates consideration of human health, the natural environment, and the built environments of site and community. During 2002, EPD and Plant Engineering jointly sponsored a Leadership in Energy and Environmental Design training session to help familiarize staff from LLNL, Sandia/California, and Lawrence Berkeley National Laboratory (LBNL) with green building concepts.

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*. This information is also disseminated to employees by making informal and 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 identification 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 168,000 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. ORAD staff also provide guidance to the programs on preventing spill recurrence.

As previously described, the EDO is available 24 hours a day, 7 days a week to maximize efficient and effective emergency environmental response. 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, LLNL employees report all environmental incidents to the EOG staff, or 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, LLNL 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 are the ongoing research and development activities of the Chemistry and Materials Science Directorate and the Energy and Environment Directorate. These directorates conduct basic and applied 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 isotopic 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 also 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

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4

Air Effluent Monitoring

Paula J. Tate

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 U.S. 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 U.S. 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 1–9 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 μSv/y (0.1 mrem/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 μSv/y (10 mrem/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 2002, LLNL operated 74 sampling systems for radioactivity from air exhausts at 7 facilities at the Livermore site (see **Figure 4-1**) and 1 sampling system at Site 300 (see **Figure 4-2**). These systems are listed in **Table 4-1** along with the analytes of

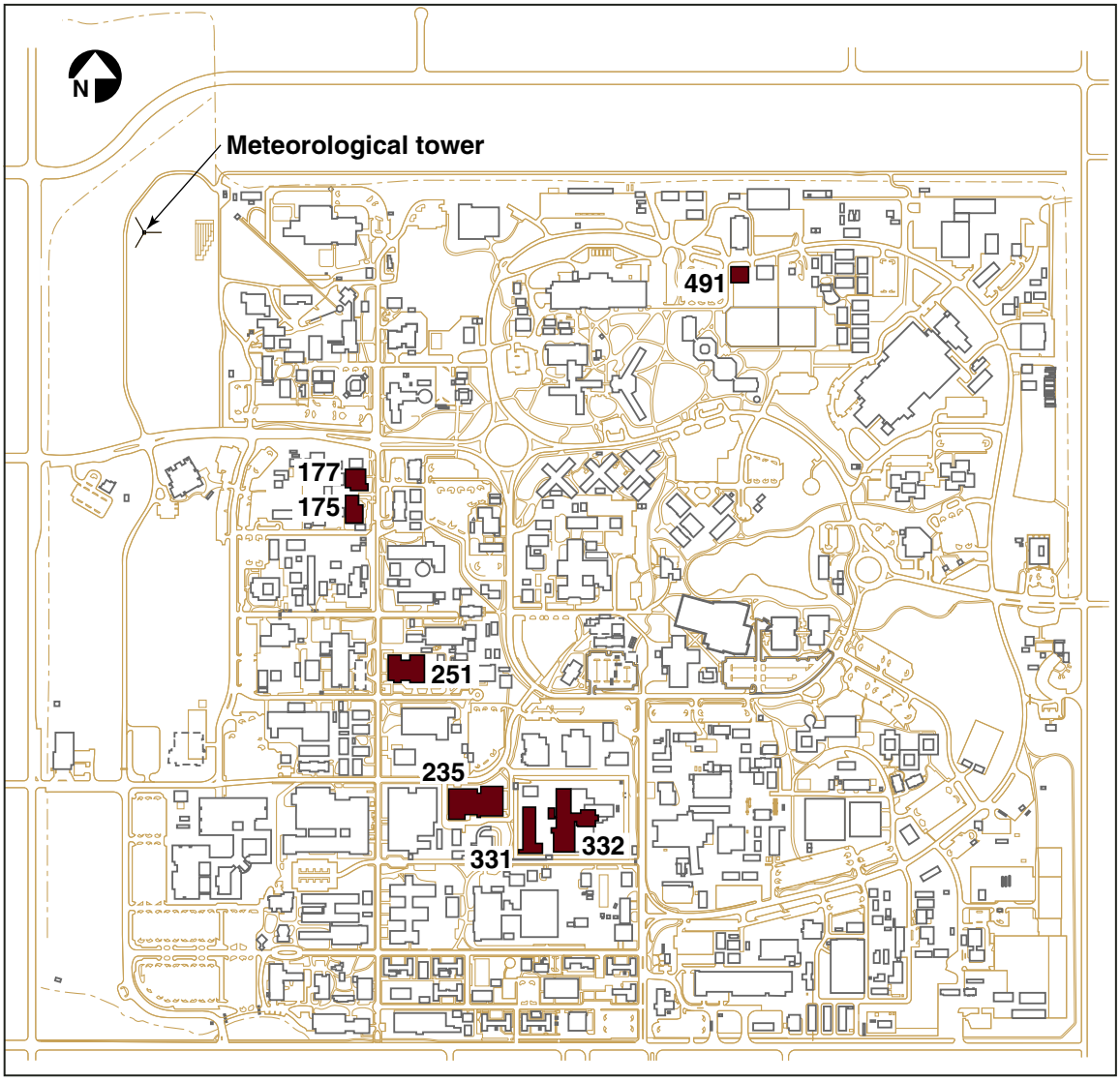

Figure 4-1. Facilities at the Livermore site with air monitoring systems for effluent gas streams during all or part of 2002

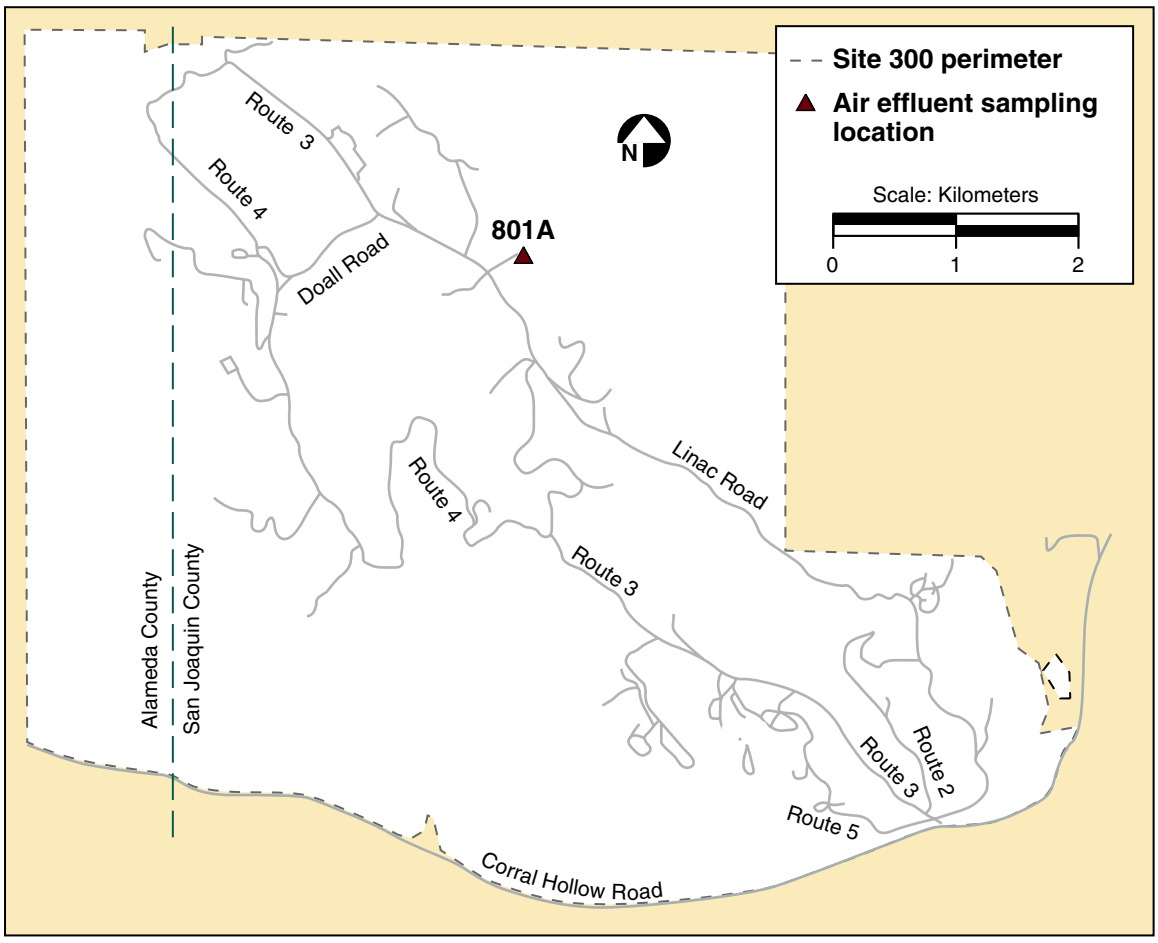

Figure 4-2. Building 801A at Site 300 with an air monitoring system for effluent gas streams

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 2002, one additional discharge point, a new operation in Building 801A at Site 300, 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. In February 2002, decontamination activities at Building 177 were completed and the sampling system was deactivated. Air effluent sampling systems at Buildings 175 and 491 continue to operate as part of the maintenance and surveillance shutdown plan for AVLIS facilities.

Sampling for particles containing radioactivity was conducted in seven 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

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	28
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
801A	Contained Firing Facility	Gross α, β on particles	Filter	1

a Alarmed systems

b CAM = Eberline continuous air monitors

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 detectable 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 2002, a total of 1.3 TBq (36.3 Ci) of tritium was released from the Tritium Facility (Building 331). Of this, approximately 1.2 TBq (32.8 Ci) were released as tritiated water vapor (HTO). The remaining tritium released, 0.13 TBq (3.5 Ci), was elemental tritium gas (HT). Weekly HTO emissions from the facility ranged from 0 Bq/m^3 (0 Ci/m^3) to 2.4×10^4 Bq/m^3 (6.6×10^{-7} Ci/m^3), while HT emissions ranged from 0 Bq/m^3 (0 Ci/m^3) to 4.4×10^3 Bq/m^3

(1.2×10^{-7} Ci/m^3). The highest single weekly stack emission from the facility was 141.3 GBq (3.82 Ci), of which 140.6 GBq (3.80 Ci) was HTO.

Emissions from Building 331 for 2002 continued to remain considerably lower than those during the 1980s. **Figure 4-3** 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

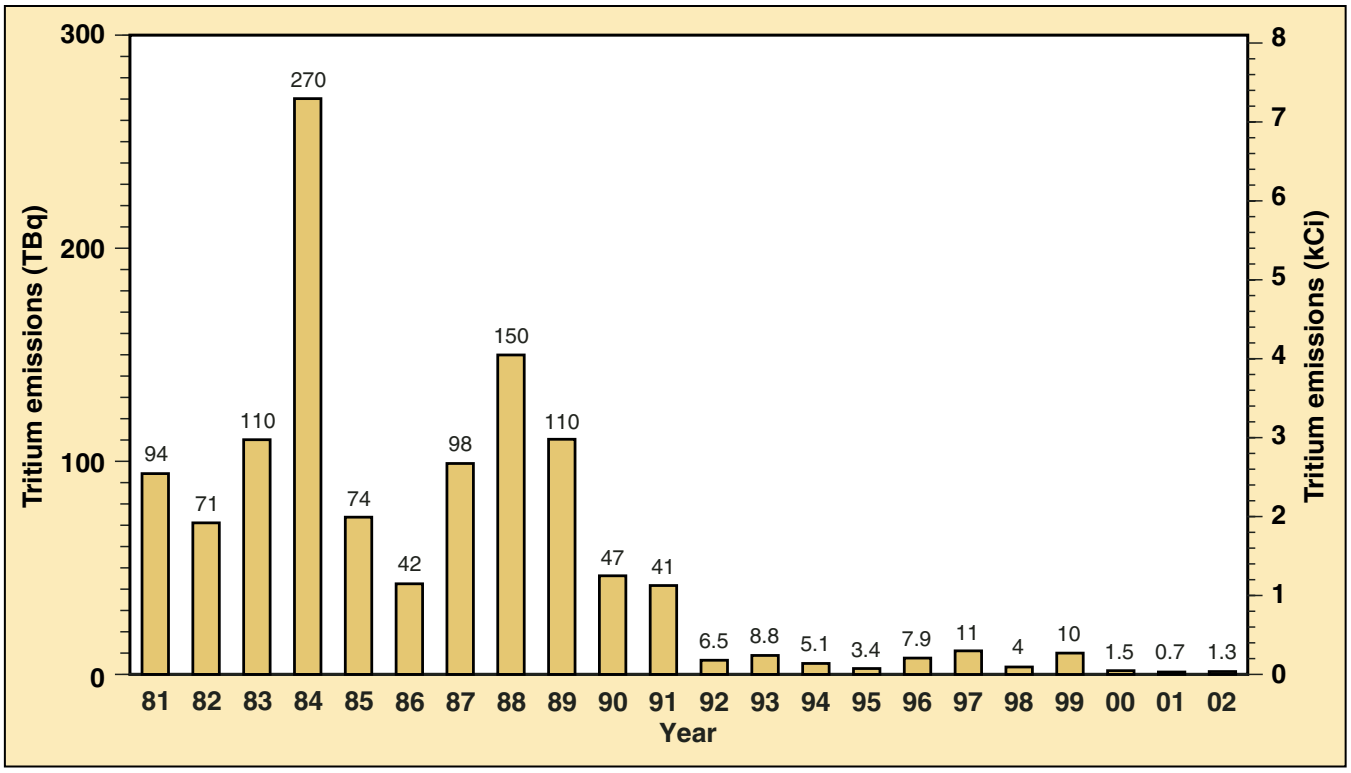

Figure 4-3. Tritium Facility combined HTO and HT emissions from 1981 through 2002

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 2002.

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

Site 300

An effluent sampling system was installed in Building 801A at Site 300 in early 2002. Although all facility operations are HEPA filtered, this building has a large high bay room that exhausts to the stack without HEPA filtration. Consequently, some of the air sampled by the effluent sampling system is essentially outside, ambient air. In order to determine if any releases actually occurred from this facility, the sampling results must be compared to ambient air. In 2002, five samples out of 38 had concentrations greater than the MDC. The median concentration of the Building 801A detections, 1.3×10^{-4} Bq/m^3 (3.6×10^{-15} Ci/m^3), is lower than the median concentrations of the detections from two offsite sampling locations that are used to establish background levels of gross alpha and beta activity for direct comparison to results from the air effluent samplers (See Chapter 5 for a description of the offsite sampling systems and data results). The median of all 38 of the Building 801A samples, 3.0×10^{-5} Bq/m^3 (8.0×10^{-16} Ci/m^3), is approximately three times lower than the median of all of the offsite sampling location samples. Therefore, it is reasonable to conclude that Building 801A operations did not have radioactive emissions.

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 2002, LLNL evaluated potential emissions of radionuclides from 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 2002 Annual Report* (Harrach et al. 2003) and are summarized in Chapter 13 of this report.

The radionuclide isotope responsible for the majority of the 2002 EDE was tritium. Emissions from the Tritium Facility, in the form of HTO, accounted for 36% 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 2002 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 109 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 2002 total airborne releases for criteria pollutants.

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 2002 were approximately 8.3×10^4 kg/day, compared with an estimate for LLNL releases of 67 kg/day for the Livermore site (0.08% of total Bay Area emissions from stationary sources). The BAAQMD estimate for reactive organic emissions was 9.8×10^4 kg/day for 2002, versus the Livermore site's estimated releases of 16 kg/day (0.02% of total Bay Area emissions from stationary sources) in 2002.

Table 4-2. Nonradioactive air emissions, Livermore site and Site 300, 2002

Pollutant	Estimated releases (kg/day)	
	Livermore site	Site 300
Organics/volatile organics	16	0.23
Nitrogen oxides	67	1.1
Carbon monoxide	17	1.0
Particulates (PM-10)	6.1	0.09
Sulfur oxides	2.8	0.07

Certain operations at Site 300 require permits from SJVUAPCD. The total estimated air emissions during 2002 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 2002 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 0.081 µSv/y (0.0081 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 0.056 µSv/y (0.0056 mrem/y).

In either case, the dose is far below the NESHAPs standard of 100 µSv/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** for a summary of doses.

Estimated nonradioactive air emissions, which are also very small compared with emissions in surrounding areas, are well below standards and pose no 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.

5

Ambient Air Monitoring

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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 metals 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. 2003).

Methods

Monitoring networks are established for surveillance of air particulates and tritium in the environs of the Livermore site 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 **Figures 5-1** to **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 2002 at all perimeter locations except CRED. To satisfy beryllium reporting requirements and determine the effects of the LLNL'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 $^{239+240}$Pu	Monthly Gamma & $^{235, 238}$U[a]	Monthly beryllium	Biweekly tritium
Network	Air particulate					Air vapor
Collection Media	Membrane	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
B292						X
B331						X
B514						X
B624						X
POOL						X
VET						X
ZON7		X	X			X
PATT		X	X			X
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 Gamma & $^{239+240}$Pu[a]	Monthly $^{235, 238}$U	Monthly beryllium	Biweekly tritium
Network		Air particulate				Air vapor
Collection Media		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 composite samples include portions of weekly filters from the specified locations.

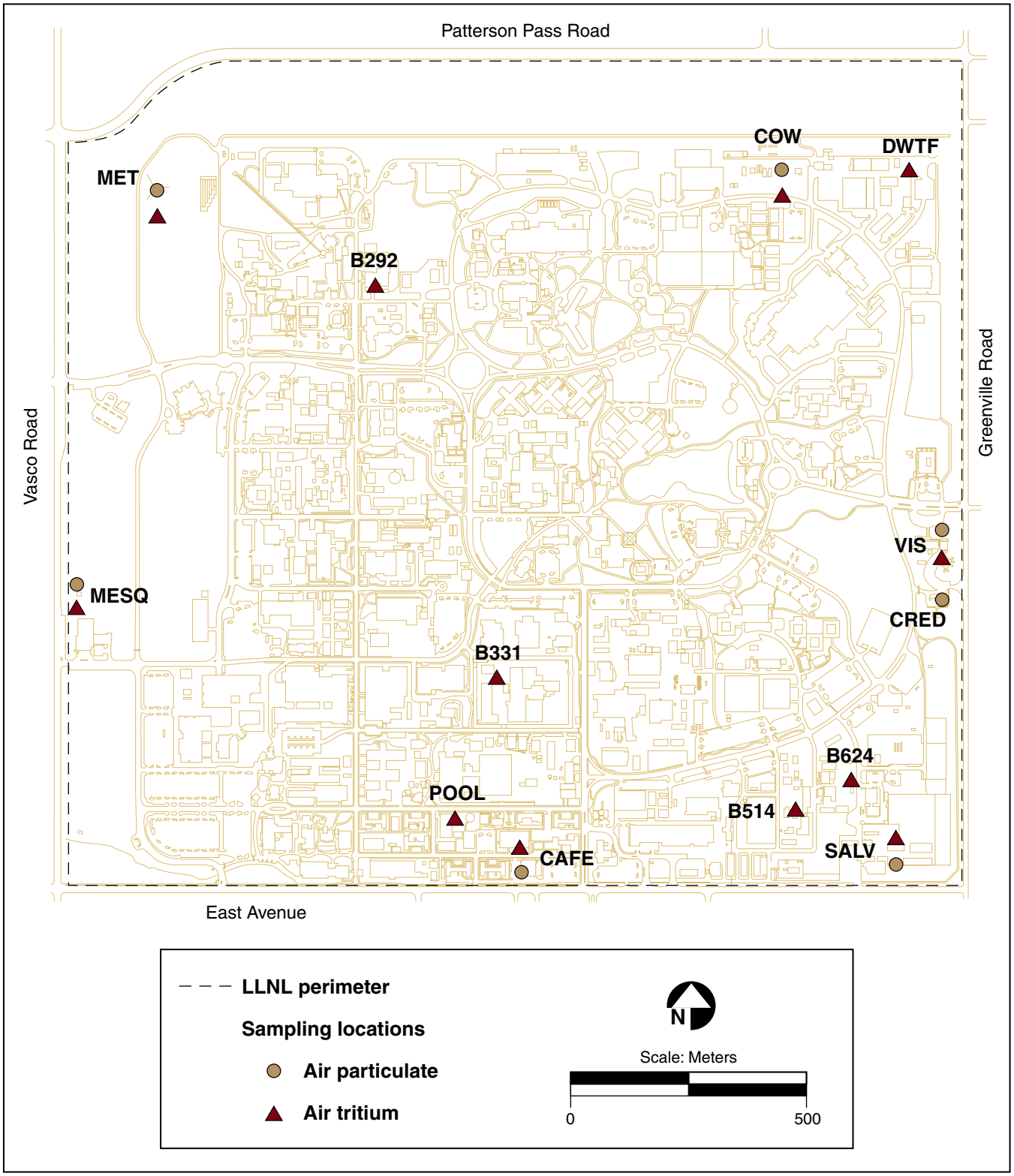

Figure 5-1. Air particulate and tritium sampling locations on the Livermore site, 2002

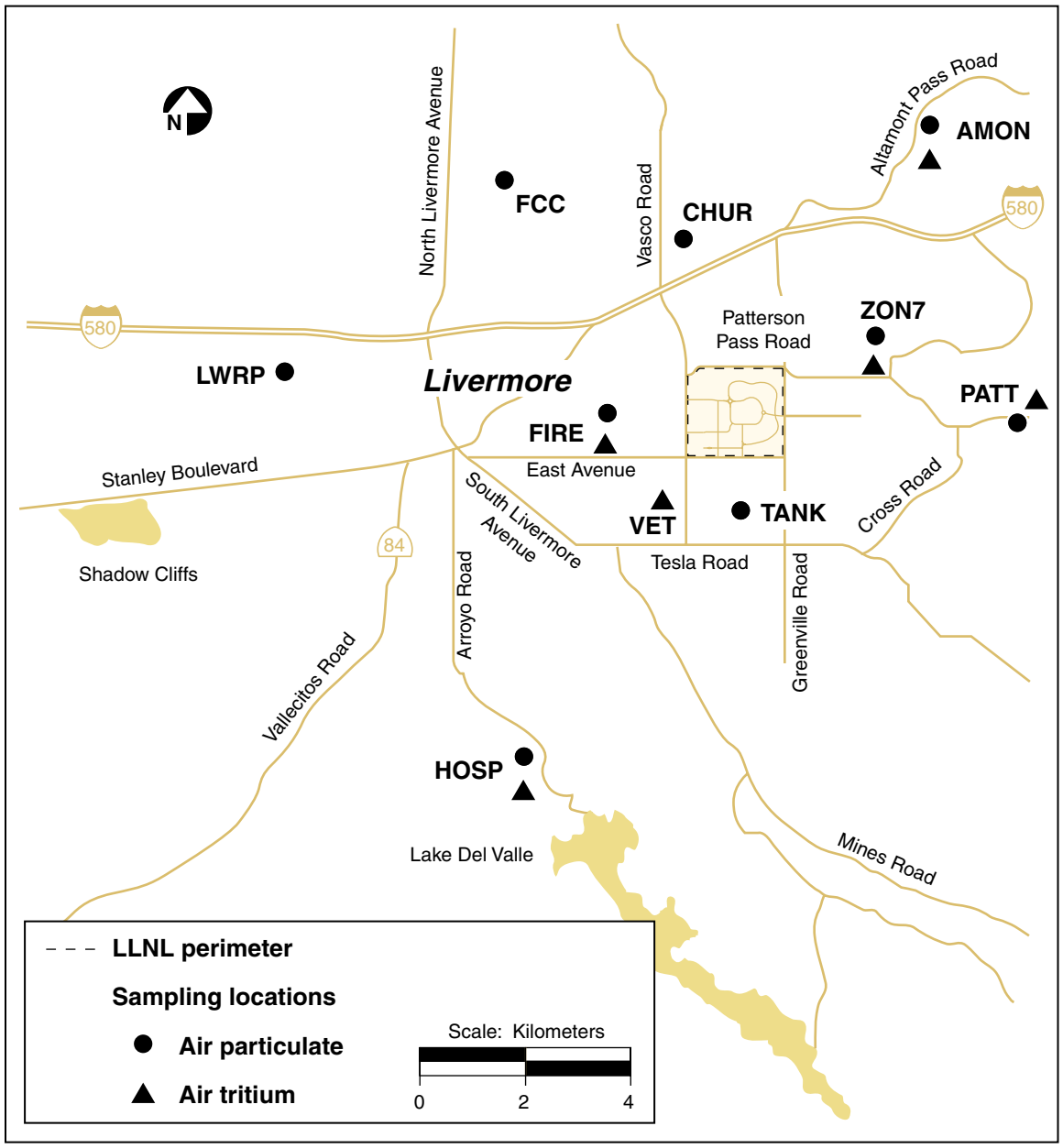

Figure 5-2. Air particulate and tritium sampling locations in the Livermore Valley, 2002

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**) to assess current activities that

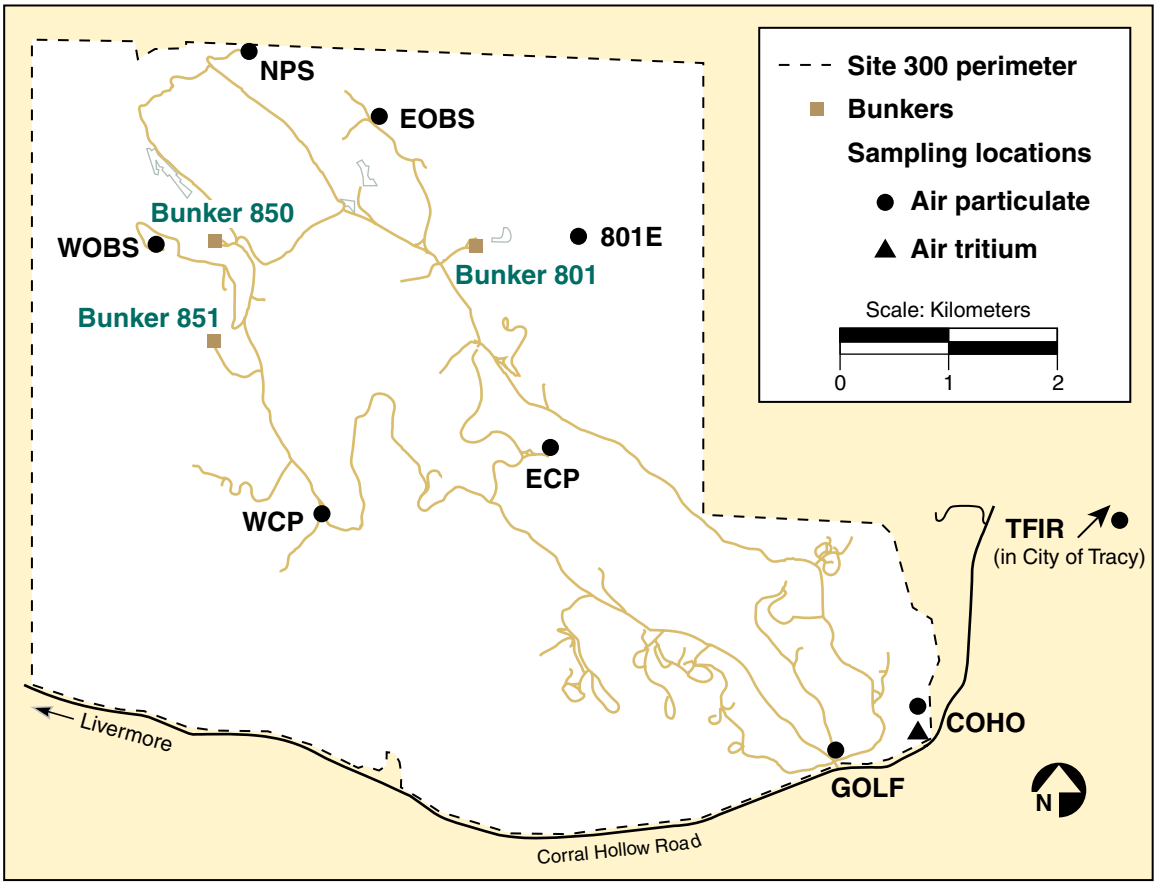

Figure 5-3. Air particulate and tritium sampling locations at Site 300 and off-site, 2002

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 isotopes by alpha spectrometry; uranium isotopes by mass spectrometry; gamma emitters by gamma spectroscopy; and tritium by liquid scintillation. 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 data table in this chapter presents the DCG and the percent of the DCG for the given isotope.

Results

This section discusses the air monitoring results from all air surveillance locations at the Livermore site, Site 300, and all off-site ambient air monitoring 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. Given this background activity and the difficulty the analytical laboratories have in digesting glass fiber filters, LLNL determined that the data had less uncertainty using cellulose than glass filters. In 2001, LLNL made a request to DOE to switch the filter medium back to cellulose. This request was granted and in January 2002 high-volume air particulate samplers were once again collecting particulate on cellulose filters.

Another significant change in 2002 involved the analysis of the filters. From January through May, the analysis was performed off site by a commercial laboratory. In June, the analysis for the high-volume air particulate filters was brought to an on-site laboratory with improved methods of detection. For all samples the counting time was extended and for uranium the method changed from alpha spectrometry to inductively coupled mass spectrometry. These changes resulted in less uncertainty and more reliable data results.

Livermore Site

Airborne Radioactivity

Figure 5-4 shows the three-year history of monthly gross alpha and gross beta median activities for the Livermore site perimeter, Livermore Valley, and Site 300 sampling locations. Detailed location results for the high-volume network for gross alpha and gross beta concentrations for 2002 are found in the Data Supplement Tables 5-1, 5-2, and 5-3 along with the summary statistics. The gross alpha and gross beta values are similar to historical values and tend to increase in September and decrease once the winters rains begin.

In 2002 the typical gross alpha activity (annual median value) for the Livermore site perimeter is 24 $\mu Bq/m^3$ (0.65 fCi/m^3); for the upwind Livermore Valley stations, the value is 54 $\mu Bq/m^3$ (1.5 fCi/m^3); and for the downwind Livermore Valley stations the value is 55 $\mu Bq/m^3$ (1.5 fCi/m^3).

The gross beta activity ranged from the lowest annual median value recorded at an onsite location (MESQ) at 288 $\mu Bq/m^3$ (7.8 fCi/m^3) to the highest median value of 409 mBq/m^3 (11 fCi/m^3) at a another Livermore site station (MET). There were two weeks where the gross beta values were significantly higher in all air particulate samples (including the low-volume network where samples are analyzed by a different laboratory). These data reflected the sampling period ending December 3 and December 10. No other isotopic data (plutonium, uranium, or gamma) increased during this

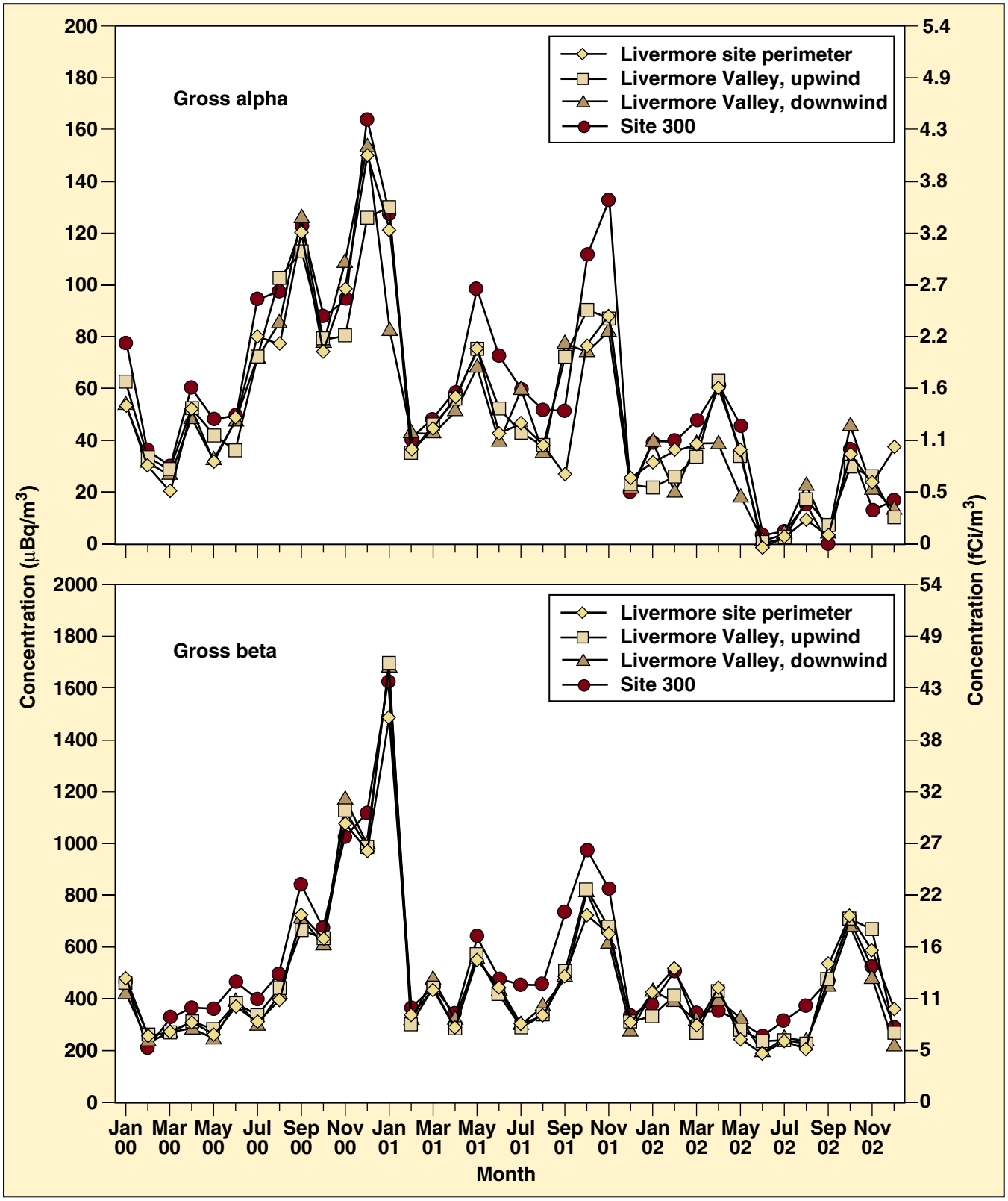

Figure 5-4. Three-year history of the median gross alpha and gross beta activities for all particulate samples grouped by area, 2000-2002

period and these occasional high values are routinely detected during winters months (see **Figure 5-4**). The trend is being investigated and is likely the result of meteorological factors.

The primary sources of the alpha and beta activities are the naturally occurring radioisotopes of uranium and thorium, primarily from resuspension from soils and any residual fallout from atmospheric weapons testing and the 1986 Chernobyl reactor accident. The high-volume 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 an environmental suite of gamma-emitting radionuclide concentrations in air. Of those isotopes, beryllium-7 and potassium-40, both naturally occurring in the environment, were consistently detected. These data are shown in **Table 5-2**. No other significant gamma isotopes were detected in the Livermore site composite samples. 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.

Table 5-4 in the Data Supplement shows the concentrations of airborne plutonium-239+240 on air filters from the Livermore site perimeter locations. Of the over 80 samples analyzed for plutonium along the perimeter in 2002, 13 showed positive detections. Of these samples, the highest value was detected during September at MET, a location along the west perimeter of the Livermore site. This value of 245 nBq/m^3 (6.6 aCi/m^3) is still only 0.033% of the DCG. The MET sample for the following month was well within the historical range for this location. The annual median plutonium activity for the perimeter locations was 6.14 nBq/m^3 (0.16 aCi/m^3) or 0.0008% of the DCG.

Table 5-5 in the Data Supplement shows the monthly plutonium-239+240 data for the Livermore Valley samples. Plutonium was detected in 13 of the 108 samples analyzed at off-site locations. The location LWRP, a special interest location due to previous localized contamination, had six of these detections with the highest overall detection of 0.17 µBq/m^3 (4.6 aCi/m^3), which is 0.0054% of the DCG. The median value for all off-site locations (excluding LWRP) was 2.1 nBq/m^3 (0.05 aCi/m^3) or 0.0002% of the DCG.

Figure 5-5 shows the monthly median plutonium-239+240 results for the Livermore site perimeter, Livermore Valley (downwind and upwind), Site 300 composite, and the special interest location (LWRP) that possessed the highest overall median for the year. There were twice as many plutonium detections in 2002 than in 2001, which is the result of the improvement in the analytical method resulting in a lower achievable detection limit in the second half of the year. The median off-site value was lower in 2002 (2.1 nBq/m^3) than in 2001 (7.5 nBq/m^3).

Figure 5-6 compares twenty years (from 1982 to 2002) of historical annual medians of plutonium-239+240 concentrations for a perimeter location (SALV) and an off-site location (FCC). The graph also plots the DCG for plutonium. Data below the detection limit are estimated activity values, meaning the values are somewhere between the reported estimated value and zero.

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

Table 5-2. Beryllium-7 and potassium-40 activity in air particulate samples for the Livermore site and Site 300 gamma composites, 2002

Month	LLNL Composite[a] (mBq/m^3)	Site 300 Composite[b] (mBq/m^3)	LLNL Composite[a] (mBq/m^3)	Site 300 Composite[b] (mBq/m^3)
	Beryllium-7		Potassium-40	
Jan	2.09 ± 0.24	2.12 ± 0.25	12.8 ± 30.3	4.3 ± 31.7
Feb	2.19 ± 0.24	2.41 ± 0.26	0.0[c]	0.0[c]
Mar	2.94 ± 0.33	2.87 ± 0.33	33.4 ± 20.8	26.2 ± 28.3
Apr	2.15 ± 0.25	2.40 ± 0.27	18.5 ± 41.9	9.6 ± 30.2
May	3.49 ± 0.40	5.61 ± 0.61	43.8 ± 29.5	13.0 ± 42.6
Jun[d]	0.44 ± 0.05	4.33 ± 0.49	2.0 ± 0.6	11.5 ± 9.5
Jul	0.99 ± 0.11	4.22 ± 0.48	<3.7	<22.6
Aug	2.76 ± 0.31	2.74 ± 0.32	11.0 ± 3.2	7.4 ± 2.9
Sep	3.09 ± 0.36	4.03 ± 0.46	18.3 ± 4.8	10.3 ± 3.4
Oct	3.32 ± 0.38	4.07 ± 0.46	7.4 ± 1.0	9.1 ± 3.2
Nov	3.63 ± 0.41	4.07 ± 0.46	11.6 ± 10.0	10.9 ± 9.2
Dec	1.86 ± 0.21	2.04 ± 0.23	7.6 ± 3.4	7.0 ± 9.8
Median	2.48	3.45	12.2	10.0
IQR[e]	1.11	1.70	10.0	3.5
Maximum	3.63	5.61	43.8	26.2
Percent of DCG	1.65×10^{-4}	2.30×10^{-4}	3.70×10^{-5}	3.02×10^{-5}
DCG (Bq/m^3)	1500		33	

Note: < sign indicates result is less than the limit of sensitivity.

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 Actual reported zero as reported by analytical laboratory

d Analytical laboratory change resulting in a longer counting time and a reduction in the uncertainty

e IQR= Interquartile range

historical activities at the Livermore site. The general downward trend at both locations is likely the result of decreasing residual global fallout.

As the result of a network assessment that was done in January 2000, Livermore site perimeter uranium analysis was changed because the activities involving uranium at the Livermore site were reduced. Instead, a composite from six perimeter locations (CAFE, COW, MESQ, MET, SALV, and VIS) is created to determine uranium activities at the Livermore site while specific locations at Site 300 receive uranium analysis. The Livermore site composite and Site 300 data are shown in **Table 5-3**. The Livermore site composite had a uranium-235 median value of 0.344 pg/m^3 which represents 0.0007% of the DCG. The uranium-238

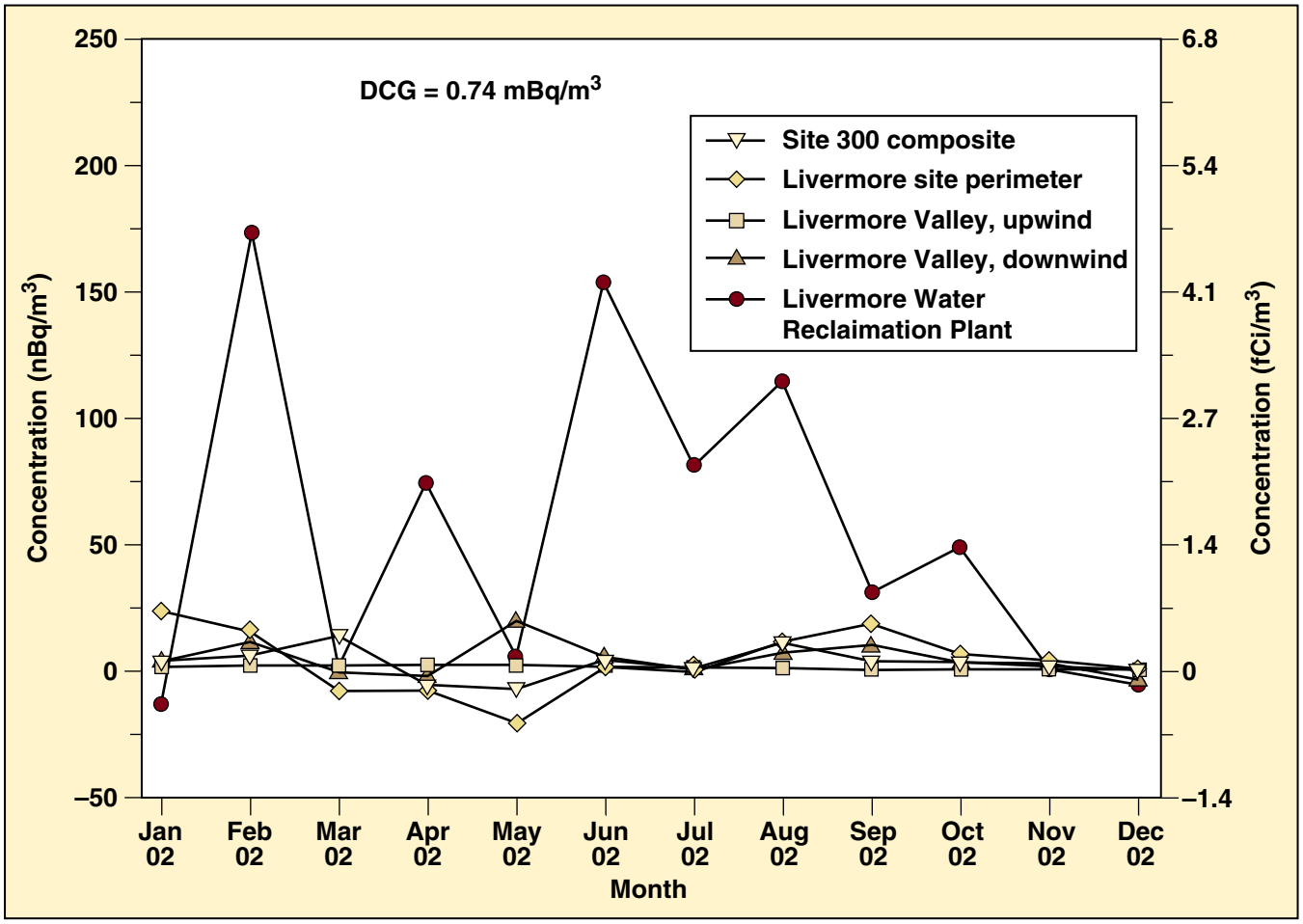

Figure 5-5. Monthly median concentrations of plutonium-239+240 in air particulate samples, 2002

median was 38.8 pg/m^3, representing 0.013% of the DCG. This composite had a median ratio (using June–December data) of 0.0080 which is slightly higher than natural background activity (0.0074).

The low-volume radiological air sampling locations FCC and HOSP have annual medians for gross alpha and gross beta activity of 85 µBq/m^3 (2.3 fCi/m^3) and 784 µBq/m^3 (21.0 fCi/m^3), respectively. (See Data Supplement Table 5-6 for monthly median data.) 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 5-15 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; B292 is near a pine tree that acts as a diffuse source of tritium because its roots are growing in water contaminated with tritium from an underground retention tank that

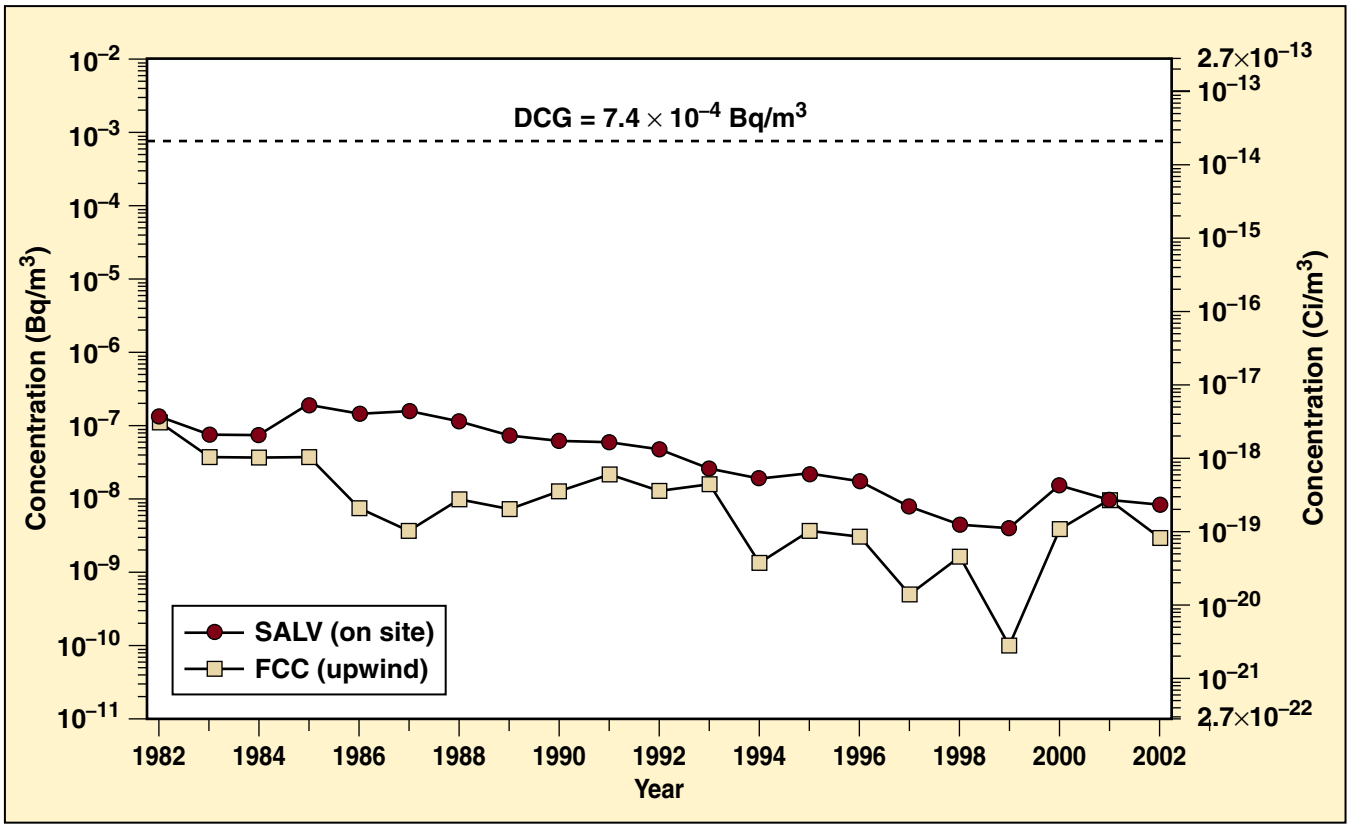

Figure 5-6. Calculated annual median concentrations of plutonium-239+240 for SALV and FCC with the DCG identified, 2002

previously leaked (see Chapter 11). Median concentrations for 2002 from all the diffuse-source samplers are comparable to those from 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 (which is 0.0026% of the DCG, calculated using the median concentration, as shown in Table 5-8, 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 2002 for all the perimeter locations are slightly more than those for 2001 except for locations MESQ and VIS. The increases correspond to higher emissions from the Tritium Facility (see Chapter 4).

Perimeter concentrations for 2002 (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 only a small impact past the perimeter fence. Sixty-nine percent of the Valley samples had concentrations indistinguishable from zero. The median concentrations for the Valley locations for 2002 are comparable to those for 2001 except for ZON7.

Table 5-3. Summary of uranium mass concentration in air samples, 2002

Location[a]	Uranium-235 (pg/m^3)[b]				Uranium-238 (pg/m^3)[c]				Median Uranium-235 to Uranium-238 ratio[d]
	Median	IQR[e]	Maximum	Percent of DCG[f]	Median	IQR[e]	Maximum	Percent of DCG[f]	
801E	0.352	0.282	1.00	0.00075	38.0	22.3	270	0.013	0.0066
COHO	0.357	0.203	0.932	0.00076	38.3	21.7	61.7	0.013	0.0072
ECP	0.239	0.201	1.11	0.00051	28.9	18.3	56.1	0.0096	0.0071
EOBS	0.260	0.463	1.05	0.00055	35.5	16.1	57.0	0.012	0.0070
GOLF	0.282	0.206	1.55	0.0006	37.5	13.4	60.9	0.012	0.0073
NPS	0.257	0.0797	0.979	0.00055	34.7	13.9	55.8	0.012	0.0073
TFIR	0.857	0.459	1.56	0.0018	90.8	69.7	178	0.030	0.0074
WCP	0.411	0.292	0.913	0.00087	33.2	10.4	155	0.011	0.0067
WOBS	0.245	0.251	1.32	0.00052	30.7	11.9	49.9	0.010	0.0072
Livermore composite	0.344	0.428	1.87	0.00073	38.8	25.8	168	0.013	0.0080

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 by the specific activity of 12,445 Bq/g.

c Uranium-238 activities in Bq/m^3 can be determined by dividing the mass by the specific activity of 80,011 Bq/g.

d Uranium 235/238 ratios median was determined from June-December data. Naturally occurring uranium has a ratio of 0.0073; values less than that indicate the presence of depleted uranium, which has a ratio of 0.002.

e IQR = Interquartile range

f Derived Concentration Guides (DCG) for activity in air are 0.3 μg/m^3 for uranium-238 and 0.047 μg/m^3 for uranium-235. Percent DCG was calculated from median value.

Table 5-4. Tritium in air samples, 2002

Sampling locations [a]	Detection frequency [b]	Median (mBq/m^3)	Interquartile range (mBq/m^3)	Maximum (mBq/m^3)	Percent of DCG [c]	Mean (mBq/m^3)	Mean Dose[d] (nSv)
Diffuse on-site sources	97/101	180	640	6600	4.9×10^{-3}	640	130
Livermore perimeter	163/197	41	44	430	1.1×10^{-3}	53	11
Livermore Valley	48/154	8.2	20	94	2.2×10^{-4}	11	2.3
Site 300	4/25	0.24	17	38	6.5×10^{-6}	0.70	0.15

a See **Figures 5-1**, **5-2,** and **5-3** for sample locations.

b Detection frequency is shown as the number of samples with measured concentrations greater than their associated uncertainty relative to the total number of samples.

c DCG = Derived Concentration Guide of 3.7 x 10^6 mBq/m^3 for tritium in air. Percent is calculated from the median concentration.

d Dose is calculated for inhalation and skin absorption (see Appendix C).

Beryllium in Air

The median concentrations of airborne beryllium for the Livermore site, Site 300, and the downtown Tracy sampling locations are plotted in **Figure 5-7**. (See Data Supplement Table 5-10 for monthly data.) The highest value at the Livermore site was 27.8 pg/m^3 which was recorded at location COW in October. This value is only 0.28% of the Bay Area Air Quality Management District ambient concentration limit for beryllium (10,000 pg/m^3). All data were similar to data collected from previous years.

Figure 5-8 is a plot of the median beryllium concentration at the Livermore site perimeter from 1975 through 2002. The decrease in median concentration in 1993 and the slight increase in 1999 were likely the result of a change in the analytical laboratory used to perform this analysis.

Site 300

Airborne Radioactivity

Table 5-11 in the Data Supplement shows the weekly gross alpha and gross beta values as well as the median, interquartile range (IQR), and maximum for sampling locations at Site 300. 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 a greater 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. In 2002 the median gross alpha activity is 23.8 µBq/m^3 (0.64 fCi/m^3); the median gross beta activity is 3.8 mBq/m^3 (0.10 pCi/m^3). 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.

Like the Livermore site perimeter samples, the monthly Site 300 composite samples are scanned for an environmental suite of gamma-emitting nuclides, and only beryllium-7 and potassium-40 were 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 and potassium-40 from Site 300.

The monthly median value for beryllium-7 from Site 300 composites was 3.5 mBq/m^3 (94.5 fBq/m^3). There were a few detections for cesium-137 at Site 300, all very close to the detection limit, with the highest concentration detected at 1.5 µBq/m^3 (0.04 aCi/m^3). This value is 0.00001% of the DCG. Cesium is periodically detected in air samples at Site 300 and is the result of resuspension from cesium in the soils. (See Chapter 10 for annual soil data). Cesium is a product of global fallout and fallout resuspension.

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 (and the only positive detection) of plutonium-239+240 was recorded in the August composite at a level of 10.4 nBq/m^3 (0.28 aCi/m^3). The median value for plutonium 239+240 at Site 300 represented less than 0.0005% of the DCG.

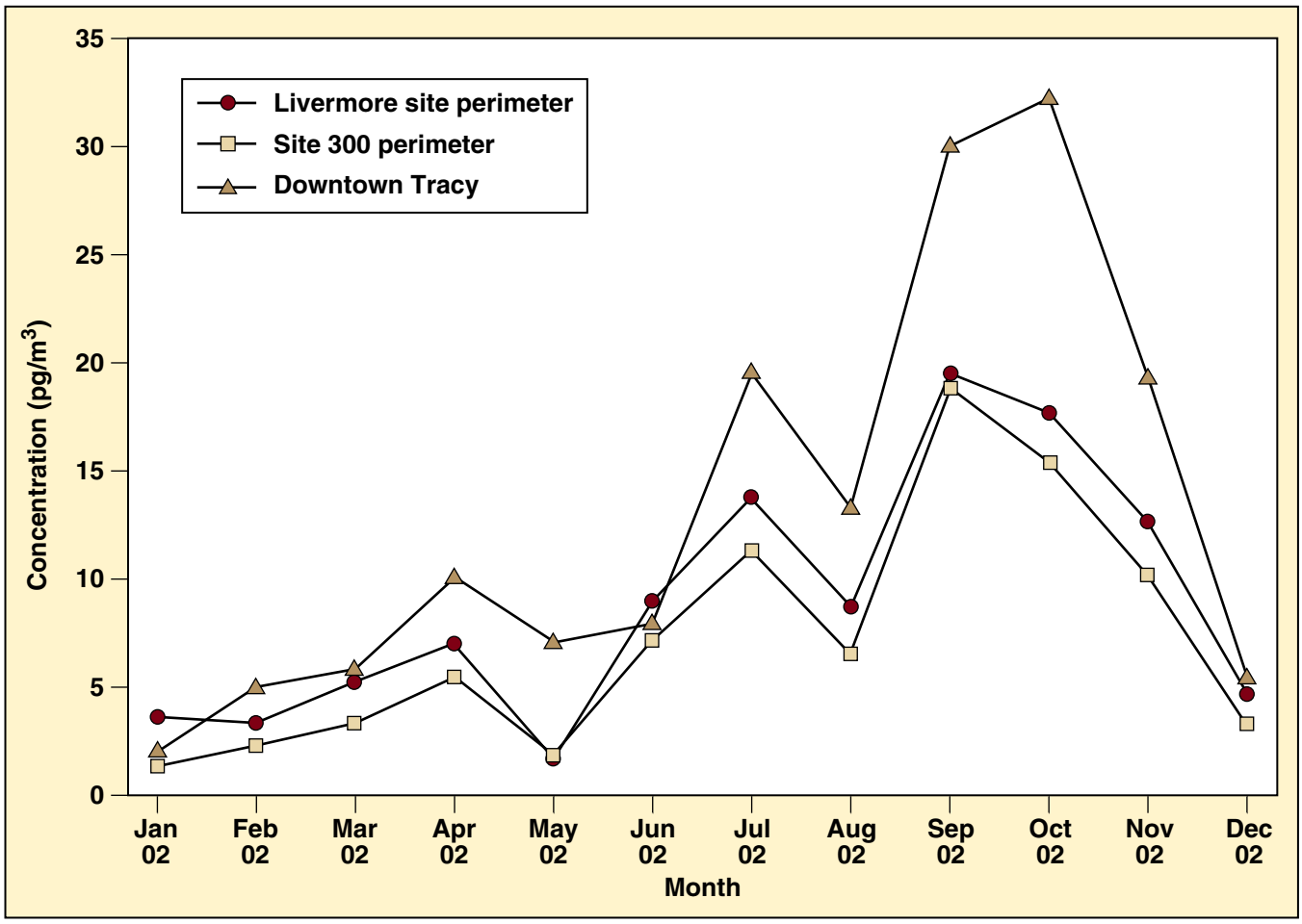

Figure 5-7. Monthly median concentration of beryllium in air particulate samples from the Livermore site perimeter, Site 300, and Tracy, 2002

Table 5-3 shows the summarized data for uranium-235 and uranium-238 for all the air samples. (See Data Supplement Table 5-13 for monthly data.) The highest median concentration were reported at TFIR. These were 0.86 pg/m^3 for uranium-235 and 91 pg/m^3 for uranium-238, which represent less than 0.03% of the DCG for both isotopes. The analytical change implemented in June 2002 resulted in lower uncertainty for these data making the uranium-235 to uranium-238 ratios a useful tool. Site 300 uranium ratios displayed typical natural background ratios at 0.007 uranium-235 to uranium-238.

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.

Beryllium in Air

The monthly median beryllium concentrations for Site 300 are shown in **Figure 5-7** with the Livermore site perimeter locations. (See Data Supplement Table 5-15 for monthly data.) The highest value in **Figure 5-7** of 32.3 pg/m^3 was

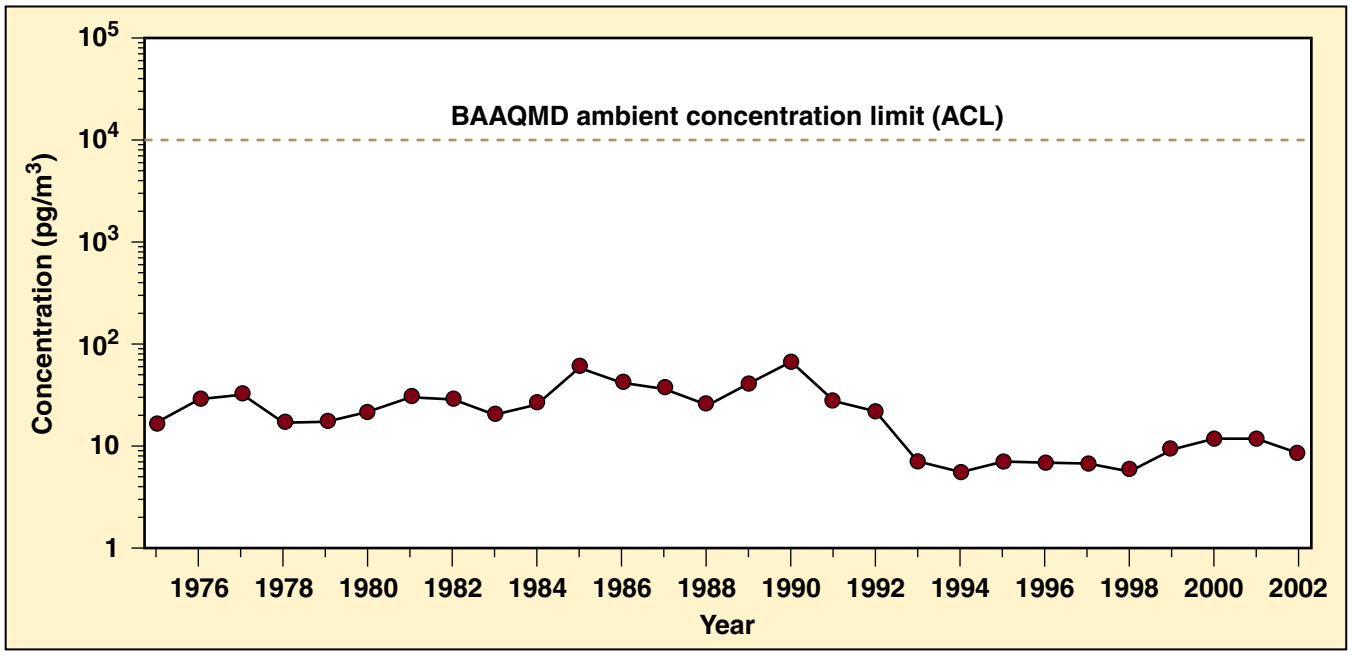

Figure 5-8. Median concentration of beryllium in air particulate samples taken at the Livermore site perimeter, 1975–2002

found in the October sample at TFIR. The concentration at this location is typically higher than at all other locations because it is located in a congested part of town and accumulates a greater amount of industrial particulate pollutants. This sample was still far below the ambient concentration limit of 10,000 pg/m^3.

Environmental Impact

Radioactive Materials

LLNL operations involving radioactive materials had little impact on radionuclide concentrations in ambient air during 2002. Radionuclide particulate 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 were generally slightly greater in 2002 than in 2001, which correlates well with increased stack emissions in the later part of 2002. The increased tritium concentrations observed at the Livermore site perimeter had minimal impact on off-site concentrations.

A maximum dose of 89 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 concentration (430 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 0.089% of NESHAPs standard of 0.1 mSv/y arising as a result of releases of radionuclides to air from DOE facilities.

Nonradioactive Materials

The concentrations of beryllium at both the Livermore site and Site 300 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 μg/m^3 of particulates. Using a value of 50 μg/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 average for the Livermore site and Site 300 (including TFIR location in Tracy) are 9.6 pg/m^3 and 9.0 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.

6

Sewerable Water Monitoring

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Introduction

In 2002, the Livermore site discharged an average of 0.91 million liters (ML) per day of wastewater to the City of Livermore sewer system, an amount that constituted 4.1% of the total flow to the system. This volume includes wastewater generated by Sandia National Laboratories/California (Sandia/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 2002, Sandia/California generated approximately 9.2% 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 (approximately 10%) of this treated wastewater is kept 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.

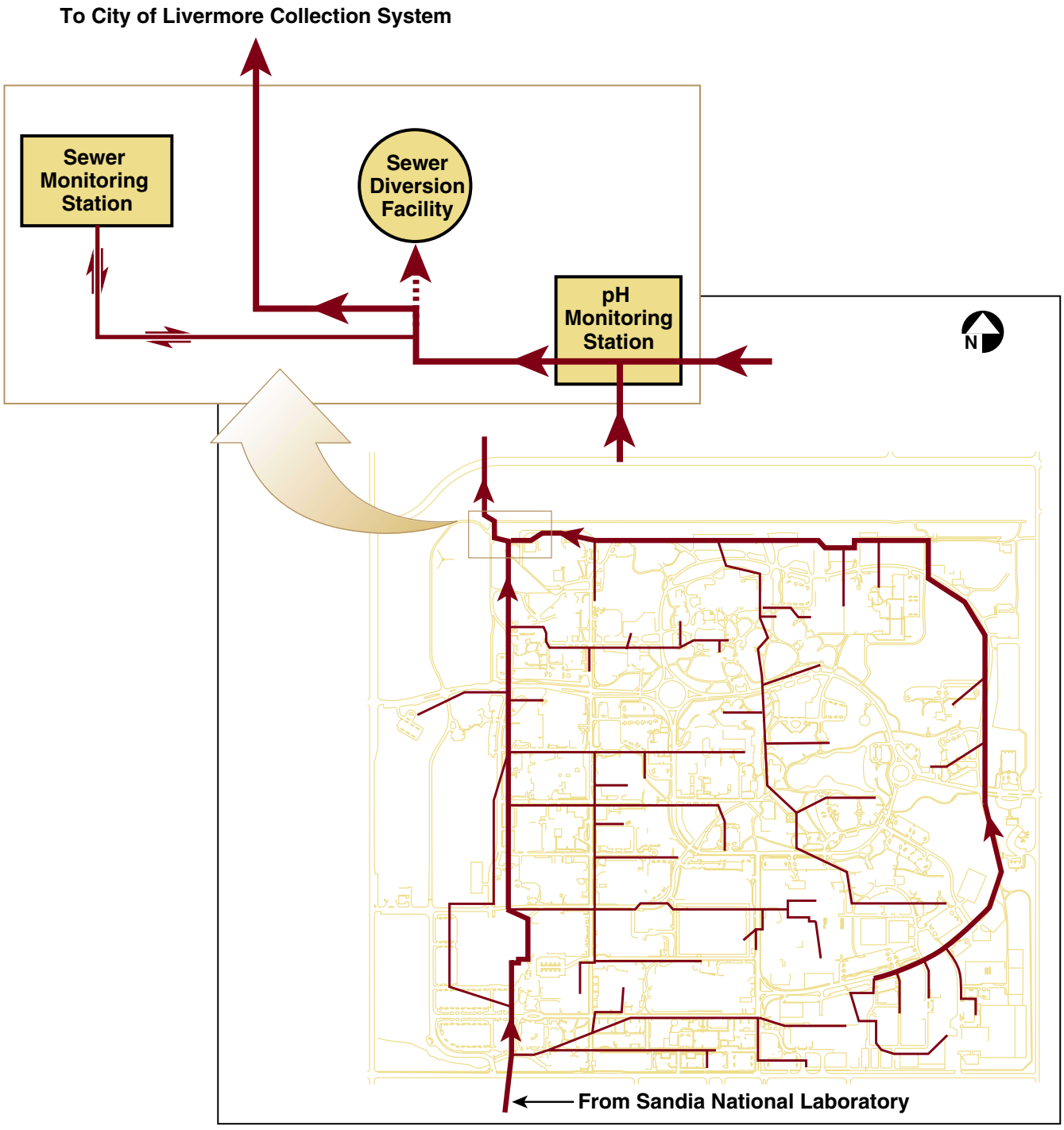


Figure 6-1. LLNL sanitary sewer system, monitoring stations, and diversion facility

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 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 permit 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 as defined in the *ES&H Manual*, Document 32.4 (LLNL 2002). 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 2002, there were approximately 33 waste retention tank systems in use at the Livermore site.

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 requirements as applied at the point of discharge into the LLNL sewer.

If pollutant levels exceed concentrations that would result in a violation of 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 the LWRP 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 at the Sewer Monitoring Station (SMS). 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 LLNL 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 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 permit range of 5 to 10 to the SDF. The pHMS duplicates the pH monitoring and diversion capabilities of the SMS but is able to initiate diversion earlier because it is located upstream of the SDF. 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 Radioactive and Hazardous Waste Management (RHWM) facilities. All the diverted sewage in 2002 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 Code of Federal Regulations [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 2002-2003 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 parameters in LLNL wastewaters

Parameter	Permit discharge limits			
	Permit 1250			Permit 1510G
	SMS[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	3.00	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]
pH (pH units)	5–10	—[c]	—[c]	5–10

a These standards apply at the Sewer Monitoring Station (SMS) (the point of discharge to the municipal sewer).

b Values shown for these categorical standards were specified by Environmental Protection Agency (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.

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

LLNL received only one Letter of Warning from the LWRP for a permit infraction in 2002. The only effluent discharge limit for wastewater that was exceeded was the discharge limit for lead.

Categorical Discharges

The U.S. 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 2002, the LWRP identified 15 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 15 identified processes meet these criteria. In 2002, LLNL analyzed samples for all regulated parameters from these three processes and demonstrated compliance with all Federal Categorical Discharge limits.

One 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.

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.

Other processes that do not discharge to the sanitary sewer but would otherwise be regulated under the Metal-Finishing Point Source Category include printed circuit board manufacturing, electrolysis plating, chemical etching, electroplating, anodizing, coating, electrical discharge machining, and abrasive jet machining. The wastewater from these processes was contained for removal and off-site shipment by LLNL's RHWM Division.

Discharges of Treated Groundwater

LLNL's groundwater discharge permit (1510G 2001/2002) allows treated groundwater from site-wide cleanup activities under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) 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 calendar year 2002, however, no LLNL groundwater, treated under CERCLA activities, was discharged to the sanitary sewer.

Radioactive Pollutants in Sewage

Monitoring Results

LLNL determines the total radioactivity released from tritium, gross alpha emitters, and gross beta emitters based on the measured radioactivity in the monthly effluent samples (see **Table 6-2**). The 2002 combined releases of alpha and beta sources was 0.155 GBq (0.0042 Ci). The combined total is based on the alpha and beta results shown in **Table 6-2**. The tritium total was 0.74 GBq (0.02 Ci), and the annual mean concentration of tritium in LLNL sanitary sewer effluent based on monthly samples was 0.0025 Bq/mL (0.068 pCi/mL). Summary results for tritium measured in the sanitary sewer effluent from LLNL and LWRP are presented in **Table 6-3**.

Table 6-2. Estimated total radioactivity in LLNL sanitary sewer effluent, 2002

Radioactive emitter	Estimate based on effluent activity (GBq)[a]	Limit of sensitivity (GBq)
Tritium	0.74	0.84
Gross alpha sources	0.005	0.049
Gross beta sources	0.15	0.067

a 37 GBq = 3.7×10^{10} Bq = 1 Ci

Summary statistics for tritium measured in the sanitary sewer effluent from LLNL and LWRP are presented in **Table 6-3**.

The monthly tritium concentrations are based on the flow-weighted average of the monthly sample results for a given month. The total monthly activity is based on the multiplication of each monthly concentration by the total flow volume over which the sample was collected. The total annual activity is the sum of the monthly activities. (All total annual results presented in this chapter for radioactive emitters are calculated by using the analysis results regardless of whether they were above or below the detection limit.)

The historical trend in the monthly concentration of tritium is shown in **Figure 6-2** (before 2002, the figure shows the calculated monthly average). 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. Note that in 2002 the LOS values are approimately 4 times lower than previous years due to an improved analytical technique. The trend indicates a well-controlled tritium discharge, orders of magnitude below the DOE tritium limit.

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 bottom of the table, the total annual activity released is given by radioisotope.

Figure 6-3 shows the average monthly plutonium and cesium concentrations in sewage since 1993. For 2002, the annual mean concentration of cesium-137 was 8.5×10^{-7} Bq/mL (2.3×10^{-5} pCi/mL); the annual mean concentration of plutonium-239 was 1.3×10^{-7} Bq/mL (3.5×10^{-6} pCi/mL).

Environmental Impact

During 2002, no inadvertent discharges exceeded any discharge limits for release of radioactive materials to the sanitary sewer system.

Table 6-3. Summary statistics of tritium in sanitary sewer effluents, LLNL and LWRP, 2002

Monitoring results			
	LLNL		LWRP
	Daily	Monthly	Monthly
Maximum (Bq/mL)	0.069 ± 0.008[a]	0.010[b]	0.0017[c]
Median (Bq/mL)	0.0009	0.002	0.0004
IQR[d] (Bq/mL)	0.004	0.001	0.001
LLNL annual total (GBq)	0.74		
Discharge limits for LLNL effluent			
	Discharge limit	Monitoring results as percentage of limit	
		Maximum	Median
LWRP permit daily (Bq/mL)	12	0.58%	0.008%
DOE 5400.5 monthly (DCG)[e] (Bq/mL)	370	0.003%[f]	0.0005%[f]
10 CFR 20 annual total (GBq)	185	0.4%	

a This daily result is for a December sample. See the Data Supplement, Chapter 6, for all daily results.

b This is the monthly value is for December. All monthly values above limit of sensitivity (LOS) are plotted in **Figure 6-2.**

c This is a monthly result for a December sample. The result was not above the detection limit for the analysis. None of the LWRP monthly 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.) See the Data Supplement, Chapter 6, for all monthly results.

d IQR = Interquartile range

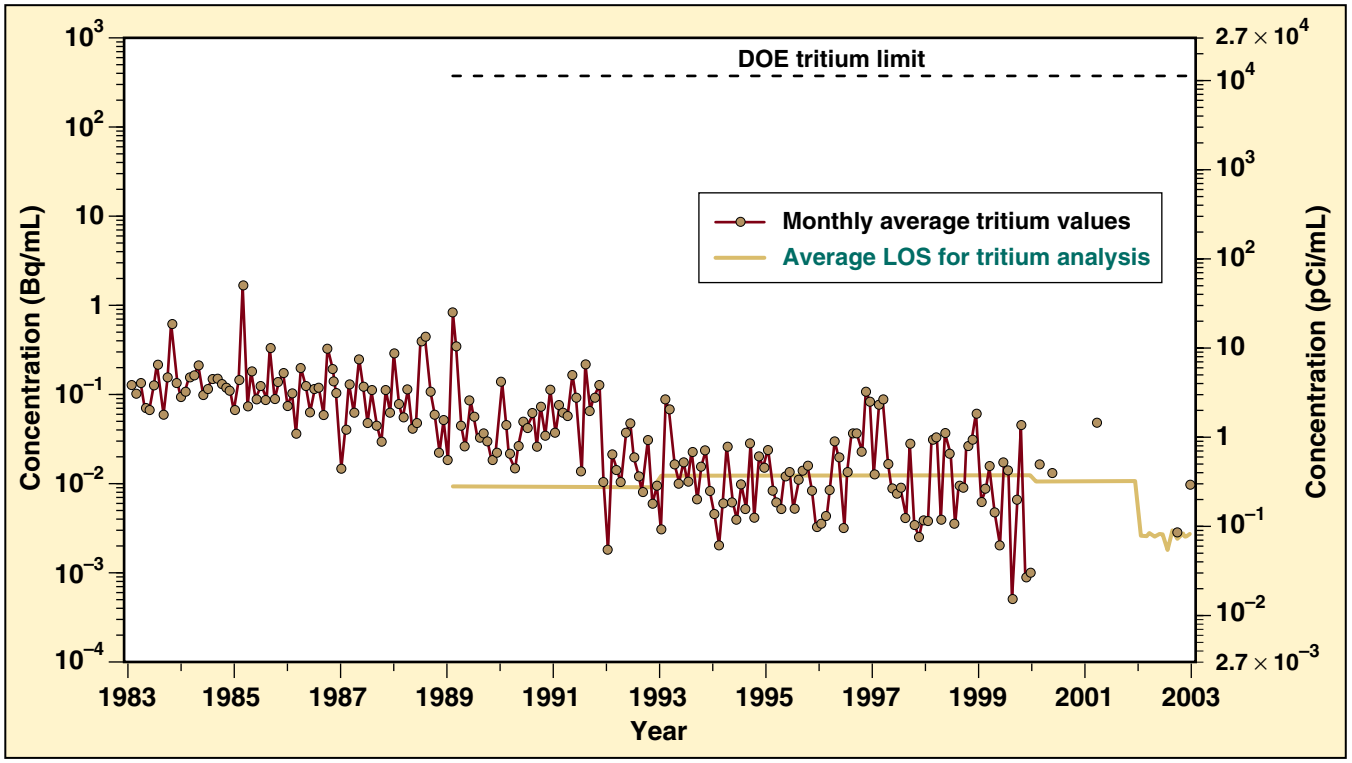
e DCG = Derived Concentration Guide

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

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 overlapping) sections from DOE Order 5400.5 and 10 CFR 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 with potential to be in the sanitary sewer effluent at LLNL.

The median monthly concentration of tritium in LLNL sanitary sewer effluent was 0.0005% of the DOE DCG, and the maximum monthly average concentration of tritium was 0.003% of the DCG (see **Table 6-3**).



Note: Only values above the LOS are plotted for 2000–2002.

Figure 6-2. Historical trend in tritium concentration in LLNL sanitary sewer effluent

The annual total discharge of cesium-137 was 0.0023% of the DOE DCG; and the annual average plutonium-239 concentration was 0.00034% of the DOE DCG. These results are shown at the bottom of **Table 6-4**.

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 2002, the total LLNL tritium release was 0.4% of the 10 CFR 20 limit. Total LLNL releases (see **Table 6-2**), in the form of alpha and beta emitters (excluding tritium), were 0.083% 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

Table 6-4. Cesium and plutonium in sanitary sewer effluents, LLNL and LWRP, 2002

Month	Cesium-137 (μBq/mL)				Plutonium-239 (nBq/mL)			
	LLNL		LWRP		LLNL		LWRP	
	Radio–activity	MDC	Radio-activity	MDC	Radio-activity	MDC	Radio-activity	MDC
Jan	0.253 ± 3.92	3.46	0.655 ± 3.47	3.1	173 ± 26.4	5.99	0.607 ± 2.72	5.4
Feb	5.07 ± 4.29	4.03	0.488 ± 3.81	3.39	126 ± 21.9	2.98	–1.1 ± 2.67	6.99
Mar	–1.57 ± 4.14	3.57	0.000603 ± 3.44	3.05	82.1 ± 19.9	7.77	–1.11 ± 1.28	5.48
Apr	1.95 ± 3.74	3.39	2.86 ± 3.74	3.45	74 ± 19.4	4.07	–0.881 ± 3.24	8.44
May	0.138 ± 3.81	3.37	2.31 ± 4.11	2.54	156 ± 26.1	6.51	0.223 ± 2.58	5.33
Jun	0.463 ± 4.11	3.67	0.169 ± 3.2	2.84	40.7 ± 15.4	8.07	1.67 ± 3.17	5
Jul	2.83 ± 4.03	2.15	1.3 ± 4.03	3.64	365 ± 43.7	8.7	1.08 ± 3.23	5.88
Aug	2.64 ± 6.99	3.01	3.05 ± 3.52	3.28	114 ± 20.7	2.96	1.68 ± 2.88	4.55
Sep	–0.574 ± 4.14	3.62	–2.57 ± 3.43	2.84	88.1 ± 19.2	3.33	1.2 ± 2.26	3.89
Oct	1.59 ± 3.81	3.46	2.16 ± 3.34	3.07	181 ± 30.4	3.96	2.57 ± 4	5.74
Nov	–0.433 ± 3.6	3.16	0.895 ± 3.16	2.85	42.2 ± 15.8	7.22	5.22 ± 4.59	4.88
Dec	–2.11 ± 3.62	3.05	–1.14 ± 3.44	2.96	67.7 ± 15.8	6.88	0.685 ± 2.61	5.85
Median	0.36		0.78		101		0.88	
IQR[a]	2.76		2.11		68.6		1.73	
	pCi/mL[b]							
Median	9.7×10^{-6}		2.1×10^{-5}		2.7×10^{-6}		2.4×10^{-8}	
IQR[a]	7.5×10^{-5}		5.7×10^{-5}		1.9×10^{-6}		4.7×10^{-8}	
	Annual LLNL total discharges by radioisotope							
	Cesium-137				Plutonium-239			
Bq/y	2.8×10^{6}				4.2×10^{5}			
Ci/y	1.0×10^{-7}				1.5×10^{-8}			
	Fraction of limit[c]							
DOE 5400.5 DCG[d]	2.3×10^{-5}				3.4×10^{-6}			

Table 6-4. Cesium and plutonium in sanitary sewer effluents, LLNL, and LWRP, 2002 (continued)

Month	Cesium-137 (mBq/dry g)		Plutonium-239 (mBq/dry g)	
	LWRP Sludge[e]			
	Radioactivity	MDC	Radioactivity	MDC
Mar	–0.286 ± 1.18	1.02	0.227 ± 0.0297	0.00529
Jun	0.659 ± 0.759	1.02	0.11 ± 0.0173	0.00562
Sep	0 ± 0	0.955	0.215 ± 0.0231	0.00426
Dec	0.466 ± 1.08	0.662	1.85 ± 0.125	0.00781
Median	0.23		0.22	
IQR[a]	0.59		0.44	
	pCi/mL[b]			
Median	6.3×10^{-3}		6.0×10^{-3}	
IQR[a]	1.6×10^{-2}		1.2×10^{-2}	

Note: Results in this table are reported as radioactivity (the measured concentration and a ± 2σ 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 IQR= Interquartile range

b 1 Ci = 3.7×10^{10} Bq

c 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.

d DCG = Derived Concentration Guide

e 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.

tritium in 2002 was 0.58% of the permit discharge limit. **Table 6-3** shows this result and the daily effluent discharge limit for tritium. The 2002 values are lower than the 2001 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 2002, a total of 0.74 GBq (0.03 Ci) of tritium was discharged to the sanitary sewer, an amount that is well within environmental protection standards and is comparable to the amounts discharged over the past 10 years.

Figure 6-3 summarizes the plutonium-239 monitoring data over the past 10 years. The historical levels observed since 1993 average approximately 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 plutonium discharged in LLNL effluent is ultimately concentrated in LWRP sludge. The median plutonium concentration observed in 2002 sludge (**Table 6-4**), 0.22 mBq/dry g, is approximately 420 times lower than the EPA

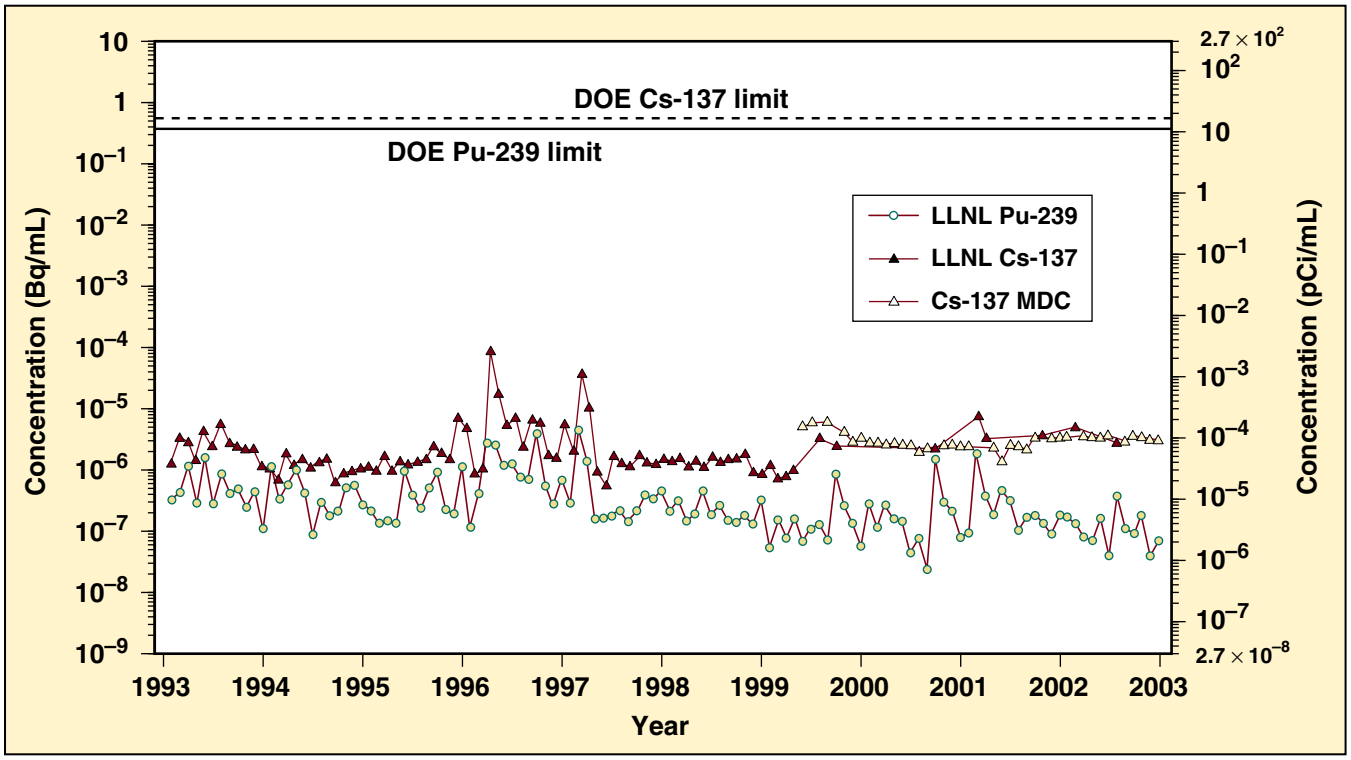


Figure 6-3. Historical trends in average monthly plutonium and cesium concentrations in LLNL sanitary sewer effluent

preliminary remediation goal for residential soil (93 mBq/dry g) and is nearly 1700 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 2002 are comparable to the lowest values seen historically, and are well below the applicable DOE DCGs. (Note that because minimum detectable concentration [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 2002. The averages were

Table 6-5. Radioactive liquid effluent releases from the Livermore site, 1993–2002

Year	Liquid effluent (GBq)	
	Tritium	Plutonium-239
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}
2002	0.74	4.2×10^{-5}

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.

obtained by a flow-proportional weighting of the analytical results for the weekly composite samples collected each month. Each result was weighted by the total flow volume for the period during which the sample was collected. The results for 2002 are generally typical of the values seen from 1994 to 2001, and median concentrations for the nine regulated metals remained at or near their respective values reported last year.

Figure 6-4 presents historical trends for the monthly 24-hour composite sample results from 1994 through 2002 for eight of the nine regulated metals; cadmium is not presented because this metal is typically not detected. All of the monthly 24-hour composite samples were in compliance with the permit discharge limits for the SMS (**Table 6-1**). As noted in both 2000 and 2001, arsenic continues to show an occasional elevated concentration, although it never exceeds 20% of the effluent pollutant limit (EPL). Both silver and lead each exhibit a single elevated monthly concentration during calendar year 2002; but neither exceed 50% of their respective EPLs. The other metals have no discernible trends in their concentrations.

The concentrations measured in the routine analysis of LLNL's 2002 sewage samples, collected once a week (seven-day composite sample) and once a month (24-hour composite sample), are presented in **Figure 6-5** for eight of nine regulated metals as a percentage of the corresponding EPL; cadmium results are not presented because the metal was not detected above the practical quantitation limit (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. The two elevated monthly concentrations discussed above, silver at 50% of its EPL in April and lead at 30% of its EPL in August, are shown in **Figure 6-5**. In addition, a total of five weekly concentrations values (**Figure 6-5**) are at or above 50% of their respective EPLs.

The elevated arsenic values, reported at 67% of the EPL for the weeks of June 5–12 and June 12–17, can be attributed to an analytical artifact resulting from matrix interference. As shown in Data Supplement Table 6-5, the actual arsenic concentrations for these two weeks were reported as <0.04 mg/L, a factor of twenty greater than the typical PQL for arsenic of 0.002 mg/L. The three remaining weekly sample concentration values (one chromium and two lead) at or above the specified action level, shown in **Figure 6-5**, are discussed further in the "Environmental Impact" section.

Table 6-6. Monthly average results for regulated metals in LLNL sanitary sewer effluent (mg/L), 2002

Month	Ag	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Jan	<0.010	0.0029	<0.0050	0.015	0.14	0.00045	0.0057	0.016	0.39
Feb	0.017	0.0042	<0.0050	0.019	0.13	0.00041	0.0063	0.014	0.29
Mar	0.011	0.0022	<0.0050	0.011	0.12	0.00025	0.0051	0.012	0.27
Apr	0.011	0.0027	<0.0050	0.012	0.15	0.00033	<0.0050	0.013	0.30
May	0.012	0.0030	<0.0050	0.016	0.15	0.00027	0.0051	0.024	0.28
Jun	<0.010	0.021	<0.0050	0.020	0.22	<0.00028	0.0058	0.026	0.39
Jul	<0.010	0.0076	<0.0050	0.040	0.24	0.00026	0.0084	0.026	0.41
Aug	0.014	0.0082	<0.0050	0.11	0.24	0.00034	0.0085	0.045	0.42
Sep	0.013	0.0058	<0.0050	0.021	0.20	0.00042	0.0083	0.020	0.38
Oct	0.022	0.0040	<0.0050	0.021	0.19	0.00060	0.0095	0.033	0.38
Nov	0.019	0.0034	<0.0050	0.017	0.18	0.00036	0.0079	0.062	0.42
Dec	0.011	0.0035	<0.0050	0.015	0.11	0.00034	0.0077	0.015	0.34
Median	0.012	0.0038	<0.0050	0.018	0.17	0.00034	0.0070	0.022	0.38
IQR[a]	0.0039	0.0033	—[b]	0.0058	0.063	0.00013	0.0027	0.013	0.10
EPL[c]	0.20	0.06	0.14	0.62	1.0	0.01	0.61	0.20	3.00
Median fraction of EPL	0.06	0.06	<0.04	0.03	0.17	0.03	0.01	0.11	0.13

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 cadmium. See Chapter 14.

c Effluent pollutant limit (LLNL Wastewater Discharge Permit 2001–2002 and 2002–2003)

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 hydroxide alkalinity (as $CaCO_3$), beryllium, and cadmium, these analytes were not detected in any sample acquired during 2002, and so are not presented in **Table 6-7**. Similarly, analytes not detected in any of the 2002 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 2002 median concentration for each metal is shown and compared with the discharge limit. In 2002, the monthly average median concentration values remained essentially unchanged from the corresponding 2001 values for all nine regulated metals. These results are

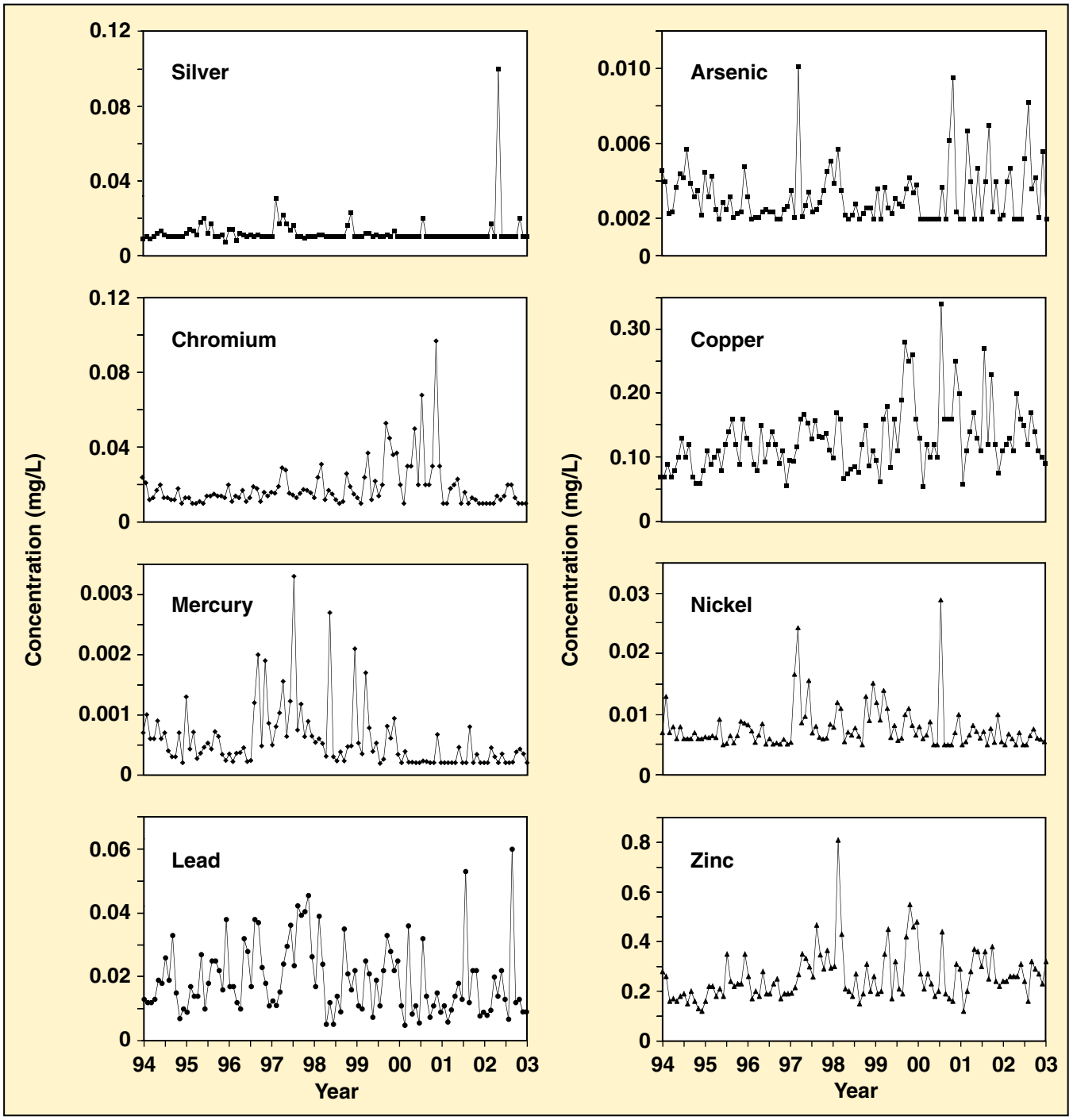


Figure 6-4. Monthly 24-hour composite sample concentrations for eight of the nine regulated metals in LLNL sanitary sewer effluent showing trends from 1994 through 2002

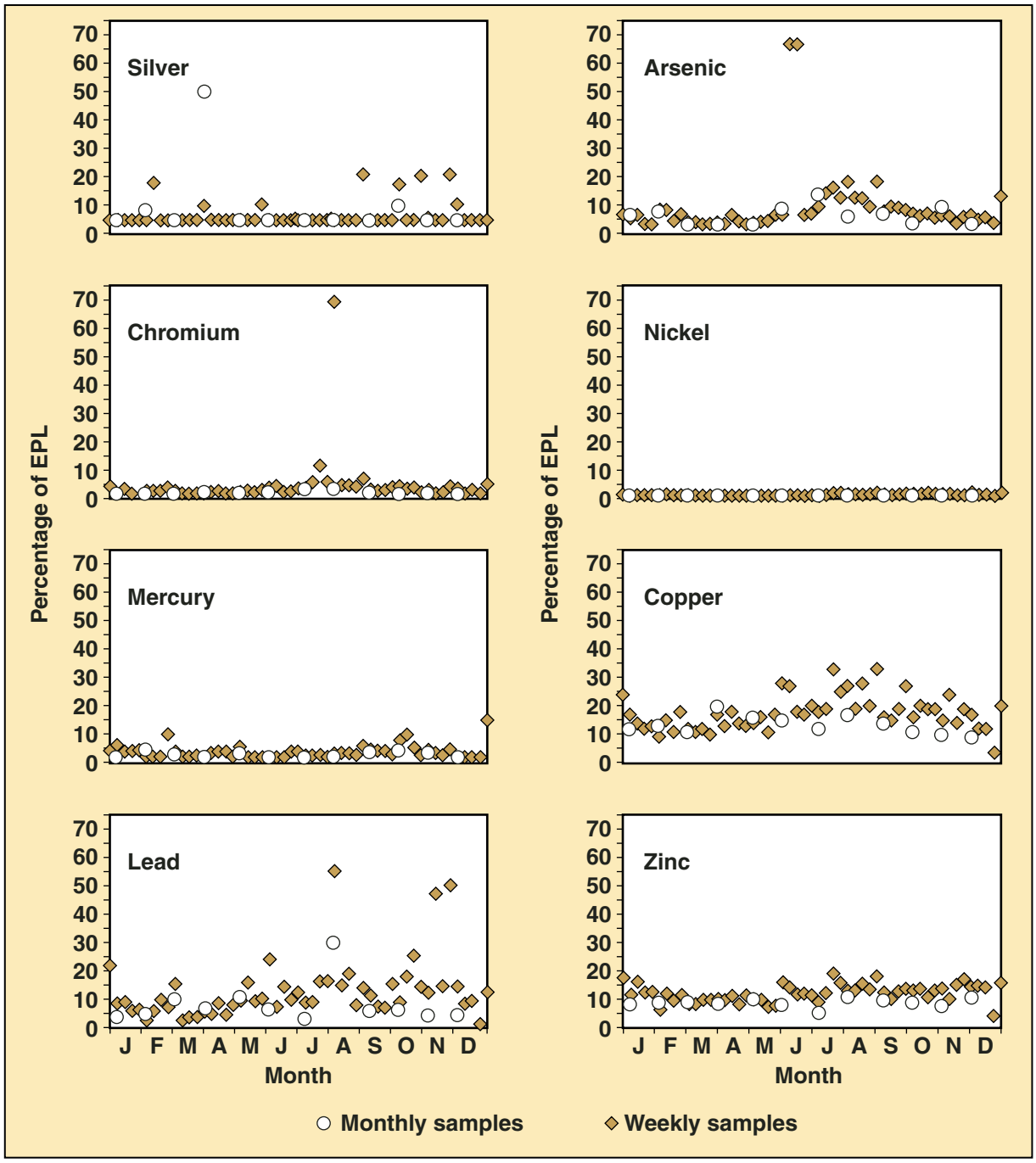


Figure 6-5. Results as percentages of effluent pollutant limits (EPLs) for eight of the nine regulated metals in LLNL sewage, 2002

Table 6-7. Monthly monitoring results for physical and chemical characteristics of the LLNL sanitary sewer effluent, 2002[a]

Parameter	Detection frequency[b]	Minimum	Maximum	Median	IQR[c]
24-hour composite sample parameter (mg/L)					
Alkalinity (mg/L)					
Bicarbonate alkalinity (as $CaCO_3$)	12 of 12	175	300	250	24.0
Carbonate alkalinity (as $CaCO_3$)	2 of 12	<5	55.0	<5	—[d]
Total alkalinity (as $CaCO_3$)	12 of 12	230	300	250	22.5
Anions (mg/L)					
Bromide	10 of 12	<0.1	1.1	0.25	—[d]
Chloride	12 of 12	41	114	61	28
Fluoride	10 of 12	<0.05	2.3	0.11	0.16
Nitrate (as N)	1 of 12	<0.1	<1	<0.44	—[d]
Nitrate (as NO_3)	1 of 12	<0.4	<4.4	<4.4	—[d]
Nitrate plus Nitrite (as N)	2 of 12	<0.1	<1	<1	—[d]
Nitrite (as N)	8 of 12	<0.02	0.33	0.19	—[d]
Nitrite (as NO_2)	8 of 12	<0.065	1.1	0.63	—[d]
Orthophosphate	12 of 12	15	23	20	4.3
Sulfate	12 of 12	12	19	15	2.3
Nutrients (mg/L)					
Ammonia nitrogen (as N)	12 of 12	43	56	47	5.0
Total Kjeldahl nitrogen	12 of 12	49	95	60	11
Total phosphorus (as P)	12 of 12	6.8	14	9.8	2.6
Oxygen demand (mg/L)					
Biochemical oxygen demand	12 of 12	163	473	315	107
Chemical oxygen demand	12 of 12	257	776	565	121
Solids (mg/L)					
Settleable solids	12 of 12	14.0	50.0	28.5	11.3
Total dissolved solids (TDS)	12 of 12	236	540	273	78.5
Total suspended solids (TSS)	12 of 12	190	660	330	138
Volatile solids	12 of 12	210	477	350	142
Total metals (mg/L)					
Aluminum	12 of 12	0.30	0.80	0.49	0.16
Calcium	12 of 12	15	27	18	2.3
Iron	12 of 12	1.0	2.5	1.6	0.30
Magnesium	12 of 12	2.5	3.0	2.8	0.15
Potassium	12 of 12	19	26	22	2.0
Selenium	2 of 12	<0.002	<0.02	<0.002	—[d]
Sodium	12 of 12	35	87	47	15
Total organic carbon (TOC)	12 of 12	39	56	53	6.3
Tributyltin[e]	1 of 2	<6	10	—[f]	—[d]

Table 6-7. Monthly monitoring results for physical and chemical characteristics of the LLNL sanitary sewer effluent, 2002[a] (continued)

Parameter	Detection frequency[b]	Minimum	Maximum	Median	IQR[c]
Grab sample parameter					
Semivolatile organic compounds (µg/L)					
Benzoic acid	10 of 12	<10	110	21	39
Benzyl alcohol	10 of 12	<2	1900	12	49
Bis(2-ethylhexyl)phthalate[g]	10 of 12	<5	32	8.1	4.7
Butylbenzylphthalate[g]	2 of 12	<2	9.4	<2	—[d]
Dibutylphthalate[g]	3 of 12	<2	16	<2	—[d]
Diethylphthalate[g]	12 of 12	6.2	35	21	15
Phenanthrene[g]	1 of 12	<2	2.3	<2	—[d]
Phenol[g]	7 of 12	<2	29	2.8	—[d]
m- and p-Cresol	11 of 12	<2	450	19	26
Total cyanide[h]	1 of 3	<0.02	0.024	—[f]	—[d]
Total oil and grease (mg/L)[i]	8 of 8	12	37	28	17
Volatile organic compounds (µg/L)					
1,1,2-Trichloroethane[g]	1 of 12	<0.5	0.58	<0.5	—[d]
1,4-Dichlorobenzene[g]	1 of 12	<0.5	0.67	<0.5	—[d]
2-Butanone	1 of 12	<20	52	<20	—[d]
Acetone	12 of 12	140	560	310	190
Bromoform[g]	1 of 12	<0.5	0.87	<0.5	—[d]
Chloroform[g	12 of 12	5.7	17	11	3.9
Freon 113	1 of 12	<0.5	0.61	<0.5	—[d]
Methylene chloride[g]	3 of 12	<1	3.5	<1	—[d]
Styrene	1 of 12	<0.5	0.59	<0.5	—[d]
Toluene[g]	2 of 12	<0.5	0.67	<0.5	—[d]

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, the interquartile range is omitted.

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

f When there are fewer than four results for a sample parameter, the median is not calculated.

g Priority toxic pollutant parameter used in assessing compliance with the total toxic organic (TTO) permit limit of 1 mg/L (1000 µg/L) issued by the Livermore Water Reclamation Plant.

h Sampling for this parameter is required on a semiannual (January and July) rather than a monthly basis. An additional sample was taken in October during the annual co-sampling event with the LWRP.

i The requirement to sample for oil and grease has been suspended until further notice based on the LWRP letter of April 1, 1999. LLNL collects these samples (four per day) semiannually as part of the source control program.

consistent with the weekly composite median values shown in Data Supplement Table 6-5. Medians of the monthly average concentrations were less than 10% of the discharge limits for all but copper, lead, and zinc, which were at 17%, 11%, and 13%, respectively.

Although median values of monthly average metal concentrations have remained well below discharge limits (see **Table 6-6**), and only one monthly (24-hour) composite sample showed any regulated metal above one-third of the respective EPL (silver was detected in the April monthly composite at 0.10 mg/L; 50% of its EPL), three weekly metal sample concentrations were identified for additional analyses based on 7-day composite results at or near the action limit (see **Figure 6-5**). (As discussed above, the two elevated weekly arsenic values can be attributed to an analytical artifact.) Action limit investigations examined a weekly sample in August (for chromium and lead at 69% and 55% of their respective EPLs) and a weekly sample in November (for lead at 50% of its EPL). 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 August 1–7 show two samples (August 3 at 0.226 mg/L and August 6 at 0.208 mg/L, representing effluent collected during the prior 24-hour periods) exceeding the 0.2 mg/L permitted discharge limit for lead. In October 2002, the LWRP issued a Warning Notice as a result of these exceedances of the EPL for lead. No corrective action was suggested or required, because LLNL had demonstrated a return to compliance and sufficient measures had been taken to investigate this inadvertent discharge. The results of similar analyses showed no chromium concentrations in the August 1–7 daily samples, or lead concentrations in the November 21–27 daily samples above their respective EPLs. 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 detected only in the January 2002 semiannual sample (at 0.024 mg/L, which is below the 0.04 mg/L permit limit). This constituent was below analytical detection limits (0.02 mg/L) in both the second semiannual (July 2002) sampling and the annual (October 2002) joint LLNL/LWRP co-sampling events. The monthly TTO values ranged from less than 0.010 mg/L to 0.10 mg/L (median was 0.039 mg/L), well below the TTO permit limit of 1.0 mg/L. In addition to the organic compounds regulated under the TTO standard, seven nonregulated organics were also detected in LLNL's sanitary sewer effluent: four volatile organic compounds (2-butanone, acetone, Freon 113, and styrene) and three semivolatile organic compounds (benzoic acid, benzyl alcohol, and 3-& 4-methylphenol).

In 2002, the SMS continuous monitoring system detected a total of six inadvertent discharges outside the permitted pH range of 5 to 10. Four of these events, one with a pH below 5 and three with a pH above 10, were completely captured by the SDF. The other two events, both with a pH below 5, occurred off-hours when the upstream pHMS was off-line. As a result, two front-end volumes (small quantity) of low pH sanitary effluent were released to the LWRP system before a diversion to the SDF could be made. The LWRP

was immediately notified of both low pH discharges; however, neither incident represented a threat to the integrity of the operations of the LWRP nor were these events considered enforceable exceedances of permit conditions. The lowest pH recorded for effluent contained in the first release, February 9, 2002, was 4.6; the second release, October 13, 2002, contained effluent with a pH as low as 4.96.

Monitoring results for 2002 reflect a very effective year for LLNL's sewerable water discharge control program and indicate no adverse impact to the LWRP or the environment from LLNL sanitary sewer discharges. Overall, LLNL achieved greater than 99% compliance with the provisions of its wastewater discharge permit.

Surface Water Monitoring

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Introduction

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, 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 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 95-174 (WDR 95-174), National Pollutant Discharge Elimination System (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 California NPDES General Permit for Storm Water Discharges Associated with Industrial Activity (WDR 97-03-DWQ), NPDES Permit No. CAS000001, State Water Resources Control Board (SWRCB 1997).

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) 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.

In 2002, LLNL also met the storm water compliance monitoring requirements of the Statewide NPDES General Permit for Storm Water Discharges Associated with Construction Activity (WDR 99-08-DWQ, NPDES Permit No. CAS000002) as modified by Resolution 2001-046 for construction projects that disturb two hectares (5 acres) 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 U.S. 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

Table 7-1. Analyses conducted on storm water samples, 2002

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	High explosives (HE)
Herbicides	Total organic halides
Gross alpha and gross beta activity	Gross alpha and gross beta activity
Tritium	Tritium
Plutonium	Depleted uranium

help evaluate LLNL's storm water management 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), state and federal 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 on samples from the Arroyo Las Positas (Livermore site) once per wet season. Currently, LLNL is not required to test for fish toxicity at Site 300.

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	0.013 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 MCLs and EPA benchmarks except for zinc, TSS, and COD.

b EPA benchmark

c RL = reporting limit = 0.0002 mg/L for mercury

d Ambient water quality criteria (AWQC)

e EPA primary maximum contaminant level

Inspections

Each directorate at LLNL conducts an annual inspection of its facilities to verify implementation of the SWPPPs and to ensure that measures to reduce pollutant loadings to storm water runoff are adequate. LLNL's associate directors certified in 2002 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 Central Valley Regional Water Quality Control Board (CVRWQCB) with the results of sampling, observations, and inspections (Campbell 2002a,b).

For each construction project permitted by WDR 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. Annual compliance certifications for 2002 covered the period of June 2001 through May 2002. When requested by the regional water quality control boards (RWQCBs), LLNL completes annual compliance status reports that cover the same reporting period.

During the 2001–2002 reporting period, LLNL inspected four projects located at the Livermore site: the National Ignition Facility (NIF), the areas associated with the Soil Reuse Project, the Tera-scale Simulation Facility, and the Sensitive Compartmented Information Facility. The SFBRWQCB requested completion of compliance status reports for three of the four Livermore site construction 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.

Resolution 2001-046 requires that construction site runoff be sampled to assess the impact of the runoff on the receiving water in certain circumstances. 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 nonvisible pollutants. LLNL projects do not have to sample for sediment-related pollutants because neither the receiving waters at 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. In many cases, more stringent material storage practices can eliminate the need to sample construction site runoff. In 2002, construction site runoff sampling was not required at the Livermore site.

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 northeastern 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.

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 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 vegetation. Seven artificial surface water bodies are

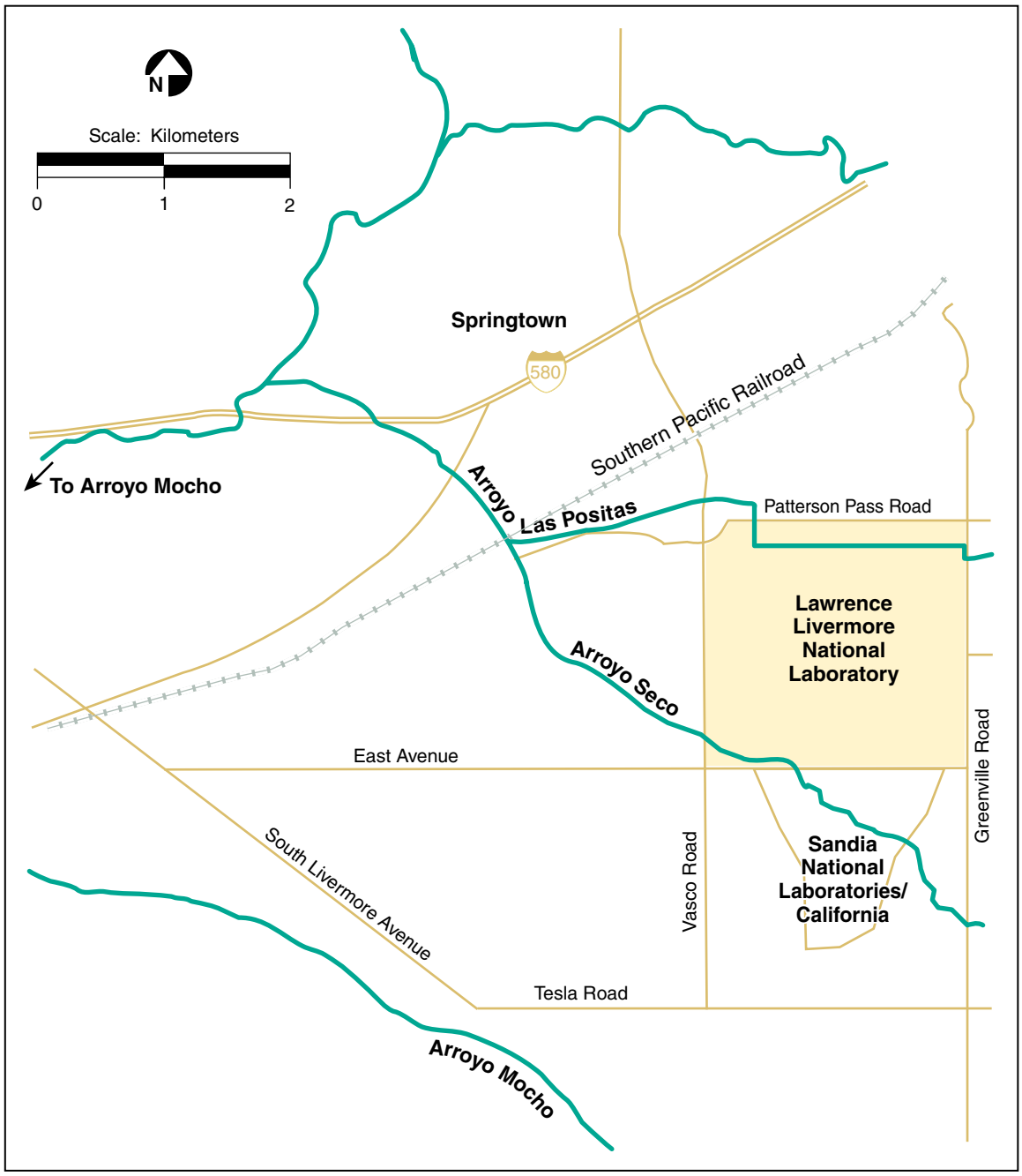


Figure 7-1. Surface waterways in the vicinity of the Livermore site

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 discussed in Chapter 9. Three wetlands created by

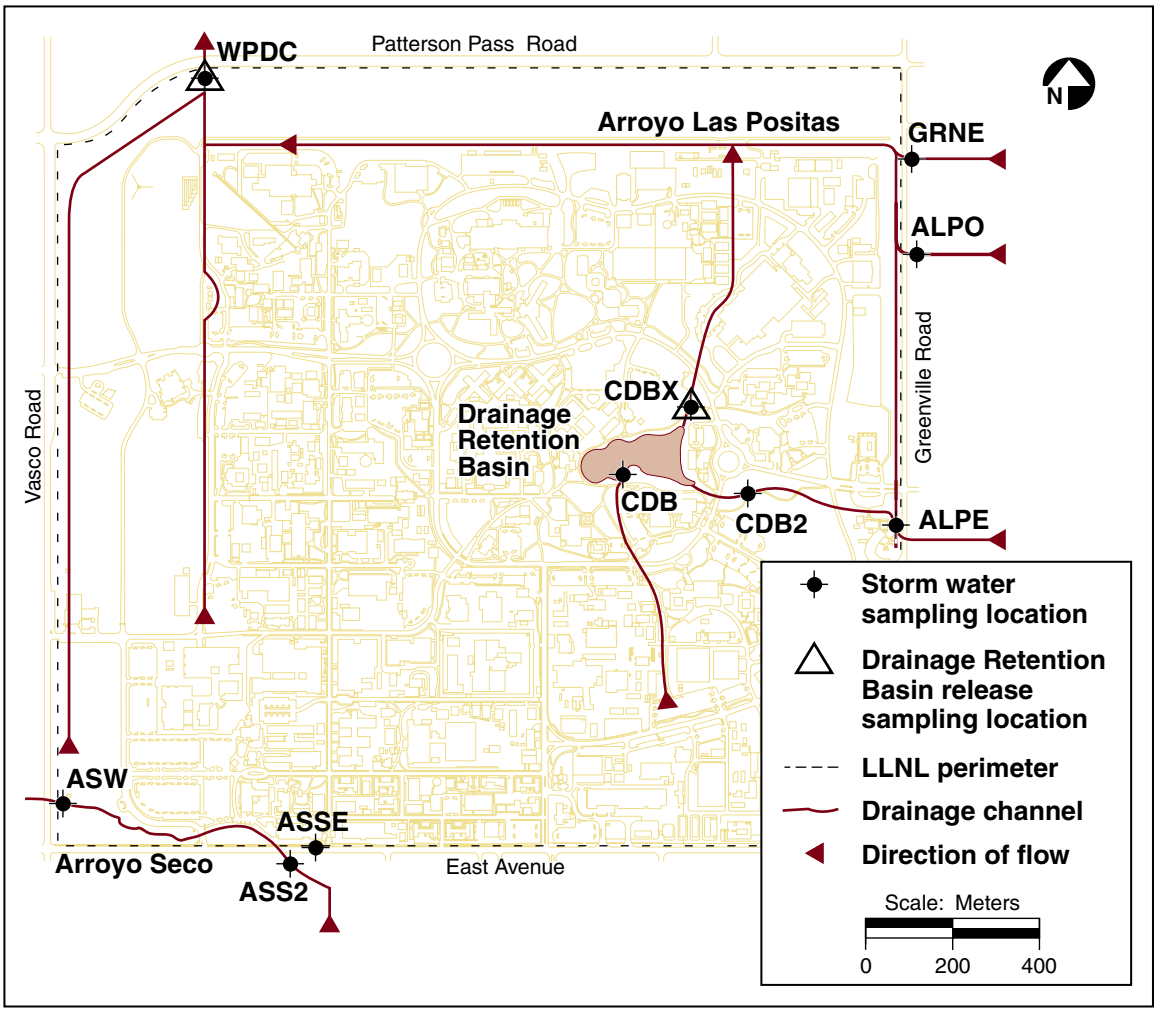


Figure 7-2. Storm water runoff and Drainage Retention Basin sampling locations, Livermore site, 2002

now-discontinued flows from cooling towers located at Buildings 827, 851, and 865 were maintained in 2002 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 7-3**). Sampling locations were selected to characterize storm water runoff at locations that could be affected by specific Site 300 activities.

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

Methods

At all monitoring locations at both the Livermore site and Site 300, grab samples are collected from the storm runoff flowing in the stream channels.

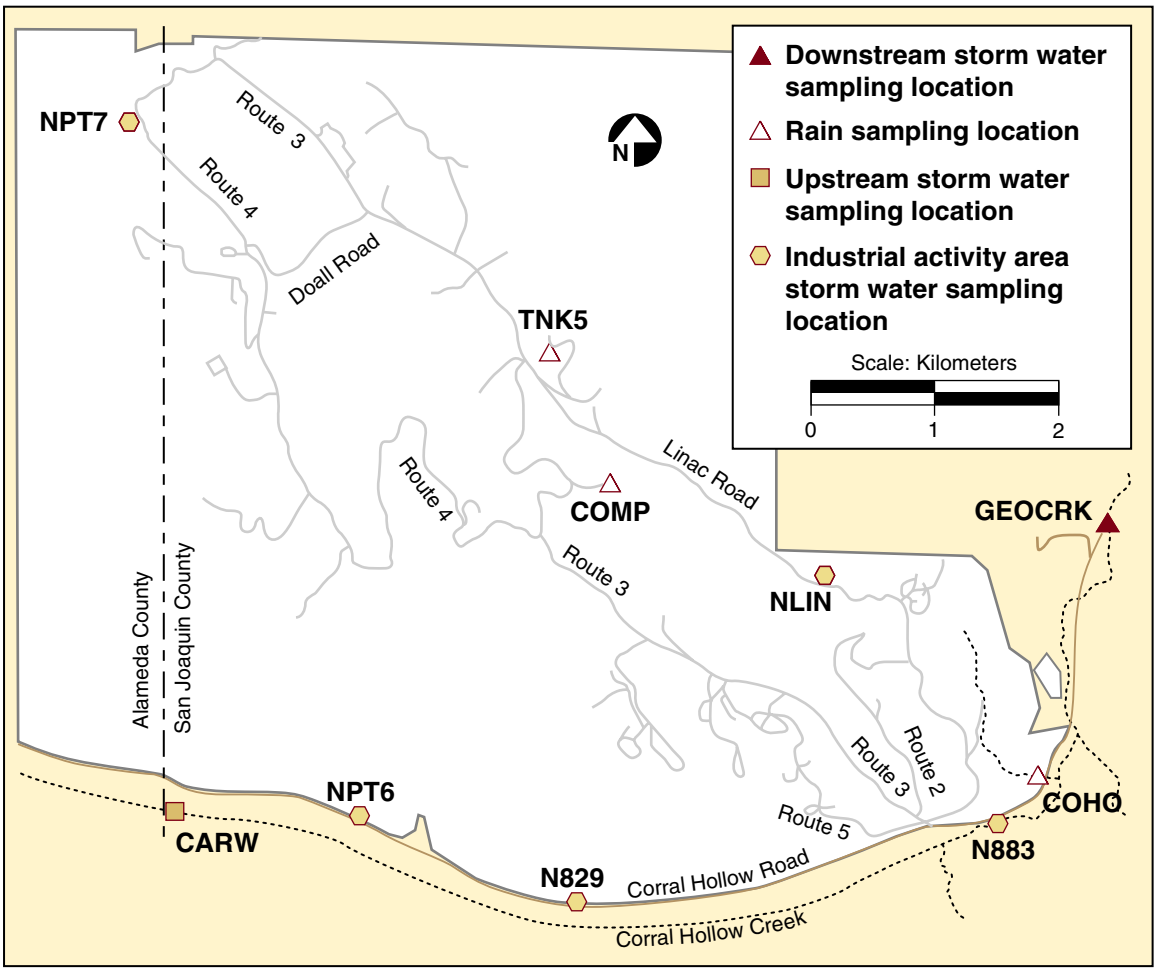


Figure 7-3. Storm water and rainwater sampling locations at Site 300, 2002

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 prevent the collection of sediment to the water samples. Sample vials for volatile organics are filled before sample bottles for all other constituents and parameters.

Results

Inspections

The Associate Director for each of the directorates certified that their facilities conducted the 2002 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 WDRs 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 the Livermore site and Site 300 *Annual Storm Water Reports* (Campbell 2002a; Campbell and Laycak 2002). There were 10 findings listed as the result of the inspections that were not consistent with the BMPs identified in the SWPPP. All of these findings 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 at the Livermore site. The findings of these inspections indicated compliance with the permit and the construction site SWPPPs, with two exceptions documented in the 2001/2002 annual compliance certifications filed in July 2002 for the period of June 2001 through May 2002. At one project, project personnel failed to perform one of the required rain event inspections. At a second project, project personnel began construction activity prior to approval and certification of the SWPPP.

Livermore Site Sampling

LLNL collected samples at all ten Livermore site locations on May 20, November 8, and December 16, 2002, where the May sampling was a reduced analysis surveillance storm to satisfy DOE Order 450.1. The fish and algae toxicity analyses were conducted on November 8 in order to catch the first flush of runoff that occurs at the beginning of the wet season.

Livermore Site 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 2002, survival in the acute test at WPDC (November 8) was 70%, while all influent locations (ALPE, ALPO, and GRNE) ranged from 75 to 88% (**Table 7-3**). All of these values were calculated to be significantly different from the control waters tested at the α=0.05 level. The growth measurements did not produce significantly different results from controls, however, fish growth in water samples from the arroyo were consistently lower. The sub-contract laboratory (Pacific EcoRisk) explained that the results appeared to be related to a fungus growing on the fish in the arroyo samples. It was their conclusion

that the observed results were due to pathogen related death and not caused by poor chemical water quality.

Table 7-3. Fish acute toxicity test results, Livermore site, November 8, 2002

Sample location	Percent survival		Growth (biomass mg)[a]	
	Control	Sample	Control	Sample
WPDC	100	70[a]	0.56	0.40
ALPE	100	75[a]	0.56	0.45
ALPO	100	83[a]	0.56	0.53
GRNE	100	88[a]	0.56	0.52

a Indicates a statistically significant difference from the control value.

In response to the November fish toxicity results, the test was performed again using water samples collected on December 16, 2002. These results found toxicity in fathead minnow caused by either pathogens or water quality issues (**Table 7-4**). In all cases the results were similar at influent and effluent storm water sampling locations, demonstrating that the observed toxicity was unrelated to operations at LLNL.

Table 7-4. Retest fish acute toxicity test results, Livermore site, December 16, 2002

Sample location	Percent survival	
	Control	Sample
WPDC	100	100
ALPE	100	100
ALPO	100	100
GRNE	100	95

In addition to the fish toxicity testing, LLNL performed acute toxicity testing with freshwater algae (*Selenastrum capricornutum*) using water collected from Arroyo Las Positas on November 8, 2002. The algae test indicated toxicity in storm water. This appears to be the result of continued upstream sources of herbicides. A historical investigation into the potential causes of the algae toxicity identified a likely source: a pre-emergent herbicide, diuron (Campbell 2001; Campbell et al. submitted).

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 7-5**. Complete results are in Data Supplement Tables 7-1, and 7-2. Tritium activities at effluent locations were less than 1% of the MCL. Radioactivity in the storm water samples collected during 2002 was generally low, with medians around background levels.

LLNL began analyzing for plutonium in storm water in 1998. Samples from the Arroyo Seco and the Arroyo Las Positas effluent locations (ASW and WPDC) are analyzed. In 2002, there were no plutonium results above the detection limit of 0.0037 Bq/L (0.100 pCi/L).

Table 7-5. Radioactivity in storm water from the Livermore site, 2002[a]

Parameters	Tritium (Bq/L)	Gross alpha (Bq/L)	Gross beta (Bq/L)
MCL	**740**	**0.555**	**1.85**
Influent			
Median	1.7	0.087	0.20
Minimum	–0.083	0.01	0.10
Maximum	20.0	0.23	0.85
Effluent			
Median	3.5	0.02	0.13
Minimum	–0.34	0.004	0.03
Maximum	18.0	0.10	0.77

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

Livermore Site Nonradioactive Constituents:

In addition to data on radioactivity, storm water was analyzed for other water quality parameters.

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 7-6**.

Many of the values above threshold comparison criteria listed in **Table 7-6** for the Livermore site were recorded at influent tributaries to Arroyo Las Positas and Arroyo Seco. In all cases where the LLNL threshold limit was exceeded at WPDC or ASW, which are effluent locations, an influent value was similar or greater demonstrating that LLNL was not the source.

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 2002, samples were collected at locations with flow on November 8 and December 16. There was no tritium above the minimum detectable activity in Site 300 storm water during 2002. The maximum values of all gross alpha and gross beta results were 0.25 and 1.1 Bq/L, respectively, approximately 45% and 59% of the drinking water MCLs (0.56 and 1.85 Bq/L). These gross alpha and gross beta values recorded on November 8 were the highest recorded from a Site 300 effluent location for the year. Although these values are higher than those at the Livermore site, they are not unusual. This area has had relatively high back-ground 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 2002.

Specific conductance and TSS at Site 300 locations were at times above internal comparison criteria and EPA benchmarks. However, in most cases effluent levels were lower than levels at the upstream location CARW, indicating that the levels observed in effluent are typical for the area. Total suspended solids results are shown in **Table 7-7**.

Most the values over the thresholds in **Table 7-6** at Site 300 are associated with high suspended sediment. The elevated lead and mercury have been demonstrated in the past to be related to total concentrations where the laboratory analysis includes the suspended sediment (Brandstetter 1998).

TSS values were measured above the LLNL comparison criteria in the November sample at upstream location CARW and discharge location NLIN. The sample concentration at NLIN of 4800 mg/L was above the comparison criteria but is consistent with the range of historic data at this location, 243 mg/L to 6600 mg/L, with an average of 2700 mg/L. It is possible that the sample concentration could have been affected by the September 5, 2002, release from a drinking water tank, which resulted in sediment from the hillside being washed into Elk Ravine, approximately 2 km upstream of this sampling location. However, the upstream receiving water location CARW TSS concentration (10,000 mg/L) was still higher than the NLIN concentration. This would also indicate that the NLIN concentration is typical for the area.

Table 7-6. Water quality parameters above the threshold comparison criteria shown in Table 7-2 from the Livermore site and Site 300 in 2002

Parameter	Date	Location	Influent or Effluent	Result (mg/L)	LLNL threshold criteria (mg/L)
Livermore Site					
Beryllium	11/8	ALPO	Influent	0.0018	0.0016
	11/8	GRNE	Influent	0.0022	0.0016
	12/16	ASS2	Influent	0.0020	0.0016
	12/16	ASW	Effluent	0.0019	0.0016
Chemical Oxygen Demand	11/8	ALPE	Influent	259	200
	11/8	ALPO	Influent	466	200
	12/16	ASS2	Influent	240	200
Copper[a]	11/8	ALPE	Influent	0.070	0.013
	11/8	ALPO	Influent	0.055	0.013
	11/8	GRNE	Influent	0.030	0.013
	11/8	WPDC	Effluent	0.018	0.013
	11/8	ASS2	Influent	0.034	0.013
	11/8	ASW	Effluent	0.028	0.013
	12/16	ALPE	Influent	0.015	0.013
	12/16	ALPO	Influent	0.021	0.013
	12/16	ASS2	Influent	0.060	0.013
	12/16	ASW	Effluent	0.051	0.013
	12/16	CDB	Internal	0.047	0.013
Diuron	12/16	ALPO	Influent	0.29	0.014
	12/16	WPDC	Effluent	0.044	0.014
Chromium(VI)	12/16	CDB	Internal	0.016	0.015
Lead[a]	11/8	ALPE	Influent	0.030	0.015
	11/8	ALPO	Influent	0.019	0.015
	11/8	GRNE	Influent	0.017	0.015
	11/8	ASS2	Influent	0.024	0.015
	11/8	ASW	Effluent	0.017	0.015
	12/16	ASS2	Influent	0.033	0.015
	12/16	ASW	Effluent	0.028	0.015
	12/16	CDB	Internal	0.020	0.015
Nitrate (as NO_3)	11/8	GRNE	Influent	11	10
	12/16	ASS2	Influent	14	10
	12/16	ASW	Effluent	13	10
	12/16	GRNE	Influent	19	10

Table 7-6. Water quality parameters above the threshold comparison criteria shown in Table 7-2 from the Livermore site and Site 300 in 2002 (continued)

Parameter	Date	Location	Influent or Effluent	Result (mg/L)	LLNL threshold criteria (mg/L)
Ortho-Phosphate	11/8	ALPE	Influent	4.24	2.5
	12/16	ALPE	Influent	5.56	2.5
	12/16	ASS2	Influent	5.61	2.5
	12/16	ASW	Effluent	5.12	2.5
pH	11/8	CDB	Internal	8.56	8.5
	12/16	CDBX	Internal	8.95	8.5
Total Suspended Solids	11/8	ALPE	Influent	1,300	750
	11/8	ALPO	Influent	800	750
	11/8	ASS2	Influent	800	750
	12/16	ASS2	Influent	1,100	750
	12/16	ASW	Effluent	980	750
	12/16	CDB	Internal	820	750
Zinc[a]	11/8	ASS2	Influent	0.46	0.35
	11/8	ASW	Effluent	0.41	0.35
	11/8	CDB	Internal	0.43	0.35
	11/8	GRNE	Influent	0.38	0.35
Site 300					
Total Suspended Solids	11/8	CARW	A	10,000	1,700
	11/8	NLIN	Effluent	4,800	1,700
	12/16	CARW	A	1,800	1,700
	12/16	GEOCRK	B	14,200	1,700
Chemical Oxygen Demand	11/8	CARW	A	393	200
	11/8	NLIN	Effluent	289	200
	12/16	GEOCRK	B	615	200
Lead[a]	11/8	CARW	A	0.174	0.015
	11/8	NLIN	Effluent	0.065	0.015
	12/16	GEOCRK	B	0.237	0.015
Mercury[a]	11/8	CARW	A	0.0003	0.0002
Total Organic Halides	11/8	N883	Effluent	160	none

A = Upstream receiving water

B = Downstream receiving water

a Includes both dissolved and total metals (including particulates)

Table 7-7. Total suspended solids in storm water samples from Site 300 in 2002

Sampled date	Location	Total suspended solids (mg/L)
11/8	CARW[a]	10,000
11/8	GEOCRK[b]	62
11/8	NLIN	4,800
11/8	N883	5.3
11/8	NPT7	400
12/16	CARW[a]	1,800
12/16	GEOCRK[b]	14,200
12/16	N883	58
12/16	NPT7	880

a Upstream receiving water location

b Downstream receiving water location

A high TSS value was also measured in the December samples at downstream location GEOCRK and at upstream location CARW (14,200 mg/L and 1,800 mg/L respectively); both of these locations are off-site. Based on historic data from these two locations, the TSS concentrations at CARW tend to be higher than GEOCRK, as was the case in the November samples. However, the December TSS concentration at GEOCRK was higher than the CARW concentration which is an anomaly. During this storm event, only one LLNL effluent location was discharging (N883), which had a TSS concentration of 58 mg/L. The low TSS concentration at N883 in addition to the lack of flow at NPT6 and NLIN indicate that LLNL activities were not the direct cause of the elevated concentration at GEOCRK. However, LLNL will continue to trend the TSS data at these locations to identify whether this data point at GEOCRK is an outlier or whether a change in LLNL activities has influenced an increase at the downstream receiving water location. Both the GEOCRK and CARW locations are influenced by the larger Corral Hollow watershed, which is dominated by a State off-road motorcycle park and ranching activities.

The elevated total organic halides (TOX) value observed in the November 8 sample from location N883 was examined in greater detail. There were no releases of solvents or chlorinated drinking water on or around this time period that could explain this result. Follow up sampling on December 16th found no TOX above the detection limit. Therefore LLNL has concluded that this was an isolated data outlier and not likely to be a result caused by operations at S300.

Complete storm water results for nonradioactive constituents are presented in Data Supplement Table 7-3.

Because of a CERCLA remedial investigation finding of past releases of dioxins related to activities in the vicinity of Building 850, analysis for dioxins was conducted at location NLIN, the storm water sampling discharge location downgradient of Building 850. The intent of the sampling was to determine whether these constituents are being released from the site in storm water runoff. Dioxins and furans detected at location NLIN (the laboratory analysis request for dioxins includes furans) ranged from 2.2 to 11,690 pg/L (**Table 7-8**). All dioxin congeners are below the equivalent federal MCL.

The federal MCL for dioxin is for the dioxin congener 2,3,7,8-TCDD. The NLIN 2,3,7,8-TCDD sample result is less than the MCL of 30 pg/L. The other dioxin congeners reported have varying degrees of toxicity. EPA has assigned toxic equivalency factors (TEFs) to specific dioxin congeners. 2,3,7,8-TCDD is considered the most toxic dioxin congener and is assigned a TEF of 1. The other congeners are assigned TEFs that estimate their toxicity relative to 2,3,7,8-TCDD. The

Table 7-8. Total toxicity equivalents of dioxin congeners in storm water runoff (pg/L) at Site 300, location NLIN, November 8, 2002[a]

	Value	TEQ[b]
Dioxin		
1,2,3,4,6,7,8-HpCDD	1,410	14.1
1,2,3,4,6,7,8,9-OCDD	11,690	11.69
1,2,3,4,7,8-HxCDD	2.5	0.025
1,2,3,6,7,8-HxCDD	59.9	5.99
1,2,3,7,8,9-HxCDD	61.6	6.16
1,2,3,7,8-PeCDD	15.6	15.6
2,3,7,8-TCDD	4	4
Furans (dioxin-like compounds)		
1,2,3,4,6,7,8-HpCDF	443	4.43
1,2,3,4,6,7,8,9-OCDF	1,290	0.129
1,2,3,4,7,8,9-HpCDF	34.8	0.348
1,2,3,4,7,8-HxCDF	47.4	4.74
1,2,3,6,7,8-HxCDF	17.5	1.75
1,2,3,7,8,9-HxCDF	11.3	1.13
1,2,3,7,8-PeCDF	2.2	0.11
2,3,4,6,7,8-HxCDF	23.9	2.39
2,3,4,7,8-PeCDF	5.5	2.75
2,3,7,8-TCDF	6.9	0.69

a No sample was collected during the December 2002 sampling event because there was no access.

b Toxicity Equivalents

toxic equivalency (TEQ) is determined by multiplying the concentration of a dioxin congener by its TEF. None of the dioxin congeners have a calculated TEQ greater than the MCL for 2,3,7,8-TCDD.

All data analysis included standard quality assurance and quality control practices; analysis information is available upon request. Records specific to storm water sampling of specific events are also maintained and available upon request.

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 activity in support of DOE Orders 5400.1 and 5400.5.

General Information

Livermore Site and Livermore Valley

Historically, the tritium activity measured in rainfall in the Livermore Valley has been attributed primarily to 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 2002 was 1.2 TBq (32.9 Ci) (see Chapter 4).

The rain sampling locations are shown in **Figure 7-4**. The fixed stations are positioned to record all ranges of tritium activity, from the background level up to the maximum activity expected. The maximum tritium activity is measured near the Tritium Facility, at the Building 343 rain sampling location (B343 in **Figure 7-4**).

Site 300

Three on-site locations (COHO, COMP, and TNK5) are used to collect rainfall for tritium activity measurements at Site 300 (**Figure 7-3**).

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 simply 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 splashback water. Rainwater samples are decanted into 250-mL amber glass bottles with Teflon-lined lids. The tritium activity of each sample is measured at a contracted laboratory by a scintillation counting method equivalent to EPA Method 906, that has a lower limit of measurement of about 2.5 Bq/L.

Results

Livermore Site and Livermore Valley

During 2002, LLNL collected sets of rain samples following 4 rainfall events in the Livermore Valley (35 total routine samples obtained) and at the Livermore site (27 total routine samples obtained).

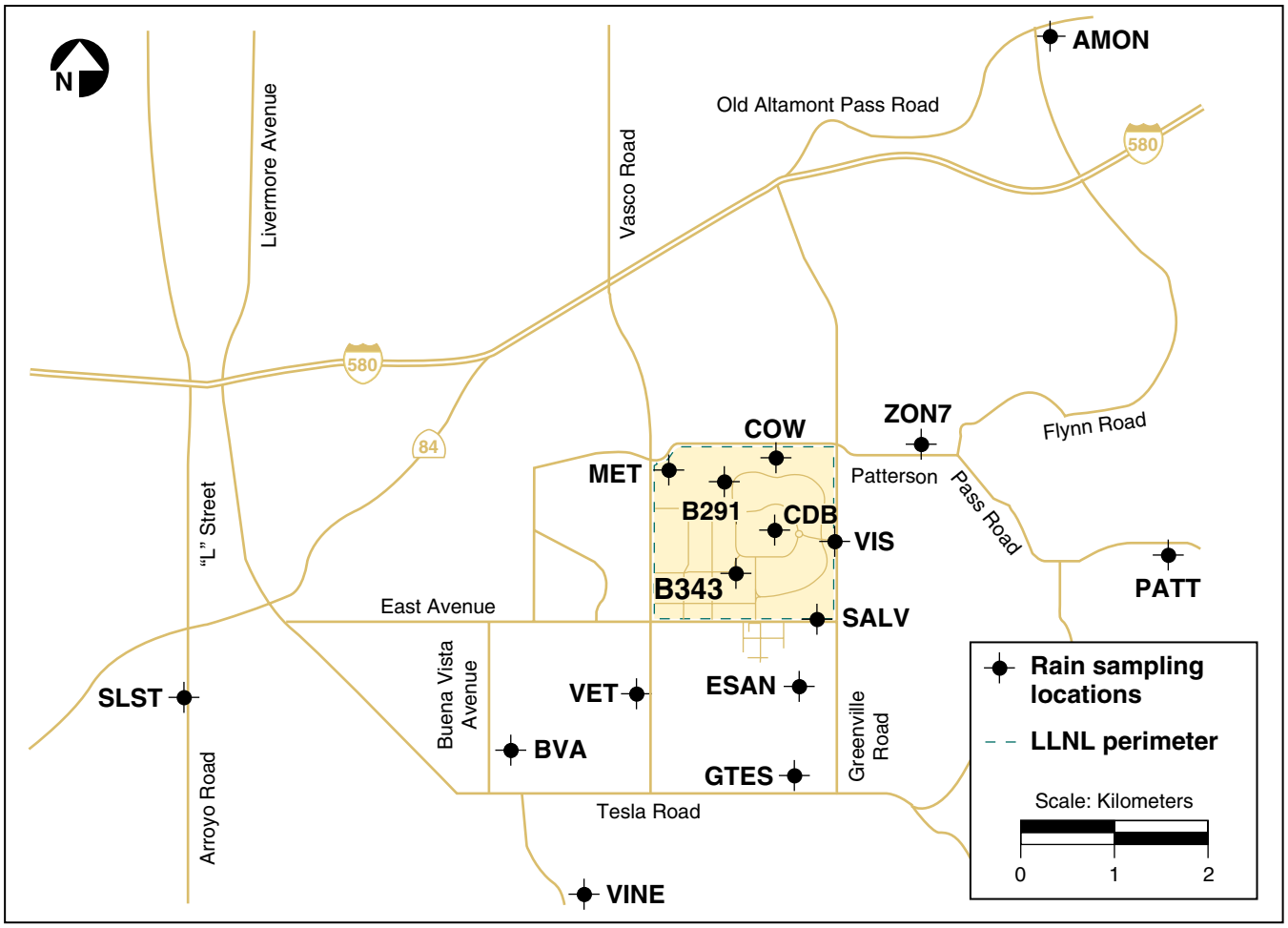


Figure 7-4. Rain sampling locations, Livermore site and Livermore Valley, 2002

Because of sparse rainfall at the semi-arid location of Site 300 during 2002, only 8 routine rain samples were obtained. The tritium activities of rainwater samples obtained during 2002 are listed in Table 7-5 of the Data Supplement.

The Livermore site rainfall has exhibited elevated tritium activities in the past (Gallegos et al. 1994). During 2002, however, no measurements of tritium activity in rainfall were above the 740 Bq/L MCL established by the EPA for drinking water. As in the past, the on-site rainfall sampling location 343B (the sampling location nearest the Tritium Facility) showed the highest tritium activity for the year: 47 Bq/L (see **Table 7-9**) for the rainfall event that immediately preceded the May 20 collection date. The tritium activities of all the off-site rainfall samples obtained during 2002 were below LLNL's lower limit of measurement of 2.5 Bq/L, which is equal to 0.3% of the tritium MCL for drinking water.

Table 7-9. Tritium activities in rainfall for the Livermore site, Livermore Valley, and Site 300, 2002

Parameter	Livermore site (Bq/L)	Livermore Valley (Bq/L)	Site 300 (Bq/L)
Median	3.1	–0.23	–0.54
Minimum	0.22	–1.7	–1.5
Maximum	47	1.8	1.1
Number of samples	27	35	8

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.

The median tritium activity measured in rainfall at LLNL increased slightly from 2.0 Bq/L in 2001 to 3.1 Bq/L in 2002 (**Figure 7-5**) and most likely reflects the slight increase of on-site HTO emissions from 0.68 TBq in 2001 to 1.2 TBq in 2002 (see Chapter 4). In 2001, the median tritium activity for rainfall at LLNL reached its lowest level since 1990 when it was 66 Bq/L.

The distribution of on-site locations where tritium activity was detected during 2002 indicates a northeastward direction of wind dispersed HTO from the stacks at the tritium facility during the sampled rain events. The historical higher values of tritium activity in rainfall samples are the result of HTO emissions from the Tritium Facilities at both LLNL and Sandia/ California. Operations at the Sandia/California Tritium Facility ceased in October 1994. The reduced measurements of tritium activity in rain since 1991 reflect the reduction of emissions from the two facilities.

Site 300

As in the past, none of the 8 routine rain samples obtained from monitoring locations at Site 300 during 2002 showed tritium activities above background activity, which is approximately 2 Bq/L (see Table 7-5 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 water runoff still dominates wet weather

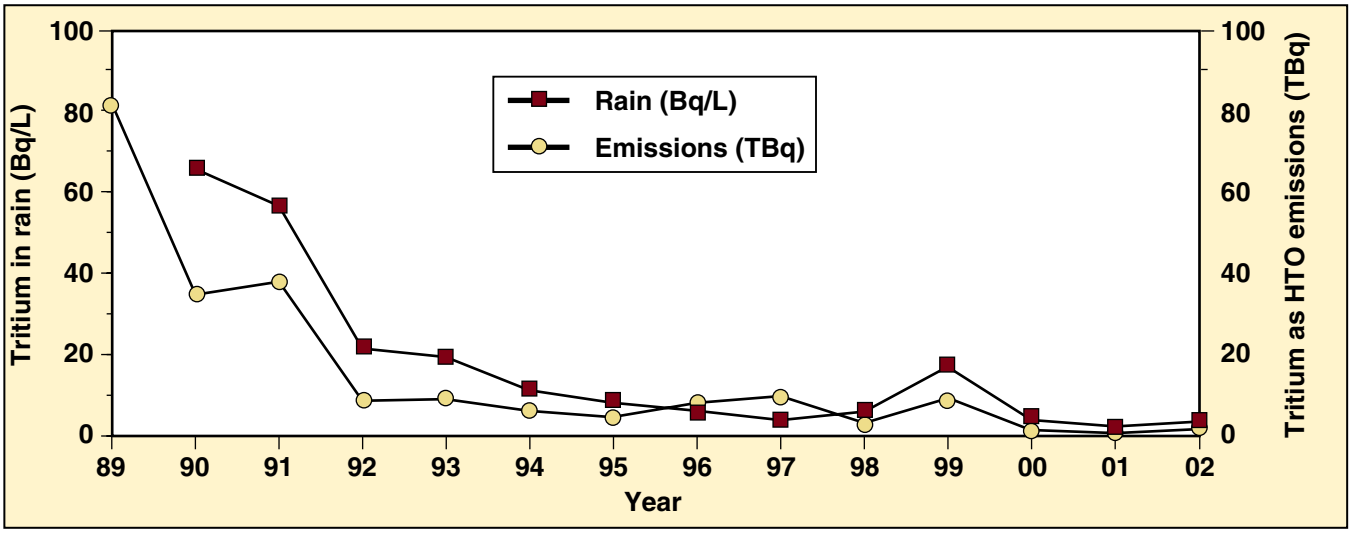


Figure 7-5. Trend of median tritium activity in rain and trend of total stack emissions of HTO. From 1989 to 1995 the emissions are from the Livermore site and Sandia/California. Emissions from 1996 to 2002 are from LLNL only.

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 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 7-6 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 7-7 and were established based on recommendations made in the DRB Management Plan. LLNL collects samples at the eight locations identified in **Figure 7-6** 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. Bird, fish, and mammal surveys were not conducted during 2002. Although no formal plant surveys were completed, no changes to plant populations were expected (nor observed in anecdotal surveys) during 2002. Spring and summer amphibian surveys were completed and results shown in **Table 7-10**.

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. State-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 2002.

Results

Some samples collected during 2002 within the DRB at CDBE for dissolved oxygen saturation, temperature, transparency, nitrate (as nitrogen [N]), total dissolved solids (TDS), total phosphorus (as phosphate [P]), chemical oxygen demand (COD), pH, and specific conductance (**Table 7-11**) did not meet the management action levels and triggered administrative review. Water

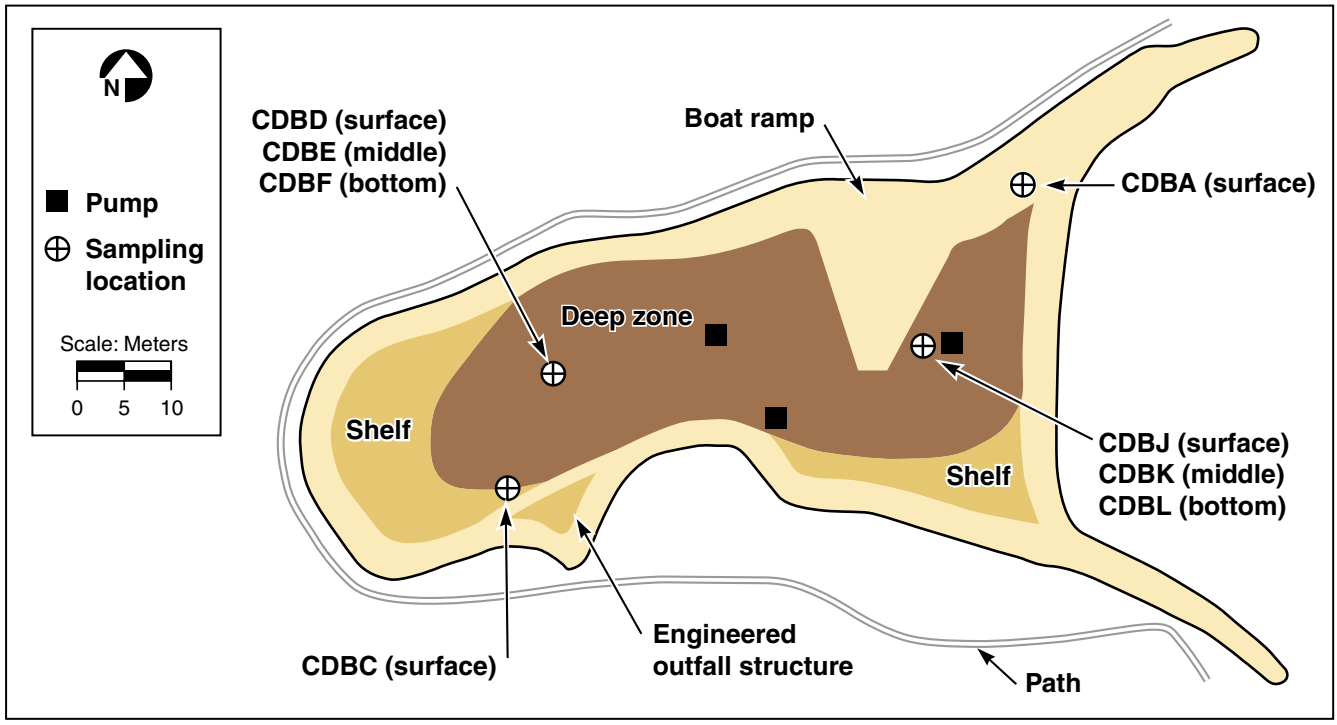


Figure 7-6. Sampling locations within the Drainage Retention Basin, 2002

Table 7-10. Inventory of amphibians in the Drainage Retention Basin, 2002

Common name	Scientific name	Date					
		30 May	25 Jul	6 Aug	15 Aug	20 Aug	17 Sept
Bullfrog	*Rana catesbeiana*	27	49	55	73	60	75
Pacific tree frog	*Hyla regilla*	3	1	4	0	3	2
California red-legged frog	*Rana aurora draytonii*	0	1	0	7	6	2
Western toad	*Bufo borieus*	0	0	1	2	2	1

releases occurred continuously to maintain relatively low nutrient levels. Samples collected at CDBX and WPDC exceeded only the pH and COD discharge limits **Table 7-11**).

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 7-8 through 7-13 in the Data Supplement.

Table 7-11. Summary of Drainage Retention Basin monitoring not meeting management action levels

Parameter	Management action level	Jan	Feb	Mar	Apr	May	June
Sampling location CDBE							
Dissolved oxygen saturation (%)[a]	<80	—[b]	—[b]	—[b]	—[b]	—[b]	—[b]
Temperature (degrees C)[a]	<15 or >26	11.2	12.4	14.4	—[b]	—[b]	29
Transparency (m)[a]	<0.91	0.84	—[b]	—[b]	—[b]	—[b]	—[b]
Nitrate (as N) (mg/L)	>0.2	2.2	2.3	2	1.1	0.57	0.9
pH (pH units)	<6.0 or >9.0	—[b]	—[b]	—[b]	—[b]	—[b]	9.21
Specific conductance (µS/cm)	>900	939	1070	1120	1110	1100	1070
Total dissolved solids (TDS) (mg/L)	>360	557	646	647	660	647	630
Total phosphorus (as P) (mg/L)	>0.02	0.22	0.15	0.06	<0.05	<0.05	<0.05
Chemical oxygen demand (mg/L)	>20	58	—[c]	—[c]	<25	—[c]	—[c]
		July	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Sampling location CDBE (continued)							
Dissolved oxygen saturation (%)[a]	<80	—[b]	76	31	—[b]	76	55
Temperature (degrees C)[a]	<15 and >26	—[b]	—[b]	—[b]	—[b]	14.2	11.1
Transparency (m)[a]	<0.91	—[b]	—[b]	—[b]	—[b]	—[b]	—[b]
Nitrate (as N) (mg/L)	>0.2	—[b]	—[b]	—[b]	1.1	1.4	1.4
pH (pH units)	<6.0 or >9.0	9.04	—[b]	9.06	—[b]	—[b]	—[b]
Specific conductance (µS/cm)	>900	1030	1160	1110	1270	1190	1020
Total dissolved solids (TDS) (mg/L)	>360	643	688	653	775	820	690
Total phosphorus (as P) (mg/L)	>0.02	0.07	<0.05	<0.05	<0.05	0.06	<0.05
Chemical oxygen demand (mg/L)	>20	36	—[c]	—[c]	29	—[c]	—[c]
		4 Jun	**1 Jul**	**6 Aug**	**3 Sep**	**24 Sep**	**8 Nov**
Sampling location CDBX							
Chemical oxygen demand (mg/L)	>20	—[c]	—[c]	—[c]	—[c]	—[c]	36
pH (pH units)	<6.5 or >9.0	9.24	9.61	9.72	9.65	9.55	8.56
Sampling location WPDC							
Chemical oxygen demand (mg/L)	>20	—[c]	—[c]	—[c]	—[c]	—[c]	81
pH (pH units)	<6.5 or >8.5	8.62	8.58	8.69	—[b]	—[b]	—[b]

Table 7-11. Summary of Drainage Retention Basin monitoring not meeting management action levels (continued)

Parameter	Management action level	16 Dec					
Sampling location CDBX							
Chemical oxygen demand (mg/L)	>20	36					
pH (pH units)	<6.5 or >9.0	—[b]					
Sampling location WPDC							
Chemical oxygen demand (mg/L)	>20	30					
pH (pH units)	<6.5 or >9.0	—[a]					

a Monthly average, measurements taken weekly

b Concentrations met management action level or discharge limit.

c Chemical oxygen demand was analyzed one per quarter at location CDBE, and only in conjunction with storm water runoff sampling events at locations CDBX and WPDC.

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. COD was above management action levels during the fourth quarter of 2002. Chlorophyll-a, though below the management action level of 10,000 µg/L, had one summer and one fall peak indicating algae blooms (**Figure 7-7**).

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 summer bloom and may be associated with the occurrence of increased photosynthesis. The higher pH readings seen in the DRB discharge samples during the summer and fall also correspond to the peak of the summer and fall blooms.

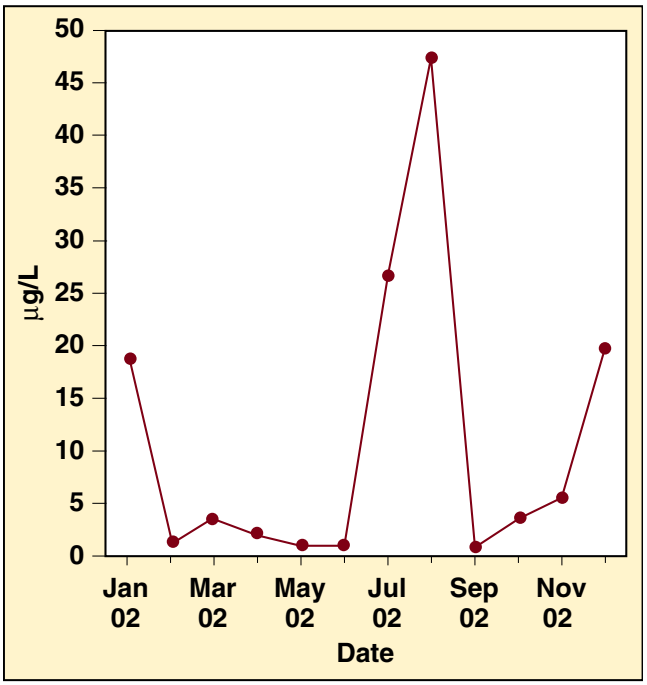


Figure 7-7. Monthly chlorophyll-a in the Drainage Retention Basin, 2002

Beginning during the summer of 1994, transparency was below the management action level of 0.91 meters. Since February 2002, the transparency in the DRB began to increase to levels consistently above the 0.91 meters clarity (**Figure 7-8**). January 2002 yielded the only measurements exceeding the action level, indicating clearer water. The loss of transparency seen during the warmer summer and fall months is most likely the result of algae growth (Harrach et al. 1996).

Beginning in the 1999/2000 wet season and throughout 2002, LLNL has operated 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 2002 (**Figure 7-9**). Concentrations were well above management action levels throughout the year, but decreased concentrations occurred in the periods when chlorophyll-a was high (**Figure 7-7**), possibly indicating an uptake of nutrients during algae growth. Total phosphorus remained fairly constant throughout 2002 at concentrations at the analytical laboratory detection limit and 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.

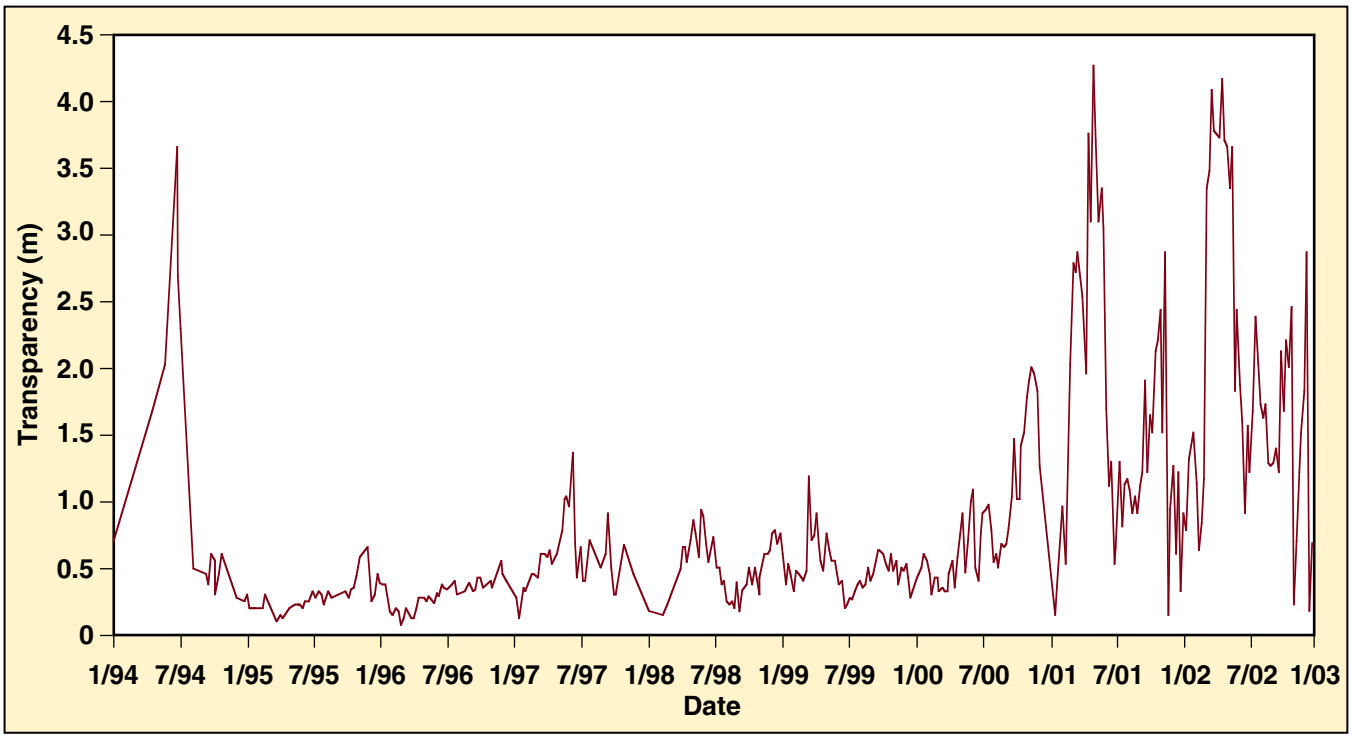


Figure 7-8. Transparency in Drainage Retention Basin, 1994–2002

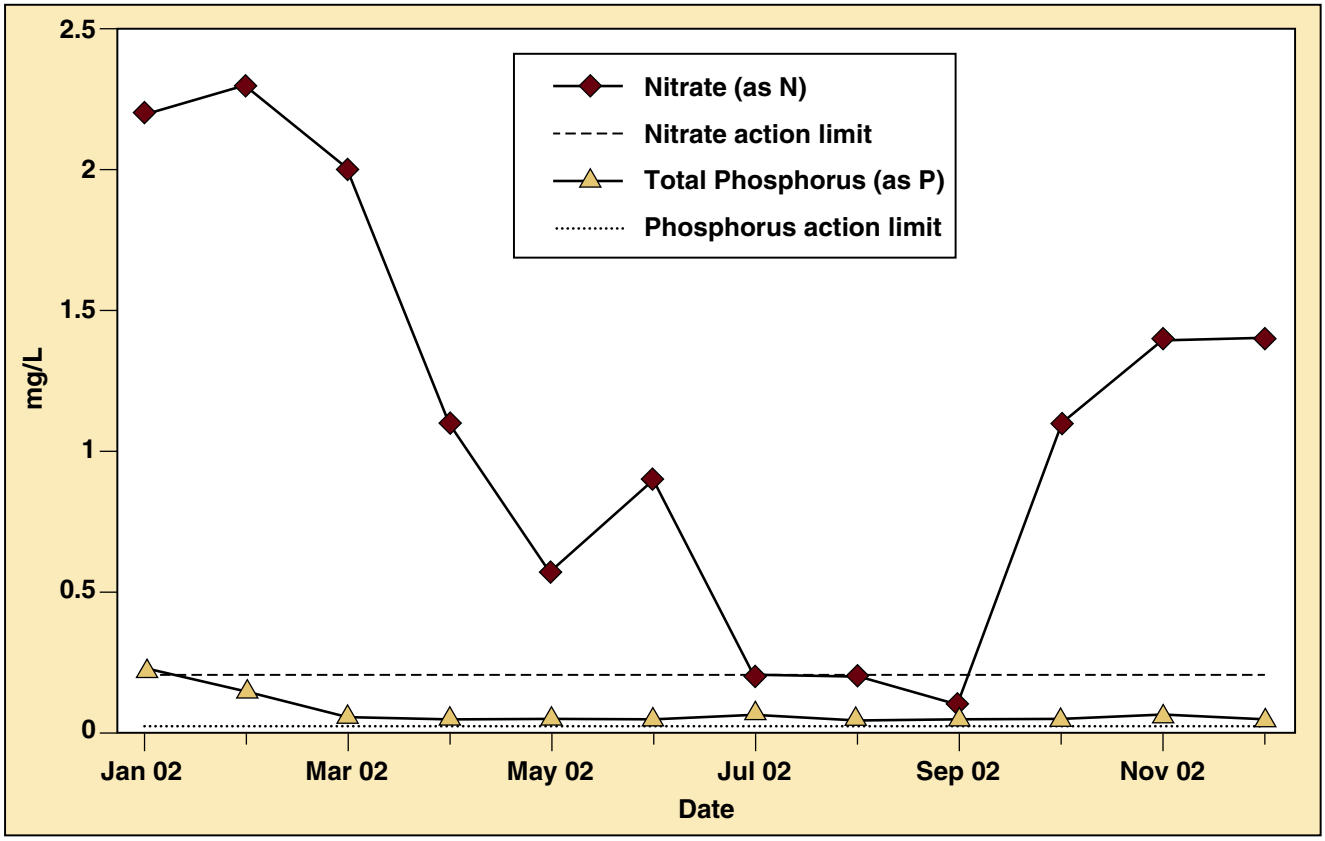


Figure 7-9. Nutrient levels in the Drainage Retention Basin, 2002

During 2002, total dissolved solids continued to exceed the management action levels (360 mg/L) in all 12 months when samples were collected. Specific conductance exceeded the management action level of 900 µS/cm for all 12 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. Amphibians found in the DRB and the Arroyo las Positas are listed in **Table 7-10**.

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 issuing a new permit (see discussion in **Chapter 2**) to incorporate these cooling tower discharges, and other low-threat discharges, going to ground. Pending the issuance of the new permit, LLNL continues to monitor the cooling tower wastewater discharges following the WDR 94-131 monitoring requirements at the direction of CVRWQCB staff.

Two primary cooling towers, located at Buildings 801 and 836A, regularly discharge to the ground. Blowdown flow from the cooling towers located at these two buildings is monitored biweekly. TDS and pH are monitored quarterly at both of these locations. The 13 secondary cooling towers routinely discharge to percolation pits under a waiver of Waste Discharge Requirements from the CVRWQCB. Cooling tower locations are shown in **Figure 7-10**.

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, LLNL 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 7-10**).

The GEOCRK sampling location is also fed by discharges of treated groundwater from Site 300. Therefore, even when the upstream location is dry, there may be flow at GEOCRK. Field pH measurements, taken by LLNL technicians using calibrated 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 only one discharge from the Buildings 801 and 836A cooling towers that was above the maximum values, previously imposed for discharges to surface water drainage courses, under WDR 94-131. The fourth quarter sample from the Building 801 tower showed a TDS value (2980 mg/L) above the previous limit of 2400 mg/L for discharges to surface waters. LLNL continues to monitor these discharges at the

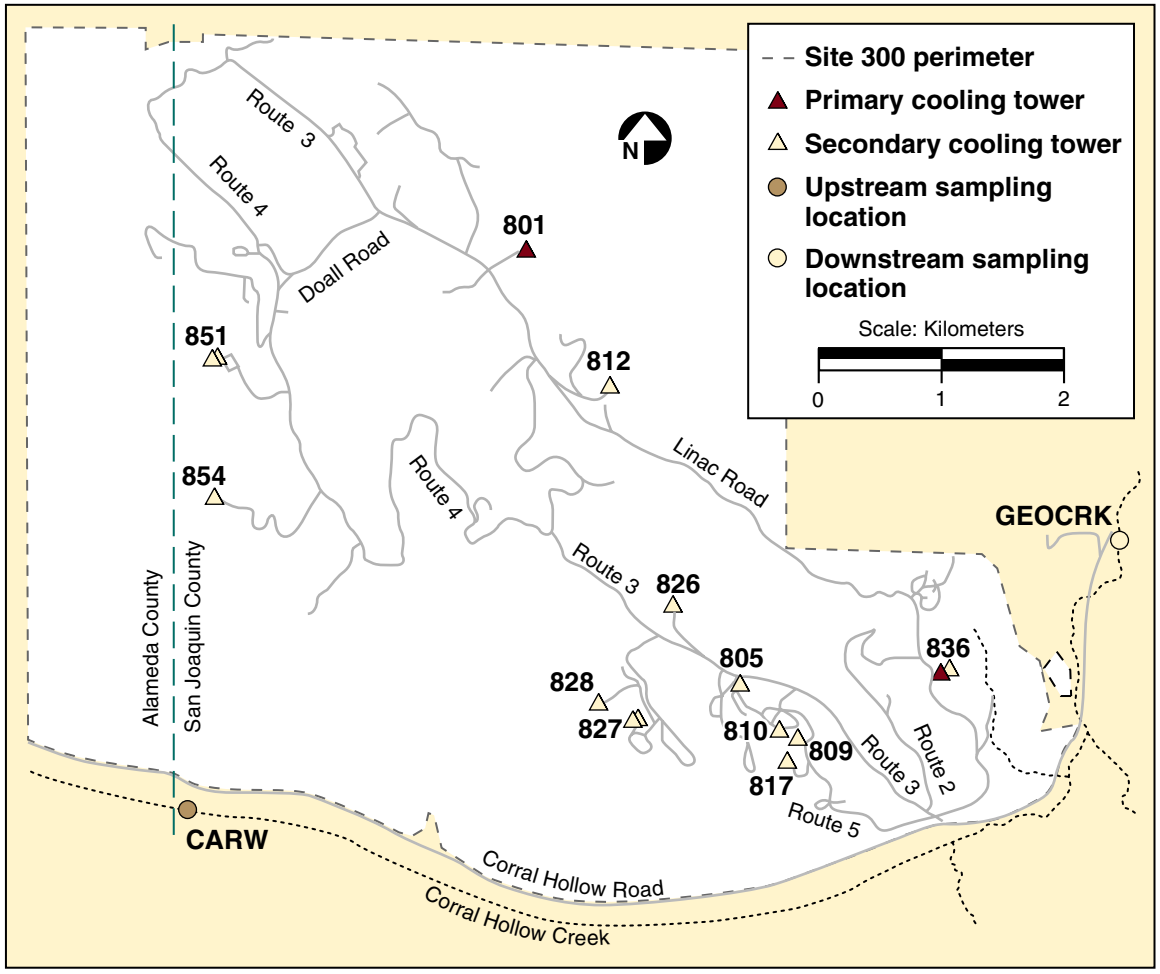


Figure 7-10. Cooling tower locations and receiving water monitoring locations, Site 300, 2002

direction of CVRWQCB staff. Resampling at this location, completed one month after the routine fourth quarter sampling, showed a TDS value of 1420 mg/L, which is a value consistent with the results from previous quarters. **Table 7-12** summarizes the data from the quarterly TDS and pH monitoring, as well as the biweekly measurements of blowdown flow.

The biweekly observations at CARW and GEOCRK reported conditions ranging from medium flow to dry for both sampling locations throughout 2002. Only on January 4 and December 18 was there adequate flow to measure pH. The resulting field pH measurements for the CARW and GEOCRK locations were 8.04 and 7.92 in January, and 8.50 and 8.51 in December, respectively. These results indicate 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 2002.

Table 7-12. Summary data from monitoring of primary cooling towers, Site 300, 2002

Test	Tower no.	Minimum	Maximum	Median	Interquartile range	Number of samples
Total dissolved solids (TDS) (mg/L)	801	1400	2980	1500	80	5
	836A	1230	1500	1350	—[a]	4
Blowdown flow (L/day)	801	0	12371	4970	4614	25
	836A	0	3596	1389	1915	25
pH (pH units)	801	9.0	9.2	9.1	—[a]	4
	836A	8.9	9.0	9.0	—[a]	4

a Not enough data points to determine

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.

Results

Monitoring results are detailed in the quarterly self monitoring reports to the CVRWQCB. Releases occurred in the first and second quarters of 2002. In both events difficulty was encountered obtaining valid chlorine readings with the field equipment due to interferences. Correction to the analysis protocols have since been instituted. The pH of all releases met the effluent limitations (see Table 7-13). These releases quickly percolated into the streambed and did not reach Corral Hollow Creek, the receiving water (see Table 7-14). In the third quarter, a line break at Tank 5 resulted in the release of 330,000 gallons of drinking water into Elk Ravine. Because of the nature of the release, water could not be dechlorinated and was not monitored. There were no releases in the fourth quarter.

Other Waters

This section discusses general information about monitoring network requirements, sampling methods, and sampling results.

Table 7-13. Measured pH and residual chlorine values in Site 300 drinking water system releases

Release location	Date	Estimated volume (gallons)	pH (units)		Residual chlorine (mg/L)	
			Effluent	Surface water	Effluent	Surface water
Permit limit		—	—	≥6.5, ≤8.5	—	0.02
Well 18[a]	March 15 (a.m.)	7200	8.4	—[a]	ND[b]	—[a]
Well 18	March 15 (p.m.)	—[a]	8.33	8.42	ND	NV[c]
Hydrant D13	April 3	70	7.66	NS[d]	NV	NS
Hydrant D6	April 3	70	7.48	NS	NV	NS
Hydrant D5	April 3	70	7.71	NS	NV	NS
Hydrant D3	April 3	70	7.79	NS	NV	NS

a Well 18 was one continuous release of 7200 gallons. Some parameters were sampled upon initiation (in the morning) and some were sampled later in the day.

b ND = Not detected at a concentration sensitivity of 0.01 mg/L.

c NV = Not valid, sample collected but result not valid due to interference.

d NS = Not sampled, volume of water entering surface water immediately soaked into the ground and a sample could not be collected.

Table 7-14. Field observations Site 300 drinking water system releases

Release location	Date	Observations
		Effluent location
Well 18	March 15	Flow rate estimated at 40 gallons per minute. Water flowed clear from defuser. No discoloration, sediment, or oil was noted in the water.
Hydrant D3, D5, D6, D13	April 3	No discoloration, sediment, or oil was noted in the water.
		Surface water location
Well 18	March 15	Flow entered Corral Hollow Creek, which was dry. Water was discolored due to sediment in the creek bed. Water flowed approximately 100 feet downstream and soaked into the dry creek bed.
Hydrant D3, D5, D6, D13	April 3	Approximately 20 gallons of flow from each hydrant entered Elk Ravine and immediately soaked into the ground.

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 7-11**. 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 7-15**) 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 January and July 2002, 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 was estimated from calculated values to be below the laboratory's minimum detectable activities, or minimum quantifiable activities. The maximum tritium activity detected was less than 1% of the MCL in drinking water from an off-site residence location PALM (**Figure 7-11**). 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 0.046 Bq/L and 0.253 Bq/L; both less than 15% of their respective MCLs (see **Table 7-15**). Detailed data are in Table 7-14 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, or in many cases greater than, the calculated values so that no trends are apparent in the data.

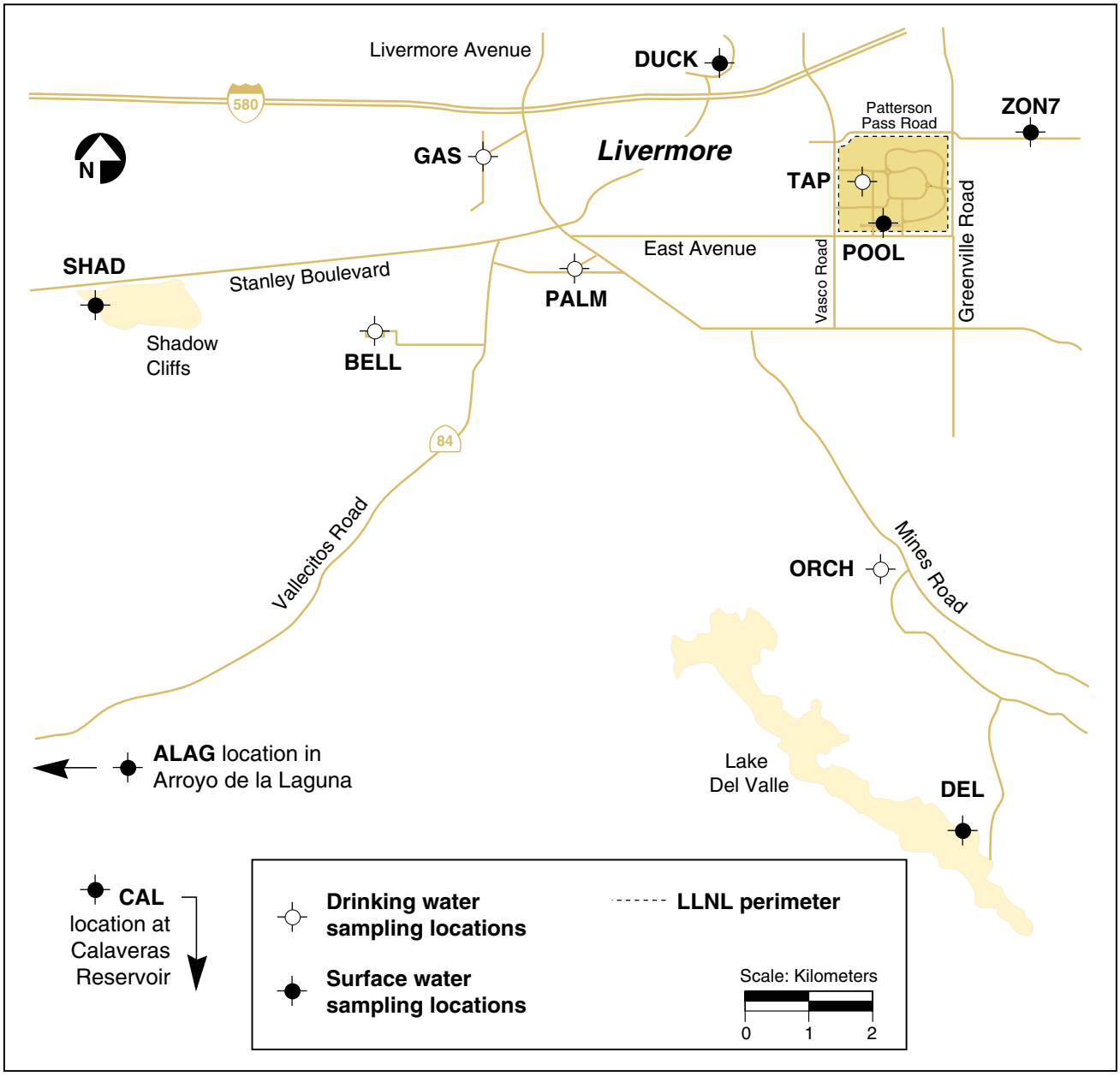


Figure 7-11. Surface and drinking water sampling locations, Livermore Valley, 2002

Historical median tritium values in surface and drinking waters in the Livermore Valley since 1988 are shown in Figure 7-12. Since 1988, when measurements began, water in the LLNL swimming pool has had the highest tritium activities until 2002 because it is closest to tritium sources within LLNL. No individual tritium activity measured in the pool in 2002 was greater than the minimum detectable activity, near 3.7 Bq/L, for these samples.

Table 7-15. Radioactivity in surface and drinking water in the Livermore Valley, 2002

Locations	Tritium (Bq/L)	Gross alpha (Bq/L)	Gross beta (Bq/L)
All locations			
Median	0.200	–0.001	0.074
Minimum	–2.36	–0.110	0.008
Maximum	4.81	0.046	0.253
Interquartile range	1.84	0.018	0.087
Drinking water locations			
Median	–0.323	0.000	0.054
Minimum	–2.36	–0.034	0.008
Maximum	4.81	0.030	0.253
Interquartile range	1.12	0.011	0.042
Drinking water MCL	740	0.555	1.85

Note: A negative number means the sample radioactivity was less than the background radioactivity.

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
- A nationwide permit for the construction of coffer dams issued by the Army Corps of Engineers in 2002

Work is done in pre-identified zones (**Figure 7-13**). Each year, no more than 20% of the arroyo length is desilted following the pre-identified patchwork pattern. During August and early September 2002, LLNL conducted maintenance work in Zones 2B, 1B (northernmost 100 feet), 1F, 5B, 2F, 4D, and 2E.

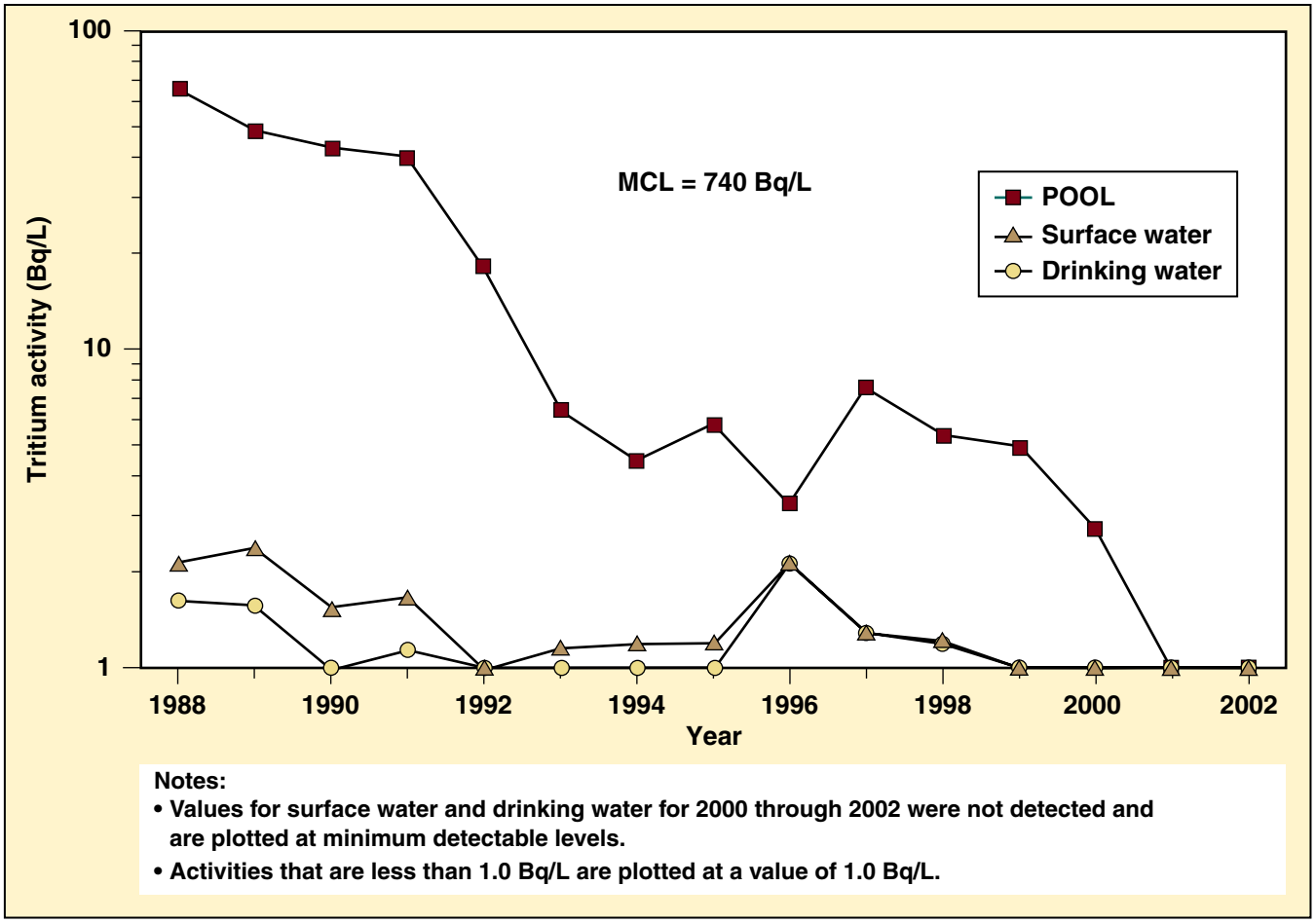


Figure 7-12. Annual median tritium activity in Livermore Valley surface and drinking water, 1988 to 2002

Discharges occur as a result of 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 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

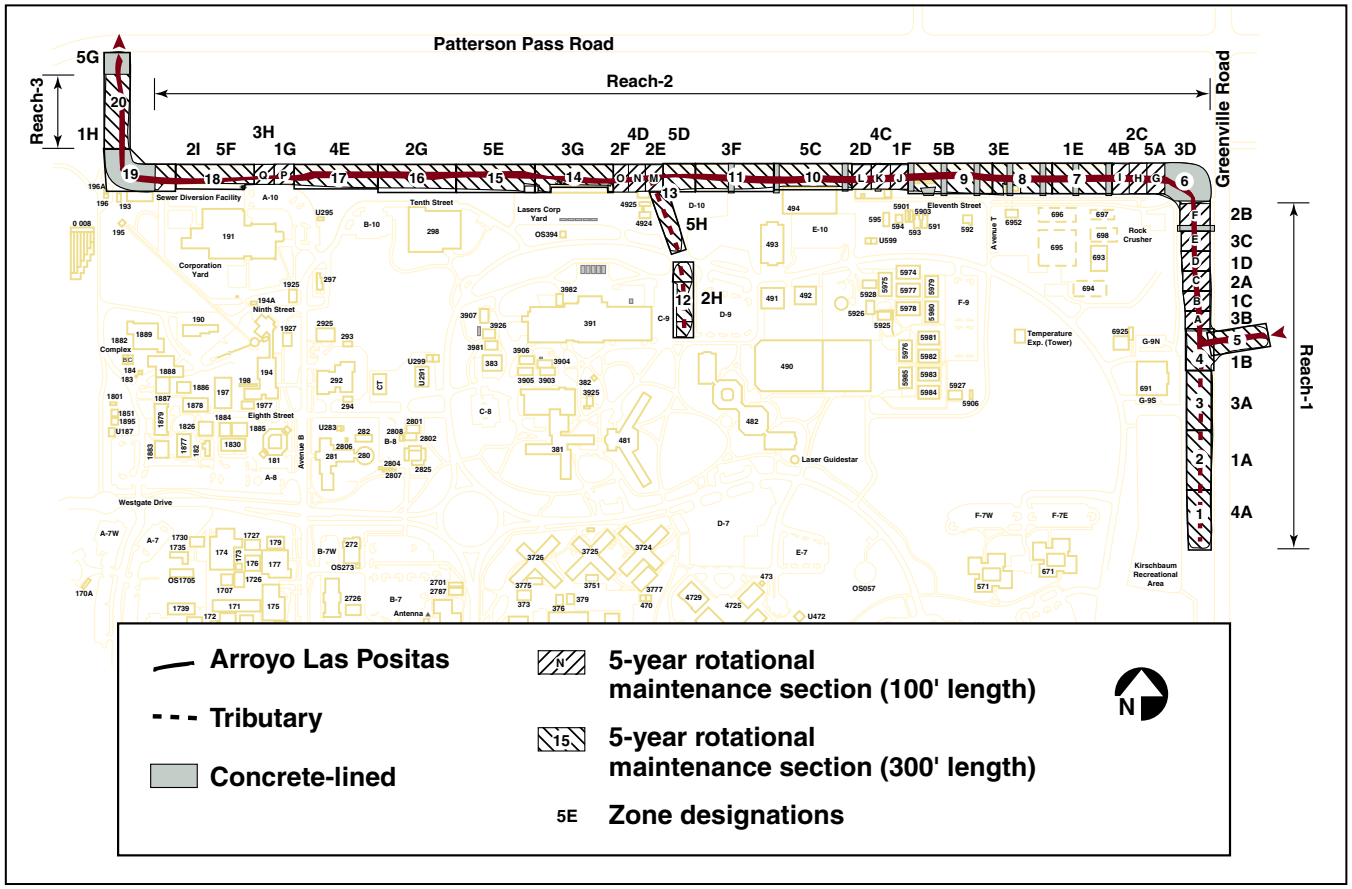


Figure 7-13. Arroyo Las Positas maintenance zones

collected to characterize the receiving water and help evaluate the impact of discharges on the receiving water.

Results

Monitoring results are presented in Table 7-16. 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 2002 so no annual self-monitoring report to the SFBRWQCB was required. Water diversion during desilting activities occurred only at Zones 1F, 5B, 2F, 4D, and 2E.

Table 7-16. Arroyo Las Positas maintenance project monitoring data, 2002

Location and Date	Time	Turbidity (NTU)	pH (pH units)	Dissolved oxygen (mg/L)
Location Zone 1F and 5B[a], prestart (background)				
July 31, 2002	1237	3.0	9.1	7.4
Location: Zone 1F and 5B[a]				
August 22, 2002	0926	2.6	9.2	6.0
August 22, 2002	1150	3.3	8.9	6.2
August 26, 2002	1000	2.8	9.1	5.9
August 26, 2002	1510	2.4	9.1	5.9
August 27, 2002	0840	3.4	9.2	6.3
Location: Zone 2F, 4D, and 2E[a], upstream (background)				
September 11, 2002	1030	3.3	9.0	5.8
September 12, 2002	1330	4.0	9.1	6.0
Location: Zone 2F, 4D, and 2E[a]				
September 11, 2002	0930	4.1	9.0	5.6
September 11, 2002	1400	3.7	8.9	5.5
September 11, 2002	1430	3.3	8.8	6.1
September 12, 2002	0930	4.4	8.8	6.1
September 12, 2002	1330	3.6	9.0	6.1

a Adjacent sections have 1 discharge sampling.

No flow diversions were required around Zones 2B and 1B because they were dry during the work period. Where flow diversions were needed, coffer dams were used in compliance with the Army Corp nationwide permit.

Environmental Impacts

This section discusses the environmental impacts of storm water, rainfall, the DRB, Site 300 cooling towers, Site 300 drinking water system discharges, other waters, and Arroyo Las Positas maintenance activities.

Storm Water

Storm water runoff from the Livermore site and Site 300 did not have any apparent environmental impacts in 2002. Tritium activities in storm water runoff effluent (location WPDC) were less than 1% of the drinking water MCL during 2002. Most values were below detection limits for tritium. Gross alpha and gross beta activities in Livermore site storm water effluent were both less than 32% of their respective MCLs.

Storm water quality runoff from Site 300 is similar to background levels. Although some 2002 storm water results were above comparison criteria at the

Livermore site, there is no evidence of any impact to off-site biota. The fish toxicity tests conducted during 2002 showed moderate toxicity in Livermore site storm water runoff likely caused by a pathogen in the arroyo unrelated to LLNL operations. Follow-up sampling in December 2002 found no fish toxicity. Algae toxicity was also identified in 2002; however, it has been demonstrated that this was caused by upstream pesticide applications not associated with LLNL 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 rose slightly from 1.97 Bq/L in 2001 to 3.1 Bq/L in 2002 (all less than 1% of the drinking water MCL). The measured tritium activities of rainfall samples taken at Site 300 were all less than the minimum detect-able activity (or less than the 2σ counting uncer-tainty). 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.

Site 300 Cooling Towers

During 2002, the monitoring results for flow, pH, and TDS from both primary cooling towers show only one value (the TDS value for the fourth quarter) above the 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

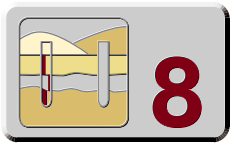
Although some difficulties were encountered in accurately monitoring the residual chlorine concentrations of the released water, releases did not reach the receiving water, Corral Hollow Creek, and most of the water percolated into dry streambeds where it could not negatively affect aquatic life.

Other Waters

The potential impact of tritium on drinking water supplies was estimated by determining the effective dose equivalent (EDE) (see Appendix C). Maximum tritium activity in drinking waters was 4.81 Bq/L. The EDE to an adult who ingested 2 L/day of water at this maximum concentration for a year would be 0.063 µSv, or 0.16% of the DOE standard allowable dose of 40 µSv 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 2002, 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 soil or 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. The sites are 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 km^2 (11.8 mi^2), 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 3.08 km^2 (1.3 m^2) is effectively one operable unit.

Livermore Site Ground Water 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 km^2. The alluvium, which is about 100 m thick, is the principal water-producing formation within the valley.

Hydrogeology of the Livermore Site

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 bodies, gravel lenses, and channels, bounded by the less permeable clay and silt.

The alluvial sediments have been mapped into nine 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 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 U.S. 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 water standards, or maximum contaminant levels (MCLs), 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 2002, the Livermore site Ground Water Project (GWP) treated more than 939 million liters of groundwater and removed approximately 146 kg of VOCs (**Table 8-1**). 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 zone (soil vapor) at the Livermore site through a system of 28 treatment facilities located throughout the 6 HSUs containing contaminants of concern. Extraction wells are used to extract groundwater for each facility, which is then treated to remove VOCs.

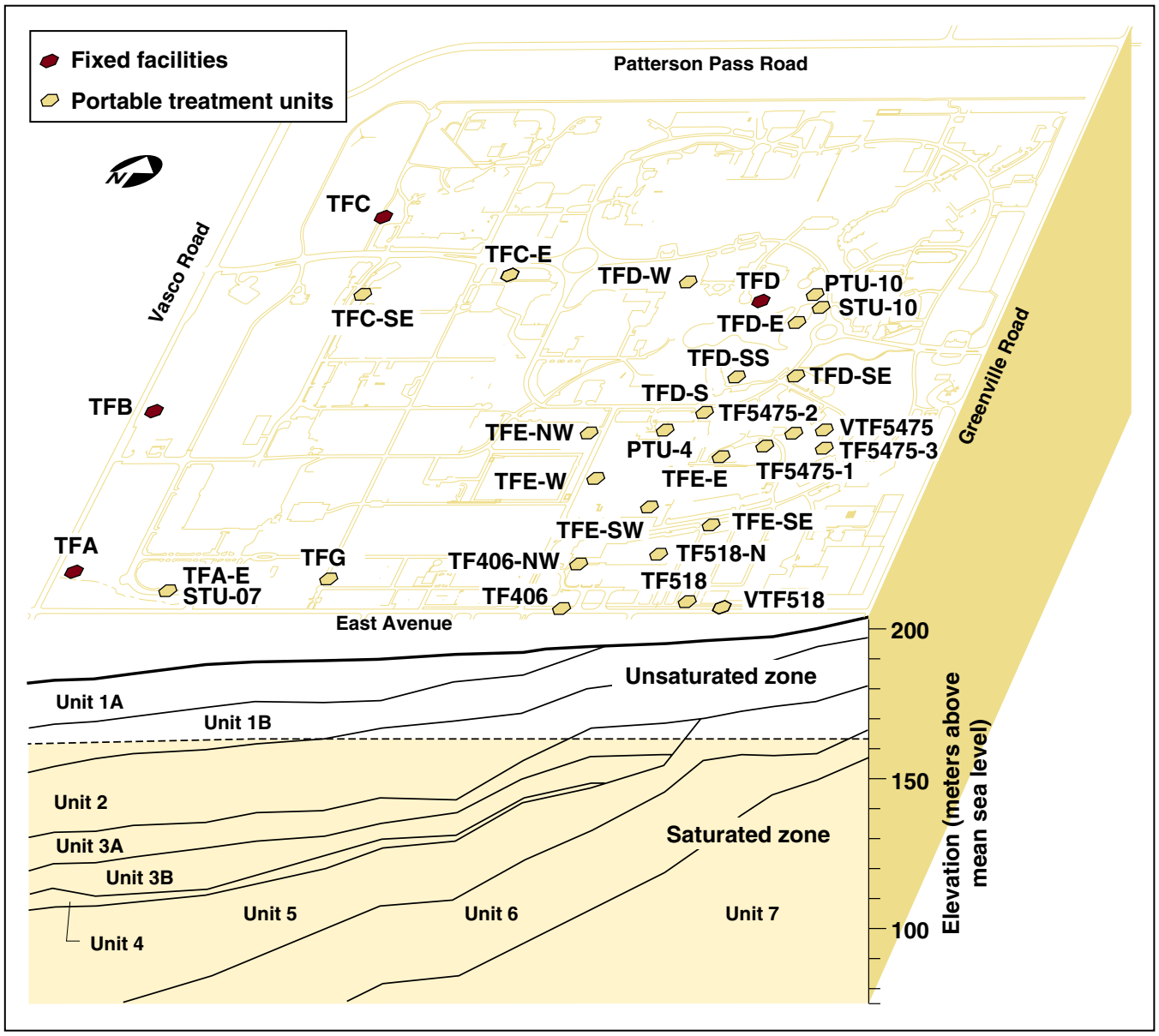


Figure 8-1. Map and cross section of the Livermore site showing hydrostratigraphic units and the locations of the treatment facilities

Treatment usually consists of removing VOCs with an air-stripping system, after which any VOCs present in the stripper's effluent air are removed with granular activated carbon filters. Treatment methods are noted in the following discussion of treatment facilities. Table 8-2 lists the extraction wells by treatment facility, according to the HSU in which they are screened, and the total flow rate for each treatment area.

Table 8-1. Volatile organic compounds removed from groundwater and soil at the Livermore site

Treatment facility[a]	Startup date	2002		Cumulative total	
		Water treated (ML)[b]	VOCs removed (kg)	Water treated (ML)	VOCs removed (kg)
TFA	9/89	251.4	5.7	3658	154
TFB	10/90	130.2	6.1	787	54.2
TFC	10/93	107.9	7.1	595	53.9
TFD	9/94	281.3	68.4	1505	500
TFE	11/96	110.5	17.5	544	139
TFG	4/96	12.1	0.7	70.4	3.7
TF406	8/96	40.5	1.0	211	7.7
TF518	1/98	4.9	0.6	37.1	4.3
TF5475	9/98	0.72	0.7	2.3	4.8
Total[c]		939	108	7410	921
		Soil vapor treated ($10^3 m^3$)	VOCs removed (kg)	Soil vapor treated ($10^3 m^3$)	VOCs removed (kg)
VTF518[d]	9/95	0	0	425	153
VTF5475[d]	1/99	143.5	37.7	659	306
Total[c]		144	38	1084	459

a Includes fixed and portable units

b ML = million liters

c Totals rounded to nearest whole number

d Vapor treatment facility

Of the 28 treatment facilities in operation in 2002, 27 are groundwater treatment facilities and 1 is a vapor treatment facility (VTF). A total of 82 groundwater extraction wells operated at 27 separate locations at an average flow rate of 1787 liters per minute (L/min). One vapor extraction well operated at an average flow rate of 0.27 m^3/min.

Since operations began in 1989, approximately 7410 million liters of groundwater and approximately 1.1 million m^3 of vapor have been treated, and more than 1380 kg of VOCs have been removed. **Table 8-1** shows both the 2002 totals and the cumulative totals of groundwater and soil vapor treated at the facilities and the estimated VOCs removed from the subsurface. A graph of VOC mass removal at the Livermore site since 1989 is presented in **Figure 8-2**. Concentrations of total VOCs in the third quarter 2002 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 new wells installed in 2002 are shown in **Table 8-3** by treatment facility area. Well construction details, well closure data, and results of hydraulic tests are provided in the *LLNL Ground Water Project 2002 Annual Report* (Dibley et al. 2003).

Table 8-2. 2002 summary of treatment facilities, associated extraction locations and wells, and extraction rates

Treatment facility area	Hydrostratigraphic Unit	Extraction wells	Average extraction rate (L/min) [a]
TFA	HSU 1B	W-262, W-254, W-408, W-520, W-601, W-602, W-1001, W-1004	478.2
	HSU 1B/2	W-415	
	HSU 2	W-109, 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	247.8
	HSU 2	W-357, W-621, W-655, W-1423	
TFC	HSU 1B	W-368, W-701, W-1015, W-1102, W-1103, W-1104, W-1116, W-1213	205.3
	HSU 2	W-413	
TFD	HSU 2	W-1215, W-1216, W-1303, W-1306, W-1308, W-1510, W-1602	535.1
	HSU 2/3A	W-906	
	HSU 3A/3B	W-1208, W-1301, W-1504, W-1550, W-1551, W-1552, W-1601, W-1603, 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-305, W-1109, W-1409, W-1518	210.3
	HSU 3A/3B	W-292, W-1422, W-1522	
	HSU 4	W-1211, W-1418, W-1520	
	HSU 5	W-359, W-566	
TF406	HSU 3A	W-1801	77.1
	HSU 5	W-1310	
TFG	HSU 1B/2	W-1111	23.0
TF518	HSU 4	W-1410	9.4
TF5475	HSU 2	W-1415	0.72
	HSU 3A	W-1302, W-1606, W-1608	
	HSU 5	W-1610	
VTF5475		SVI-ETS-504, W-1608	0.27 (scmm)[b]

a L/min= Liters per minute

b scmm = Standard cubic meters per minute

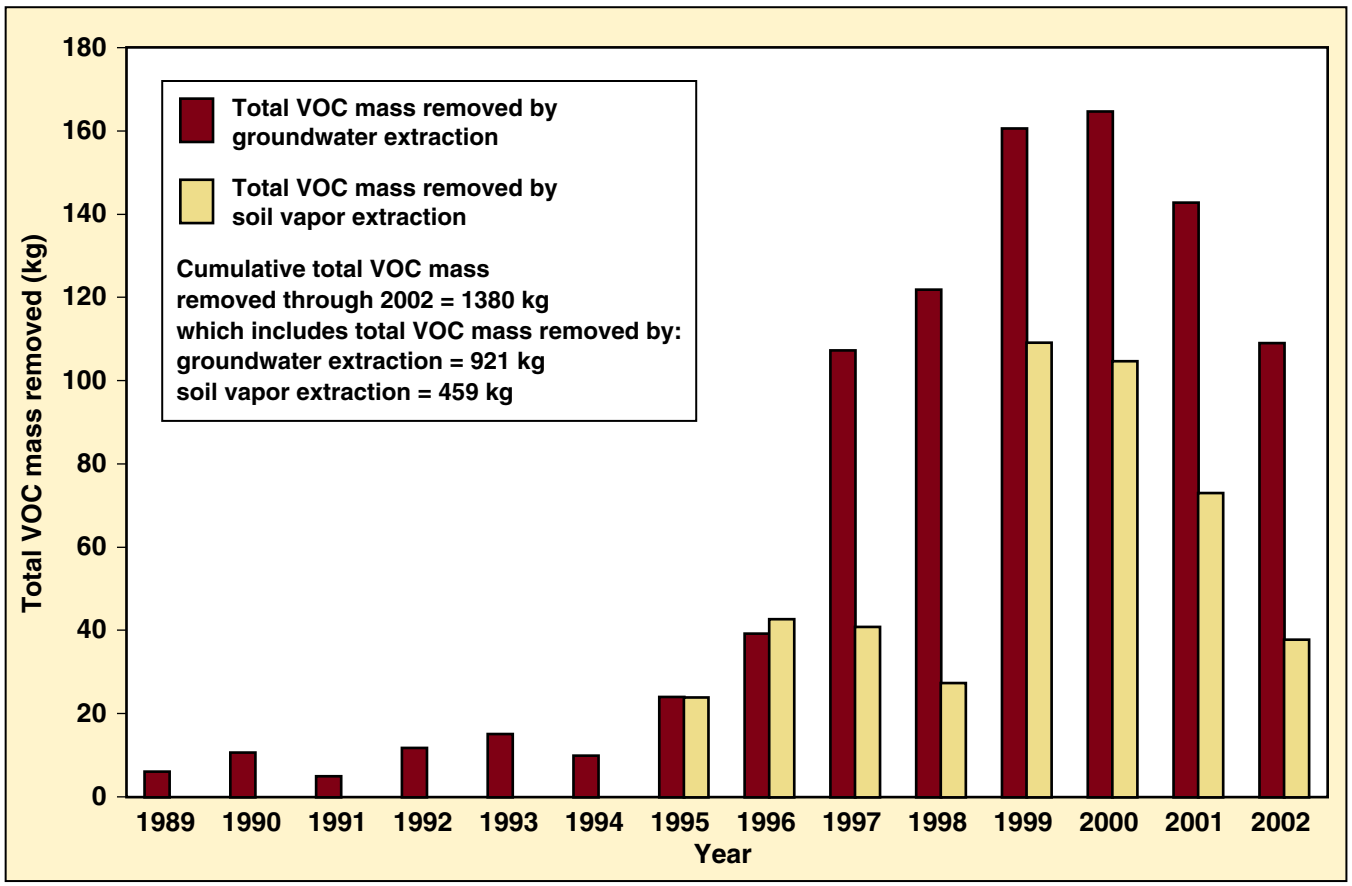


Figure 8-2. Total VOC mass removed from the subsurface of the Livermore site, 1989–2002

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 from HSUs 1B, 2, and 3A 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. 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). TFA has not exceeded the 5 parts per billion (ppb) total VOC discharge limit since the large capacity air-stripping system was installed in 1997. Solar treatment unit TFA East (TFA-E) is located east of TFA and removes VOCs in groundwater using granular activated carbon. TFA facilities were in compliance through 2002.

In 2002, wells at TFA and TFA-E pumped at a combined flow rate of about 478 L/min and the facilities treated 251 million liters of groundwater containing an estimated 5.7 kg of VOCs.

One new monitoring well (W-1805) was installed in the TFA area in 2002 (**Table 8-3**).

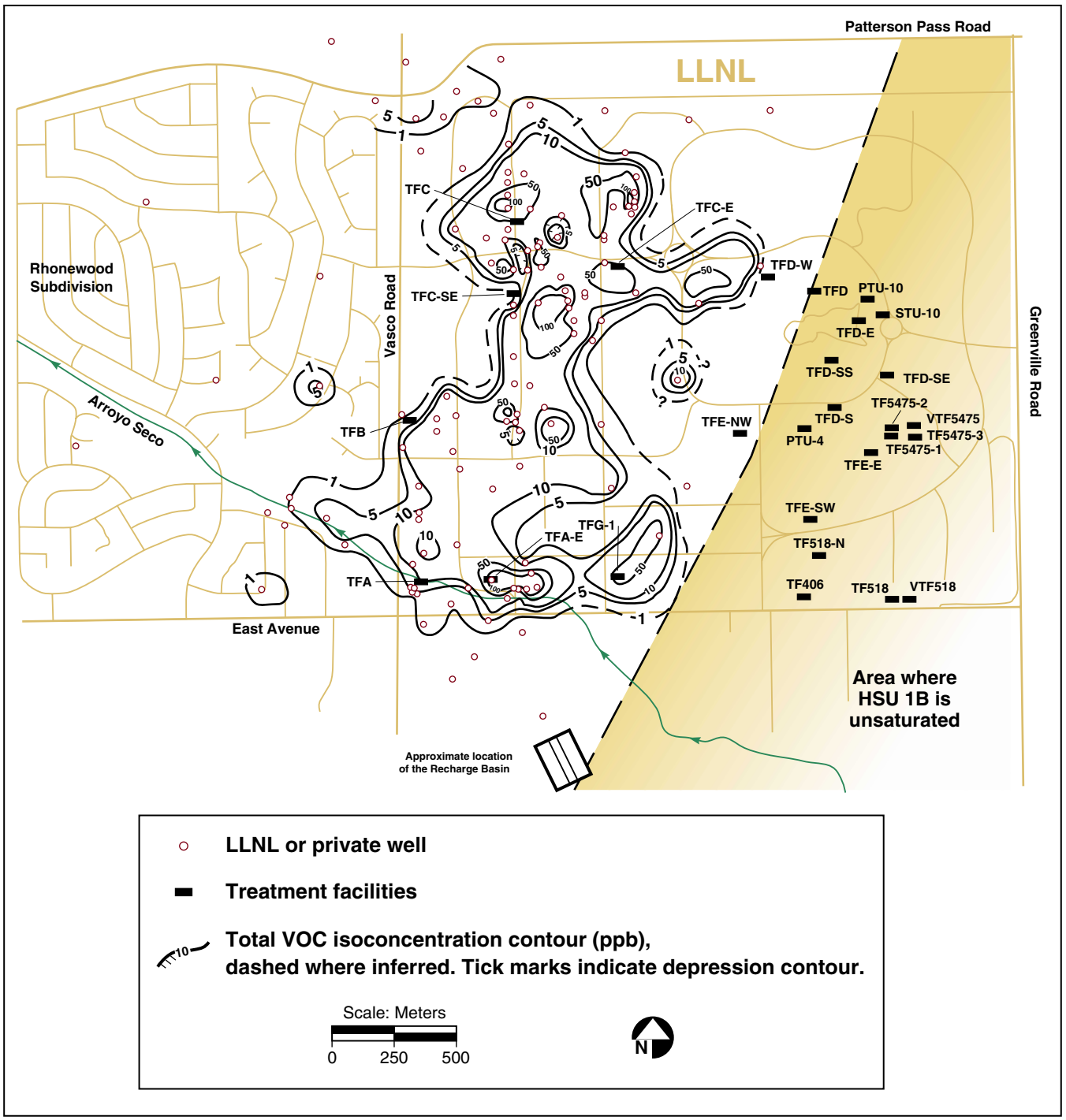


Figure 8-3. Isoconcentration contour map of total VOCs within HSU 1B (3rd quarter, 2002)

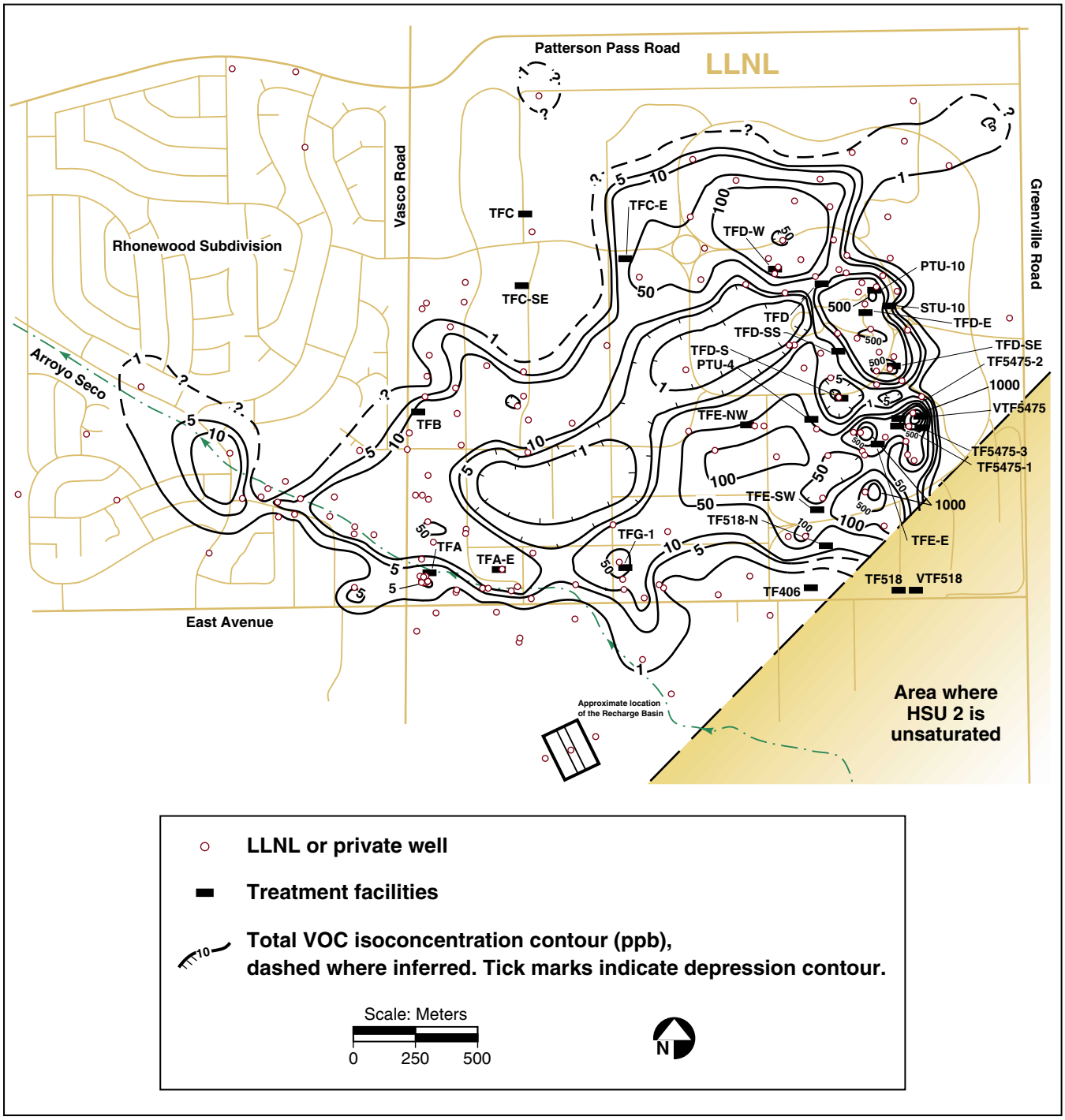


Figure 8-4. Isoconcentration contour map of total VOCs within HSU 2 (3rd quarter, 2002)

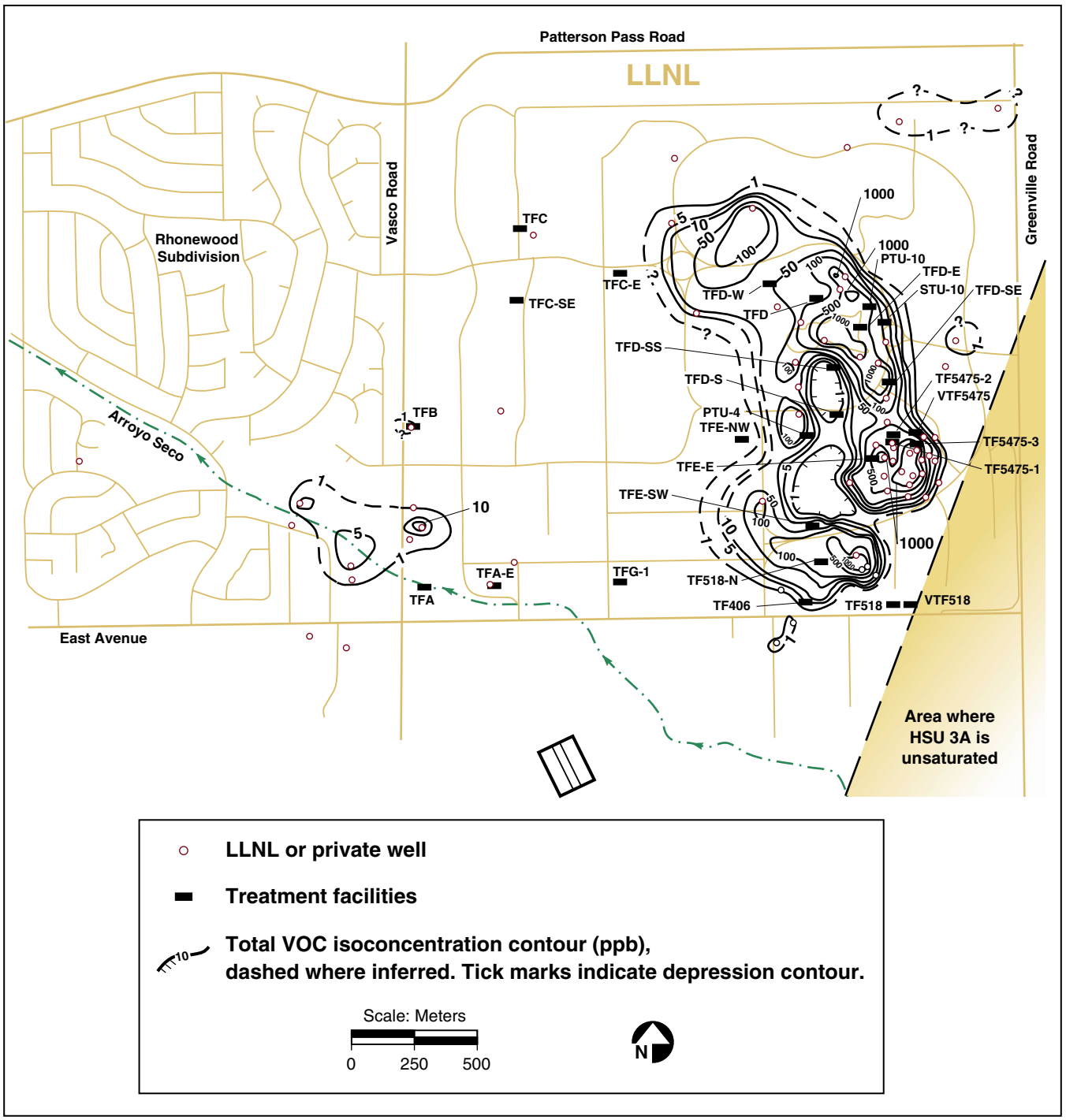


Figure 8-5. Isoconcentration contour map of total VOCs within HSU 3A (3rd quarter, 2002)

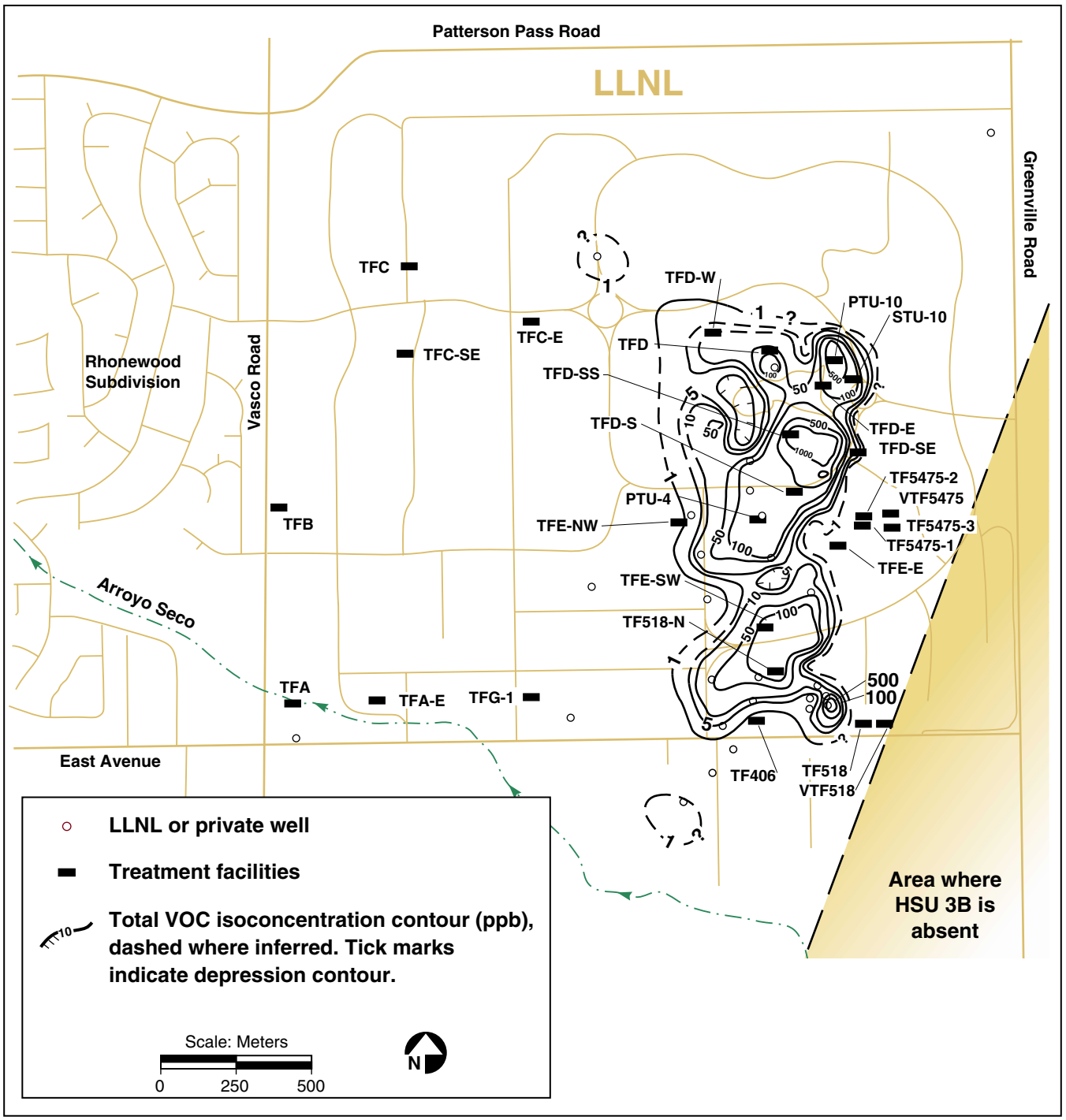


Figure 8-6. Isoconcentration contour map of total VOCs within HSU 3B (3rd quarter, 2002)

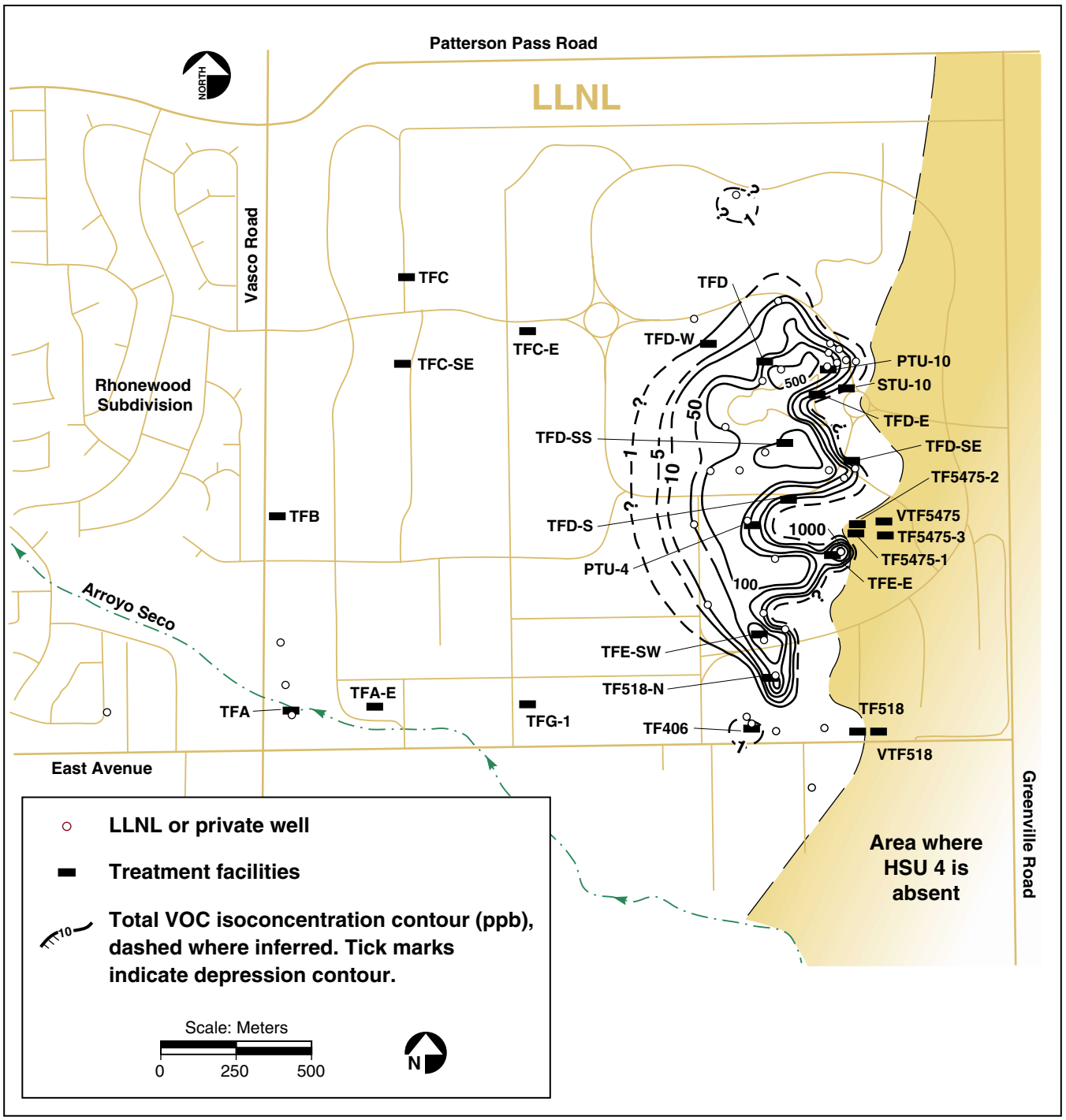


Figure 8-7. Isoconcentration contour map of total VOCs within HSU 4 (3rd quarter, 2002)

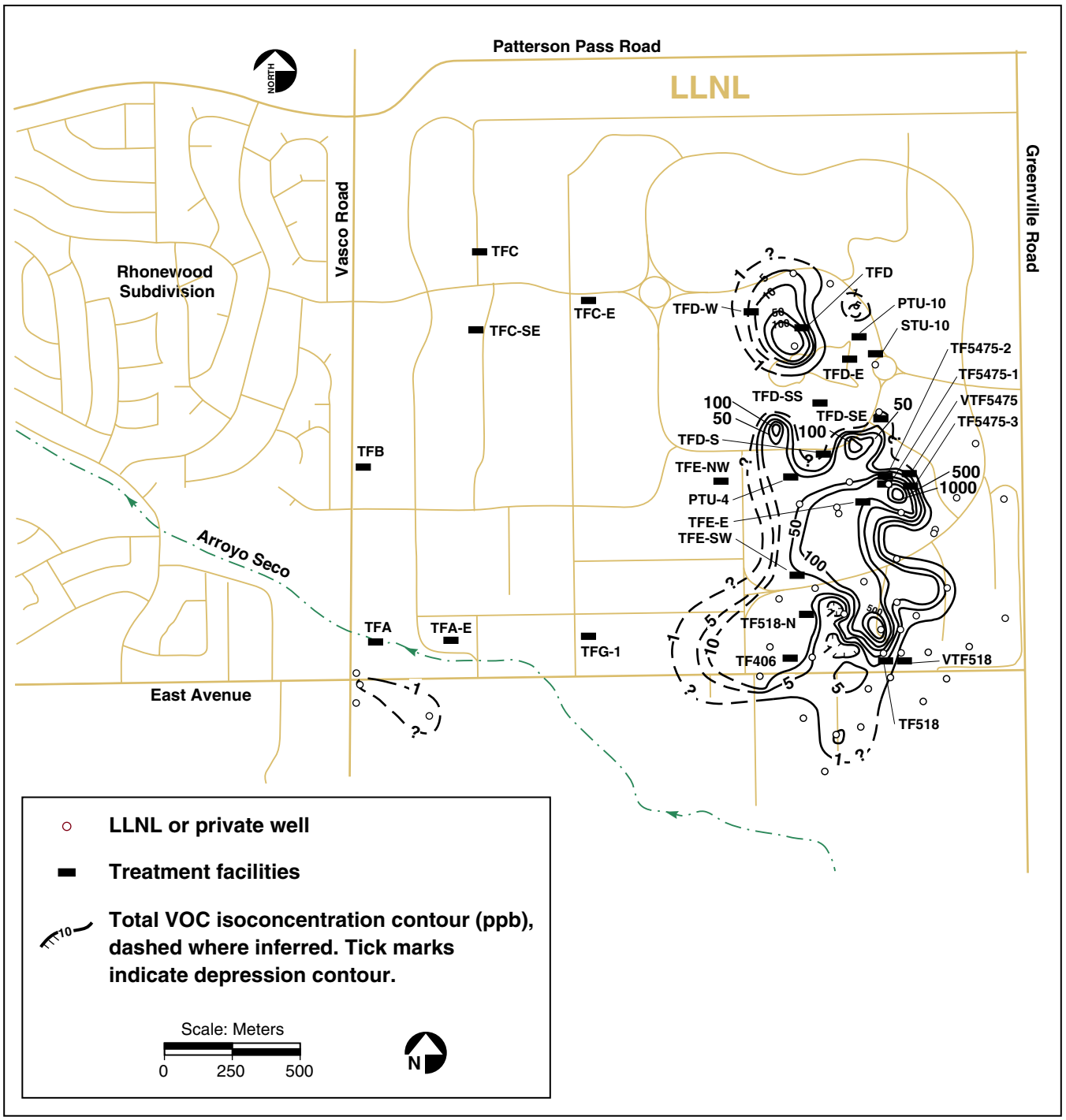


Figure 8-8. Isoconcentration contour map of total VOCs within HSU 5 (3rd quarter, 2002)

Table 8-3. Wells installed in 2002

Treatment facility area	Hydrostratigraphic unit	Monitoring/extraction well
TFA	HSU 1B	W-1805
TFB		None
TFC		None
TFD	HSU 2, 3A, 4	W-1802, W-1803, W-1804, W-1902
TFE	HSU 2	W-1903
TF406	HSU 3A	W-1801
TFG	HSU 1B, 2	W-1806, W-1807, W-1901
TF518		None
TF5475		None

Treatment Facility B

Treatment Facility B (TFB) is located in the west-central portion of the Livermore site (**Figure 8-1**). Groundwater from HSUs 1B and 2 is treated using the large-capacity air-stripping system installed in October 1998. This unit replaced an ultraviolet/hydrogen peroxide (UV/H_2O_2) system that had been in use since 1990. Groundwater is also treated for hexavalent chromium (chromium(VI)) in an ion-exchange unit, during December through March, based on the current San Francisco Bay Regional Water Quality Control Board (SFBRWQCB) 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 seven extraction wells at TFB pumped at a combined flow rate of about 248 L/min, and TFB treated about 130 million liters of groundwater containing an estimated 6.1 kg of VOCs in 2002.

In 2002, TFB was in compliance, and no new wells were installed.

Treatment Facility C

Treatment Facility C (TFC) is located in the northwest 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. A new treatment facility, TFC East (TFC-E), was constructed in 2002 and is located just west of the West Traffic Circle on the Livermore site.

TFC, TFC-E, 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 SFBRWQCB discharge substantive requirements. Treated groundwater from TFC is discharged into Arroyo Las Positas; from TFC-E and TFC-SE, groundwater is discharged into north-flowing drainage ditches that empty into Arroyo Las Positas to the north. The TFC effluent chromium(VI) concentration was below the wet season discharge limit of 22 ppb during 2002. All TFC treatment facilities were in compliance throughout 2002 (Dibley et al. 2003).

Wells in the TFC area pumped at a combined flow rate of about 205 L/min and the facilities treated about 108 million liters of groundwater containing an estimated 7.1 kg of VOCs. Since system start up in 1993, the combined TFC area facilities have treated more than 595 million liters of groundwater and removed about 54 kg of VOC mass from the subsurface.

No new wells were installed in the TFC area during 2002.

Treatment Facility D

The Treatment Facility D (TFD) area is located in the northeast quadrant of the Livermore site (see **Figure 8-1**). During 2002, 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 STU10 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, TFD-Southshore (TFD-SS), 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. PTU10 and STU10 are temporary facilities that are included in the TFD totals on **Table 8-1**. STU10 ceased operation in the TFD area in 2002.

Electroosmosis 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. Although no new electroosmosis tests were conducted in the TFD area in 2002, PTU10, located northeast of the DRB (**Figure 8-1**), continued to operate in 2002 by treating groundwater from wells W-1551, W-1552, W-1651, and W-1654 (all in HSU 3A/3B) to expedite VOC mass removal and source area cleanup.

The combined TFD facilities operated at an average flow rate of 535 L/min in 2002. During 2002, these units treated about 281 million liters of groundwater containing an estimated 68 kg of VOCs. Distal VOC plumes in the western TFD area should be hydraulically controlled now that TFC-E is operating.

Seven monitoring wells and two piezometers were sealed and abandoned in the TFD area in 2002. Monitor wells W-010A, W-211, W-360, W-414, W-1218, W-1220, and W-1221 were sealed due to construction of the Terascale Simulation Facility. Piezometers SIP-HPA-102 and SIP-HPA-103, located north of the DRB, were sealed due to the planned construction of a new cafeteria.

All TFD facilities were in compliance through 2002. Four new wells (W-1802, W-1803, W-1804, and W-1902) were installed in the TFD area during 2002 (**Table 8-3**) and a one-hour drawdown test was conducted on well W-1802 (Dibley et al. 2003).

Treatment Facility E

The Treatment Facility E (TFE) area is located in the southeastern quadrant of the Livermore site (**Figure 8-1**). Six treatment facilities, TFE East (TFE-E), TFE Northwest (TFE-NW), TFE Southwest (TFE-SW), TFE Southeast (TFE-SE), TFE West (TFE-W), and PTU4 operated in 2002 in the

TFE area (**Figure 8-1**). PTU4 is a portable hydraulic test unit that operates in the TFE area when not being used elsewhere for testing. PTU4 data are included in the TFE totals on **Table 8-1**. In 2002, 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-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.

All TFE area treatment units 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 the facilities is discharged into a drainage ditch that flows north into the DRB or into a storm drain that flows north into Arroyo Las Positas.

In 2002, TFE wells pumped at a combined flow rate of about 210 L/min and TFE area facilities treated about 110 million liters of groundwater containing an estimated 17.5 kg of VOCs. Since system startup in 1996, the combined TFE facilities have treated more than 544 million liters of groundwater and removed about 139 kg of VOC mass from the subsurface.

All TFE treatment facilities were in compliance in 2002. One new well (W-1903) was installed in the TFE area during 2002 to extract both water and soil vapor.

Treatment Facility G

Treatment Facility G (TFG) is located in the south-central portion of the Livermore site (**Figure 8-1**) and treats groundwater from one well. Groundwater is treated with a granular activated carbon unit and is discharged to a storm drain located about 15 m north of TFG. The storm drain empties into Arroyo Seco.

During 2002, TFG operated at an average flow rate of 23 L/min, treating 12.1 million liters of groundwater containing an estimated 0.7 kg of VOCs (**Table 8-1**). Since system startup in 1996, TFG has treated over 70 million liters of groundwater and removed about 3.7 kg of VOC mass from the subsurface.

All TFG treatment facilities were in compliance in 2002. Two new extraction wells (W-1806 and W-1807) and one new monitoring well (W-1901) were installed in the TFG area in 2002.

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**). 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. One new treatment facility, TF406-Northwest (TF406-NW), was added to the TF406 area in 2002. TF406-NW is a granular activated carbon treatment unit located east of Southgate Drive and south of South Outer Loop Road. Treated groundwater from TF406 facilities is discharged into the storm drain that flows north to Arroyo Las Positas.

Passive bioremediation continued in the TF406 area during 2002 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 (SFBRWQCB 1996).

During 2002, TF406 operated at an average flow rate of 77 L/min, treating more than 40 million liters of groundwater containing an estimated 1.0 kg of VOCs (see **Table 8-1**). Since system startup in 1996, TF406 has treated about

211 million liters of groundwater and removed about 7.7 kg of VOC mass from the subsurface (see **Table 8-1**).

All TF406 facilities were in compliance through 2002. One new extraction well (W-1801) was installed in 2002.

Groundwater Treatment Facility 518

One groundwater treatment facility, TF518 North (TF518-N), operated in the TF518 area in 2002. TF518-N is located south of South Outer Loop Road, north of Building 411 (**Figure 8-1**). 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 2002, TF518-N operated at an average flow rate of 9.4 L/min, treating 4.9 million liters of groundwater containing an estimated 0.6 kg of VOCs. Since system startup in January 1998, TF518 has processed approximately 37 million liters of groundwater containing an estimated 4.3 kg of VOCs (**Table 8-1**). No new wells were installed and no hydraulic tests were conducted in the TF518 area in 2002. All TF518 facilities were in compliance in 2002.

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**). VTF518 did not operate during 2002 due to a blower malfunction that was not repairable. The very low soil vapor flow rates (<0.028 m^3/min) yielded by VTF518 vapor extraction wells in 2001 were interpreted to be due to the high moisture content of shallow sediments at this location. The entire area around VTF518 was paved during 2002 to help reduce infiltration of surface water that may be contributing to the high moisture conditions. This area will be addressed by July 30, 2004 when both groundwater and soil vapor extraction and treatment are scheduled to be implemented.

Groundwater Treatment Facility 5475

Three groundwater treatment facilities (TF5475-1, TF5475-2, TF5475-3) operated in 2002 in the Treatment Facility 5475 (TF5475) area, located in the east-central portion of the Livermore site (**Figure 8-1**). TF5475-1 and TF5475-3 use catalytic reductive dehalogenation (CRD) to remediate the VOCs. Dual phase soil vapor and groundwater extraction capacity was added to the HSU 3A extraction wells at TF5475-2 in 2002.

During 2002, the TF5475 area facilities operated at an average flow rate of 0.72 L/min to treat about 0.72 million liters of groundwater containing an estimated 0.7 kg of VOCs. Since system start up in 1998, the combined TF5475 facilities have treated about 2.3 million liters of groundwater and removed about 4.8 kg of VOC mass from the subsurface (**Table 8-1**).

All TF5475 facilities were in compliance in 2002. No new boreholes or wells were drilled and no hydraulic tests were conducted in the TF5475 area during 2002.

Vapor Treatment Facility 5475

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**). 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 triti-

ated 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 2002, VTF5475 operated at an average flow rate of 0.27 m^3/min and treated 144 m^3 of vapor containing an estimated 38 kg of VOCs. Since system start up in 1999, VTF5475 has treated about 659,000 m^3 of vapor containing an estimated 306 kg of VOCs (**Table 8-1**).

Two instrumented membrane system (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. In 2002, VTF5475 was expanded to treat vapor from HSU3A dual phase extraction wells at TF5475-2.

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 LLNL's ability to forecast, monitor, and interpret the progress of the groundwater remediation program. In 2002, LLNL continued to improve its three-dimensional (3-D) and two-dimensional (2-D) groundwater models for the Livermore site, and began incorporating capabilities to evaluate regional scale dewatering issues. Continued use of the existing models and development of new models in 2002 are described below.

Three-Dimensional Models

In 2002, LLNL continued to use the 3-D groundwater flow and transport model developed for HSUs 1B and 2 (HSU 1B/2 model) to evaluate PCE and TCE transport throughout the Livermore site. The model was used to optimize extraction well flow rates, evaluate potential capture zones of proposed extraction wells, and evaluate plume migration and hydraulic interference patterns under increased pumping conditions. The HSU 1B/2 model was also used to evaluate the role of the Recharge Basin in the overall remediation of the TFA area. The model was revised to include recent well pumping histories, changing boundary conditions, and refined flow and transport parameters to evaluate the effect of varying the quantity of TFA effluent discharged to the Recharge Basin. LLNL 3-D simulations indicate that potential decreases in effluent discharge to the Recharge Basin would not adversely affect groundwater elevations or capture zones, and therefore should not prolong the overall remediation of the TFA area (Dibley et al. 2003).

In addition to the HSU 1B/2 model, preliminary work began to develop a new 3-D model that incorporates all identified HSUs beneath the Livermore site. The objectives of this 3-D model are to provide decision support for well field management that incorporates the limited vertical communication between HSUs, help understand the recharge characteristics of the deeper HSUs, and help evaluate regional-scale dewatering issues. The new 3-D model should be functional in fiscal year 2004.

Two-Dimensional Models

In 2002, LLNL continued to develop and improve 2-D models for deeper HSUs 3A, 3B, 4, and 5. The primary purpose of the individual 2-D models was to understand the flow and transport characteristics of each HSU separately before incorporating them into the larger, all HSU, 3-D model for the entire Livermore site. The 2-D models proved very useful in identifying the recharge and discharge boundary conditions of these HSUs, as well as areas of vertical communication. The 2-D model for HSU-2 was further refined to evaluate the effects of a potential injection well near the edge of saturation in the TFD area, and to help select the location for newly installed injection well W-1904. Alternative scenarios for the optimal location of an injection well and for different injection rates were simulated to evaluate the impact of injection in relation to plume migration, source area remediation, and dewatering issues.

Site 300 CERCLA Project

Environmental investigations and cleanup activities at Site 300 began in 1981. Site 300 became a CERCLA site in 1990, when it was placed on the National Priorities List. 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**. CERCLA work at Site 300 is conducted under a Federal Facility Agreement (FFA) and other requirements. Key milestone and deliverable due dates for 2002 are listed in **Table 8-5**.

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 volcaniclastic rocks.
- Jurassic-Cretaceous (65–180 million years ago)—Great Valley sequence (marine sedimetary rocks and ophiolites) and Franciscan Complex (sheared and variably metamorphosed sedimentary and igneous rocks).

Distinctive blue-gray to brown weathering volcaniclastic 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.

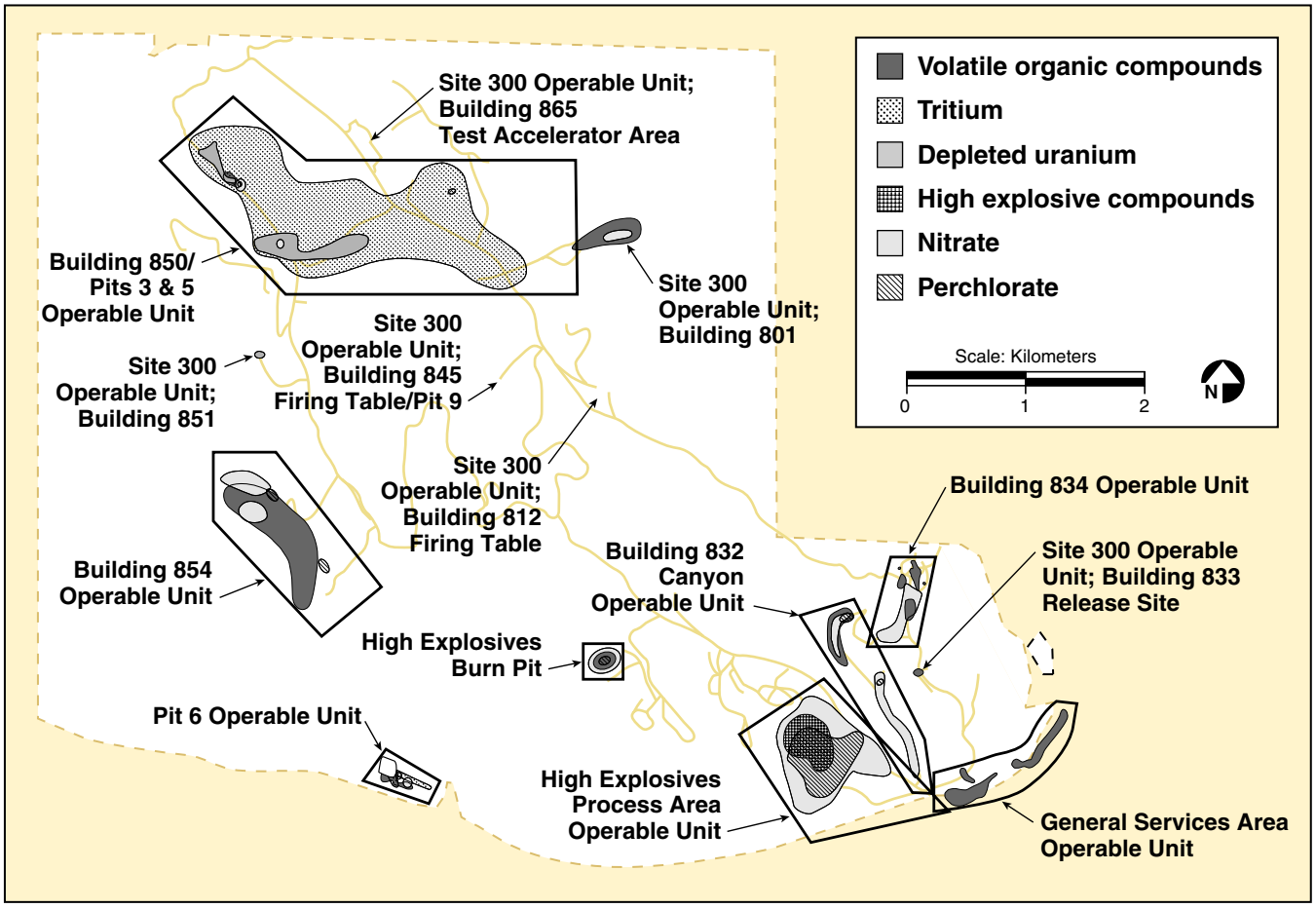


Figure 8-9. Contaminants of concern at environmental restoration operable units at Site 300

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
Pit 6 (OU3)	VOCs (primarily TCE), tritium, nitrate, perchlorate
High Explosives Process Area (OU4)	VOCs (primarily TCE), HE (primarily RDX), nitrate, perchlorate
Building 850/Pits 3 & 5 (OU5)	Tritium, depleted uranium, VOCs (primarily TCE), nitrate, perchlorate
Building 854 (OU6)	VOCs (primarily TCE), nitrate, perchlorate
Building 832 Canyon (OU7)	VOCs (primarily TCE), nitrate, perchlorate
Site 300 (OU8)	VOCs (primarily TCE and Freon 113), nitrate, perchlorate, depleted uranium, tritium, metals, RDX

a See Acronyms and Abbreviations for list of acronyms.

Table 8-5. Deliverable and milestone dates for Site 300 environmental restoration activities outlined in the FFA and other agreements, 2002

Deliverable/Milestone[a]	Due Date
Building 834 Draft Final 5-Year Review report	January 7, 2002
Building 834 Final Remedial Design report	January 28, 2002
Building 834 Final 5-Year Review report	February 7, 2002
High Explosives Process Area Draft Interim Remedial Design Report	February 18, 2002
Draft Site-Wide Compliance Monitoring Plan and Contingency Plan for Interim Remedies	March 29, 2002
Public Workshop for the Draft Site-Wide Compliance Monitoring Plan and Contingency Plan for Interim Remedies	April 16, 2002
Building 854 Characterization Summary report	May 3, 2002
High Explosives Process Area Draft Interim Remedial Design report	July 1, 2002
High Explosives Process Area Draft Final Interim Remedial Design report	August 1, 2002
Draft Final Site-Wide Compliance Monitoring Plan and Contingency Plan for Interim Remedies	August 13, 2002
High Explosives Process Area Final Interim Remedial Design report	August 15, 2002
Final Site-Wide Compliance Monitoring Plan and Contingency Plan for Interim Remedies	September 13, 2002
Construct B815-PRX groundwater extraction and treatment facility in the High Explosives Process Area OU	September 30, 2002
Initiate build-out and upgrade of the B834-SRC groundwater and soil vapor treatment facility in the Building 834 OU	December 2, 2002

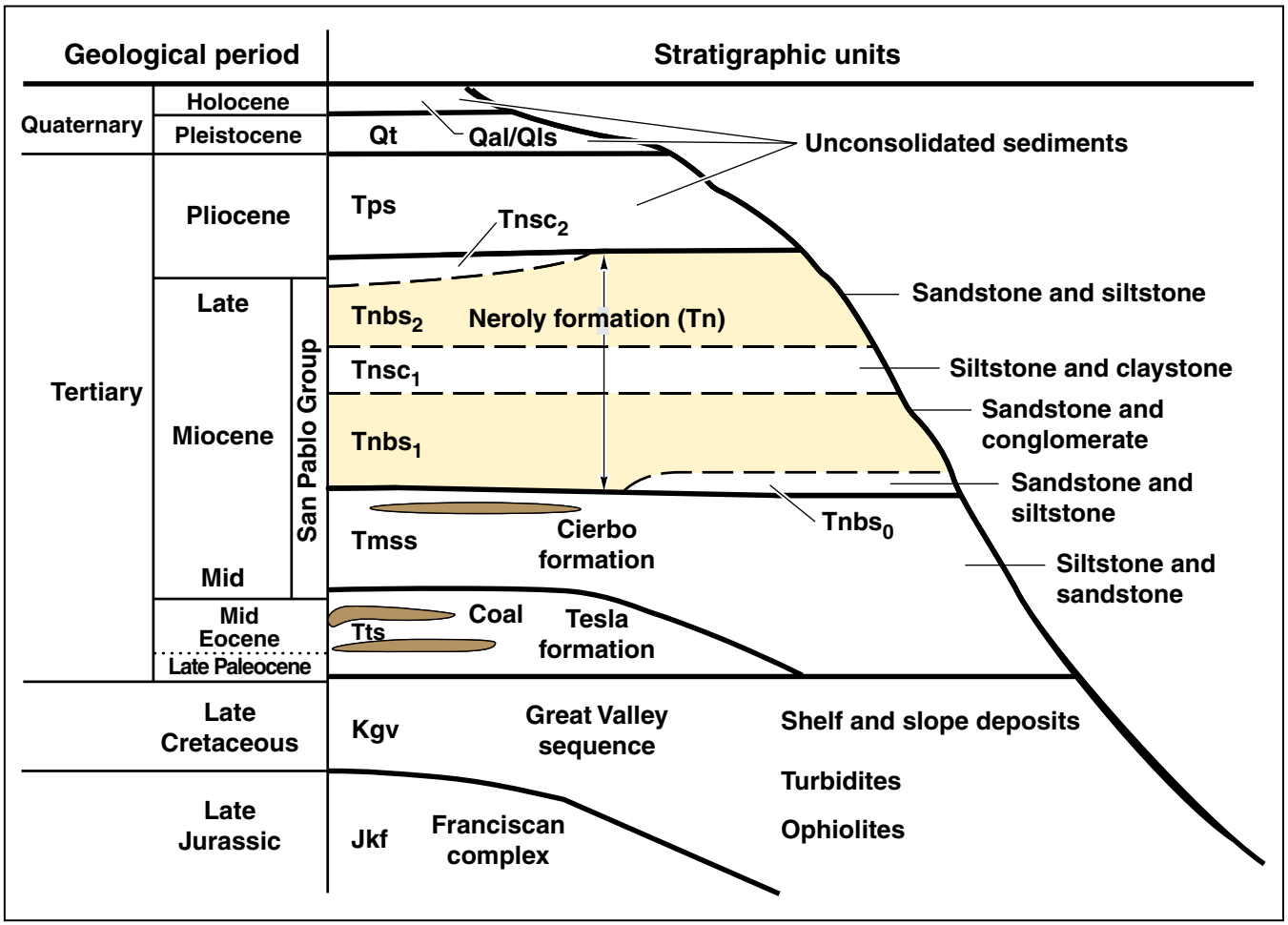
a See Acronyms and Abbreviations for list of acronyms.

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**).



Source: Webster-Scholten 1994

Figure 8-10. Site 300 stratigraphy

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 High 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 continuous water-bearing zone at

Site 300, which principally occurs in the Neroly lower blue sandstone aquifer ($Tnbs_1$).

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/High Explosives 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 High 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.

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 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**.

Remediation Activities at Site 300

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 documentation to oversight agencies on time in 2002. (See Chapter 2.)

Dedicated groundwater and soil vapor extraction and treatment facilities operate at the eastern GSA, central GSA, and Building 834 areas. Eight portable treatment facilities also are operating. Thus, in all, 11 treatment facilities that remove and treat VOCs operated throughout 2002. Twenty-

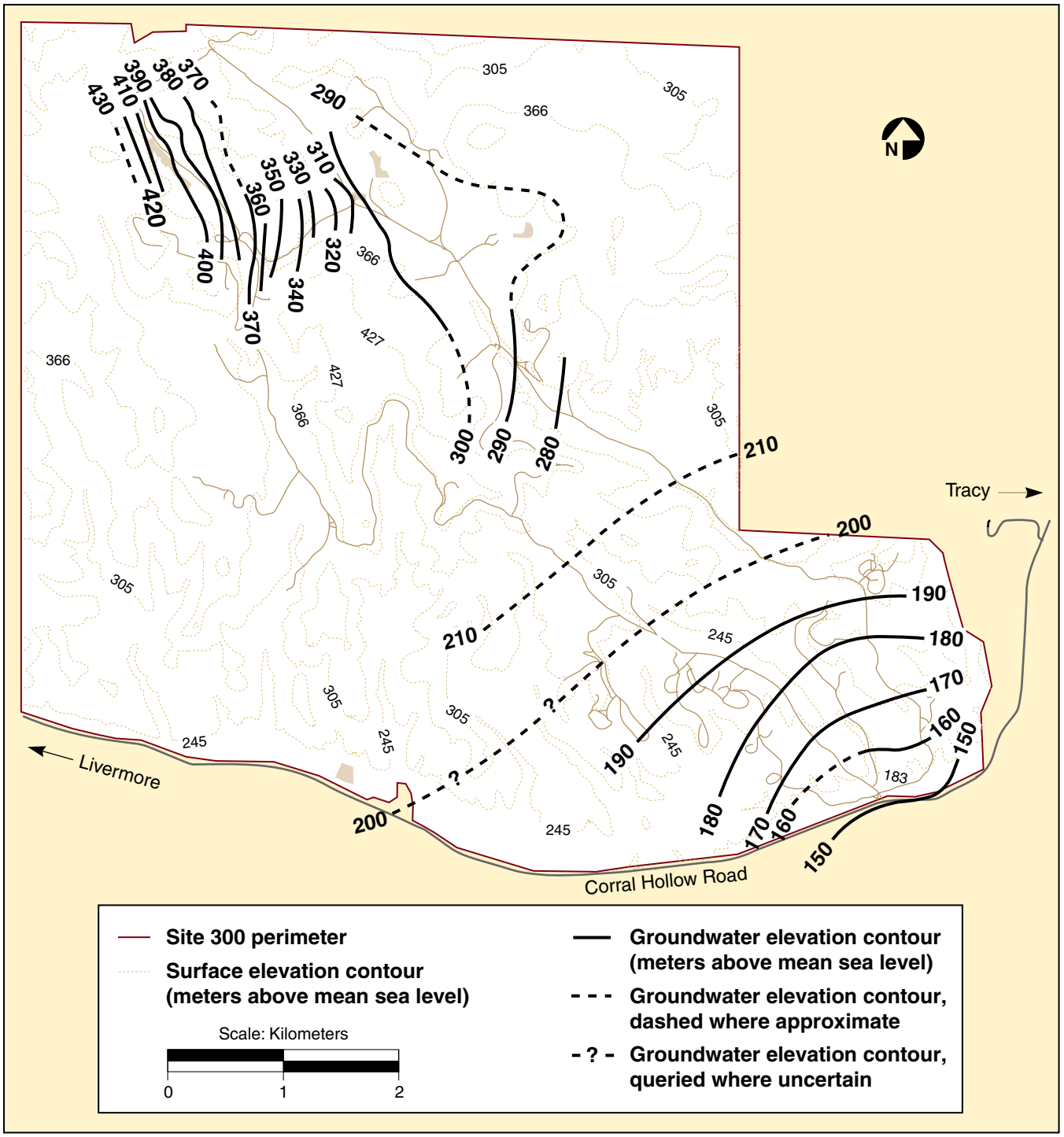


Figure 8-11. Approximate groundwater elevations in the principal continuous water-bearing zone at Site 300

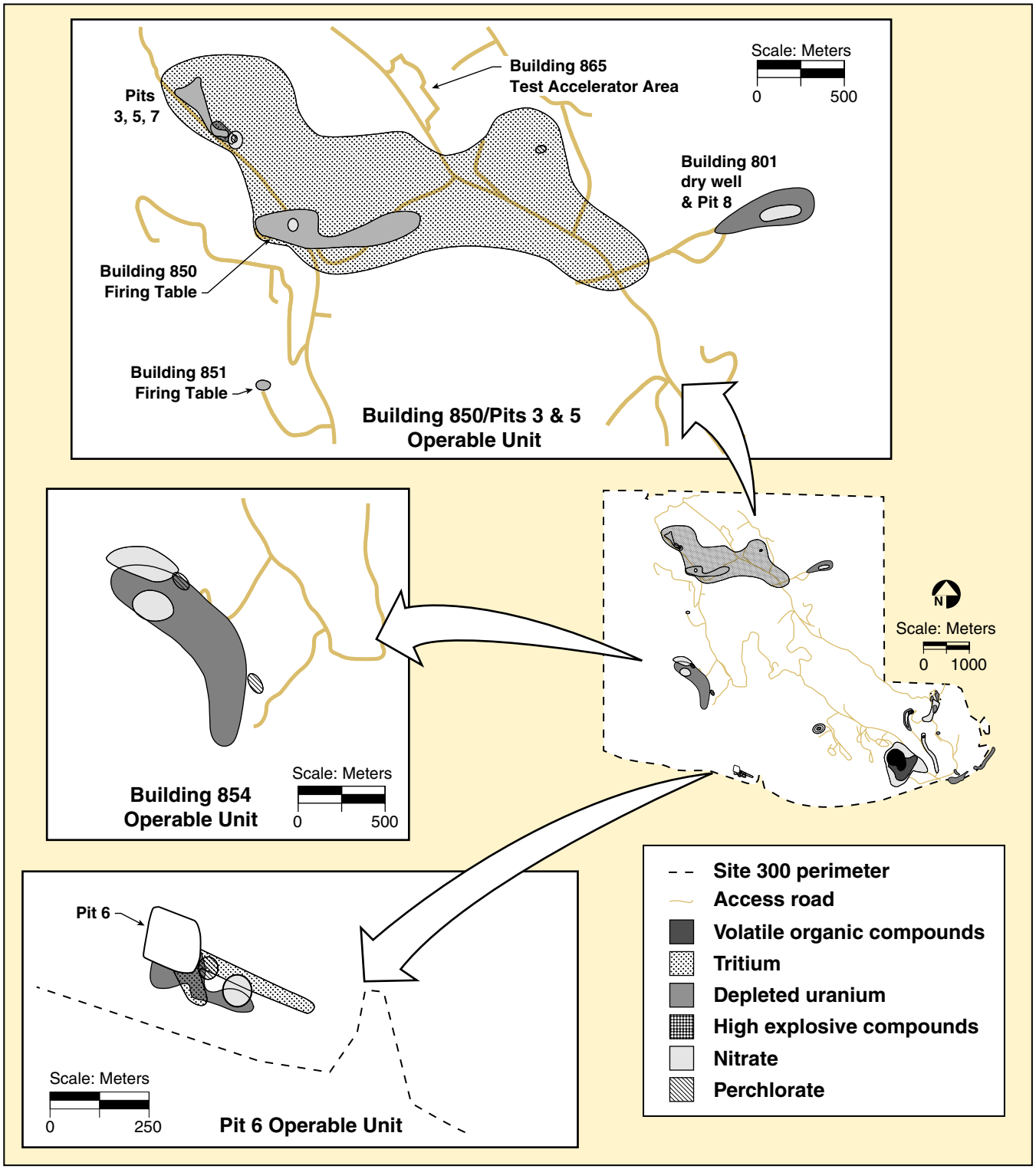
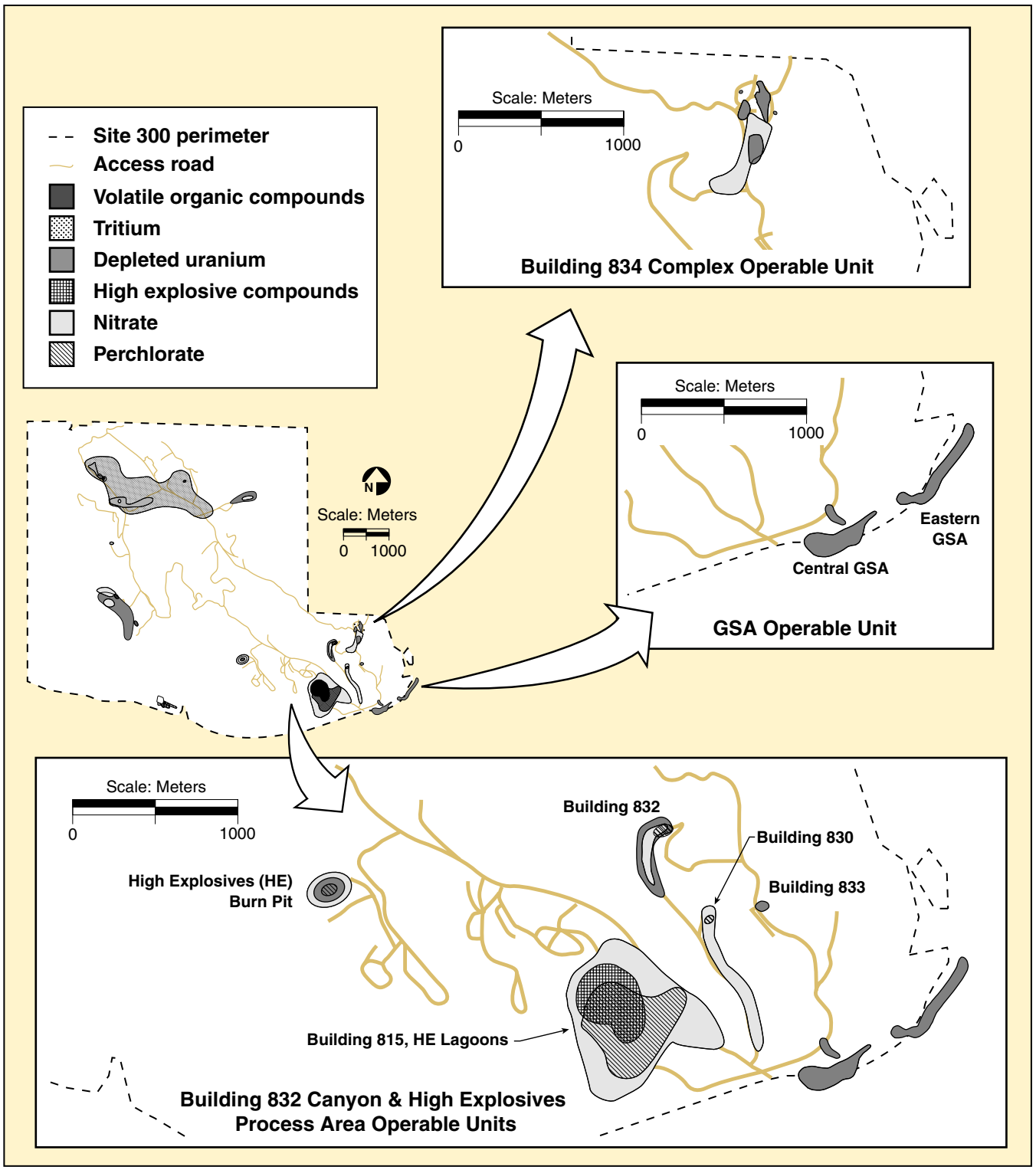


Figure 8-12. Extent of groundwater contamination at Site 300


Site 300 perimeter
Access road
Volatile organic compounds
Tritium
Depleted uranium
High explosive compounds
Nitrate
Perchlorate
Scale: Meters
0
1000
Building 834 Complex Operable Unit
N
Scale: Meters
0 1000
Scale: Meters
0
1000
Eastern GSA
Central GSA
GSA Operable Unit
Scale: Meters
0
1000
Building 832
Building 830
Building 833
High Explosives (HE) Burn Pit
Building 815, HE Lagoons
Building 832 Canyon & High Explosives Process Area Operable Units

one wells that extract only groundwater, 7 wells that extract only soil vapor, and 24 wells that extract both groundwater and soil vapor, operated during 2002. The 23 wells that extract only groundwater and the 24 wells that extract both groundwater and soil vapor yielded about 93.1 million L of groundwater. The 24 wells that extract both vapor and groundwater and the 7 wells that extract only vapor removed 795,960 m^3 of vapor. In 2002, the Site 300 treatment facilities removed approximately 9.5 kg of VOCs. Since remediation efforts began in 1990, more than 865 million L of groundwater and approximately 3.93 million m^3 of vapor have been treated, yielding about 231 kg of removed VOCs.

Table 8-6 summarizes 2002 and cumulative totals of volumes and masses of contaminants removed from groundwater and soil vapor at Site 300.

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 5 treatment systems discharge to air by misting.

Table 8-6. Volumes of groundwater and masses of volatile organic compounds (VOCs) removed from groundwater and soil vapor at Site 300

Operable Unit	Startup date	2002		Cumulative total	
		Water treated (ML)[a]	VOCs removed (kg)	Water treated (ML)[a]	VOCs removed (kg)
Eastern GSA	1991	78.7	0.17	806.6	6.19
Central GSA	1993	4.19	0.59	29.16	10.66
Building 834	1995	0.11	0.81	0.93	31.84
High Explosives Process Area	1999	4.5	0.012	10.5	0.058
Building 854	1999	3.67	0.78	12.25	6.14
Pit 6	1998	—[b]	—[b]	0.268	0.0014
Building 832	1999	1.90	0.12	5.68	0.44
Total		93.1	2.48	865.4	55.33
		Soil vapor treated ($10^3 m^3$)	**VOCs removed (kg)**	**Soil vapor treated ($10^3 m^3$)**	**VOCs removed (kg)**
Central GSA	1994	293.58	1.54	1987.18	66.16
Building 834	1998	406.18	5.19	1657.56	108.26
Building 832	1999	96.2	0.28	282.5	1.39
Total		795.96	7.01	3927.44	175.81

a ML = 1 million liters

b Groundwater treatment is not routine at Pit 6. A hydraulic pump test was conducted there in 1998.

The following sections describe background information, a summary of characterization activities, and groundwater remediation activities for each of the OUs. See Chapter 9 for a discussion of 2002 groundwater monitoring.

General Services Area Operable Unit

In the GSA, past leaks of solvents from storage areas and buried debris have resulted in several plumes of VOCs in groundwater. There are three major TCE plumes and two treatment facilities located within the GSA OU: the central GSA and the eastern GSA.

The VOC groundwater plume in the eastern GSA is present in a subsurface stream channel alluvium (Qal) at 3 to 9 m below ground surface; the plume, as defined by the 4th quarter 2002 1 ppb concentration contour, is about 427 m long (**Figure 8-13**). Groundwater flows east and northeast through the alluvium within Corral Hollow Creek. The maximum 4th quarter 2002 total VOC concentration in groundwater taken from eastern GSA wells was 7.5 ppb. The Qal is hydraulically connected to the Neroly Formation lower blue sandstone ($Tnbs_1$) unit.

Two VOC groundwater plumes in the central GSA are present in terrace alluvium (Qt) and Neroly Formation upper blue sandstone ($Tnbs_2$), at a depth of 3 to 9 m below ground surface. These VOC plumes, as defined by the 1 ppb concentration contour, are about 107 m and 488 m long (**Figure 8-14**). The maximum 4th quarter 2002 total VOC alluvial groundwater concentration was 958 ppb. Deeper regional groundwater also contains total VOCs at a maximum 4th quarter 2002 concentration of 5 ppb. This groundwater occurs at depths of 11 to 56 m below ground surface.

Details of current and planned environmental restoration activities at the GSA are summarized in the *Final Remedial Design* document (Rueth et al. 1998). The remedial design document includes the Contingency Plan and Compliance Monitoring Plan for the GSA OU.

Following dewatering of bedrock through groundwater extraction, soil vapor extraction and treatment of VOCs began in 1994. During 2002, 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 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.

Wells W-7R, W-7PS, and W-7P 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. This phase-two plan was presented to and accepted by the regulators at the Regional Project Managers meeting held on January 28, 2002. The addition of these extraction wells would enhance the system's ability to capture the contaminant plume and increase the mass removal.

Treatability tests are being scheduled to determine if passive venting of soil vapor extraction wells in the central GSA area would result in a suitable long-term remedial technology.

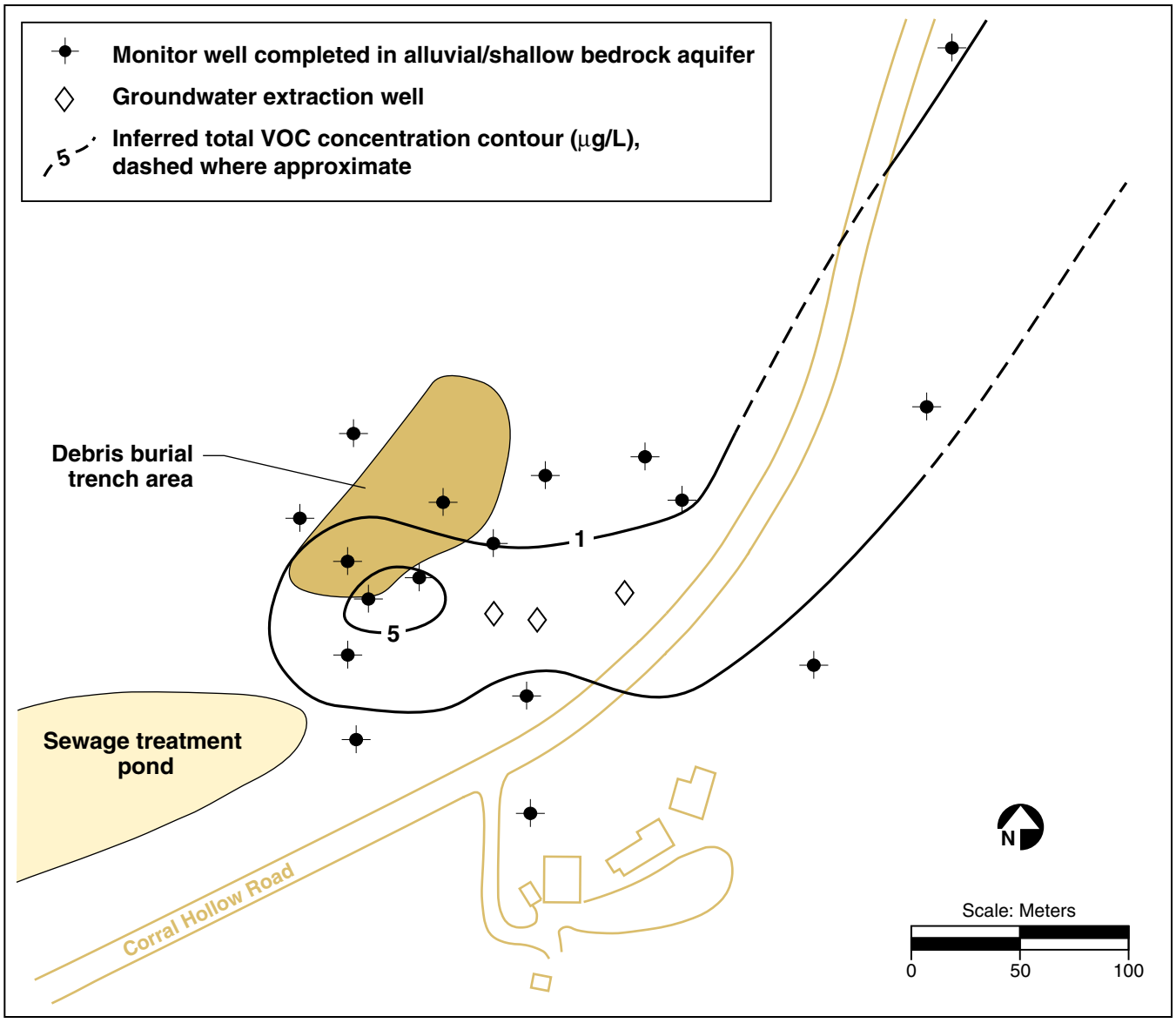


Figure 8-13. Total VOC concentrations in groundwater in the eastern GSA and vicinity (4th quarter, 2002)

Currently 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.

Table 8-6 shows the amounts of groundwater treated and VOCs removed at both the eastern and central GSAs.

Groundwater treated at the eastern GSA groundwater treatment facility was discharged off site to Corral Hollow Creek, in accordance with Waste

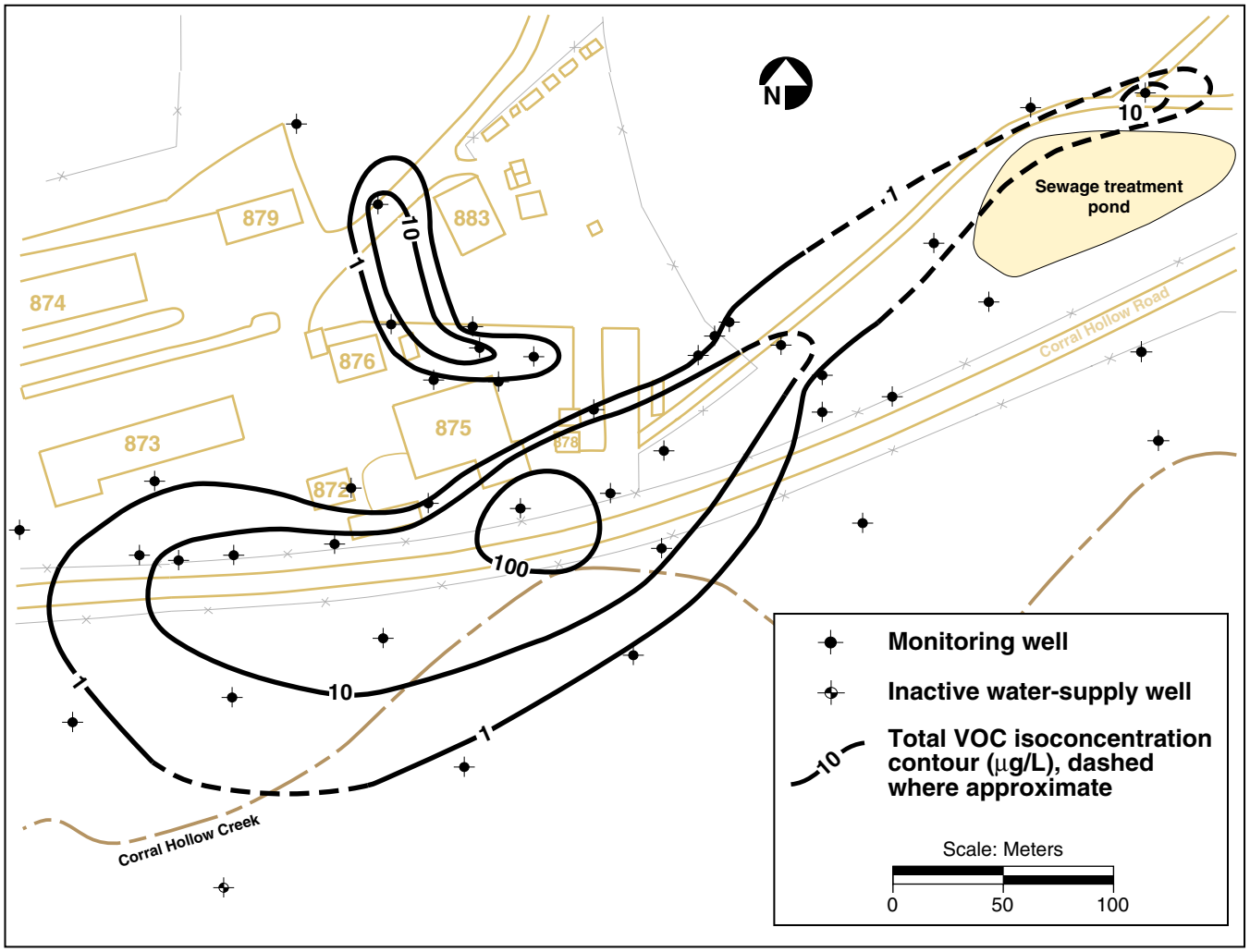


Figure 8-14. Total VOC concentrations in groundwater in the central GSA and vicinity (4th quarter, 2002)

Discharge Requirements Order No. 97-242 (WDR 97-242), National Pollutant Discharge Elimination System (NPDES) Permit No. CA0082651.

The central GSA groundwater treatment system is operating under substantive requirements for wastewater discharge issued by the CVRWQCB. Permit requirements for the central and eastern GSA groundwater treatment system are listed in Table 8-7. Both the central and eastern GSA treatment systems operated in compliance with regulatory requirements during 2002. LLNL submitted quarterly reports for the GSA treatment systems to the CalEPA and the CVRWQCB in accordance with the WDR 97-242 for the eastern GSA and the Substantive Requirements for Waste Discharge for the central GSA (Lamarre 2002a,b,c,d).

Building 834 Operable Unit

Since the late 1950s, the Building 834 facilities, consisting of twelve separate buildings, have been used for weapons testing activities. TCE was used as the primary heat transfer fluid in experiments involving thermal cycling of weapons components. TCE was pumped between buildings through

Table 8-7. General Services Area groundwater treatment system surface discharge permit requirements

Parameter[a]	Treatment facility[a]	
	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

a See Acronyms and Abbreviations for list of acronyms.

aboveground pipes. Occasionally, TCE was mixed with silicone oils, tetrabutyl ortho silicate (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-dichloroethene (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. LLNL believes that within this Tpsg unit there are multiple distinctive plumes that may be in hydraulic communication only during high groundwater elevations following

heavy rainfall events. The Tpsg is underlain by a clay perching horizon (Tps) that is also nearly saturated. The perched zone Tpsg and Tps strata crop out on all sides of the hill housing the Building 834 complex and are isolated from the underlying regional aquifer by more than 90 m of vadose zone. Although the maximum VOC groundwater concentrations within the Tpsg during 2002 was 87,000 µg/L, the highest VOC concentrations in groundwater were found in the Tps perching horizon. This perching horizon has a very low hydraulic conductivity, but does yield some groundwater. The highest concentration of VOCs in groundwater samples obtained from the Tps during 2002 was 220,000 µg/L, which was predominantly TCE. VOC distribution within the Tpsg is presented in **Figure 8-15**. The highest concentration of TBOS and TKEBS in groundwater during 2002 was 490,000 µg/L. High levels of nitrate (up to 280 mg/L) also occur in 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.

Currently, groundwater and soil vapor extraction (SVE) and treatment, using air-sparging and granular activated carbon, respectively, are in progress. The well field consists of twelve dual-phase extraction wells and three additional wells used for only SVE. Work was initiated during 2002 to expand the well field to wells outside of the core area. Testing the use of aqueous phase granular activated carbon for VOC removal from the groundwater continued during 2002. Plans are being made for the replacement of the current air-sparging system with aqueous phase granular activated carbon. Groundwater treatment began during the 4th quarter of 1995, followed by soil vapor extraction and treatment during the 3rd quarter of 1998.

Two major documents, both RDWP milestones, became final during 2002 (see **Table 8-5**). One peer-reviewed journal article was released for publication in 2002: "Anaerobic Biotransformation of Trichloroethene Driven by Tetraalkoxysilanes at Site 300, Lawrence Livermore National Laboratory, CA" (Vancheeswaran et al. 2002).

In 2002, the groundwater and SVE treatment system were operated at full scale for the first half of the year. Equipment problems, followed by programmatic activities, prevented any facility operations for the remainder of the year. The Defense Technologies Evaluations Program (DTEP) began conducting experiments in October 2002, which due to the hazardous nature of these experiments, resulted in personnel being excluded from the area. These experiments have continued into 2003 and will likely affect future operations. LLNL had been observing a significant drop in both groundwater and soil vapor VOC concentrations in the Building 834 area over the last couple of years. These declining VOC concentrations and temporary suspension of treatment operation provided an opportune time to allow for rebound of contaminants. LLNL will be conducting detailed monitoring activities following completion of the DTEP experiments to evaluate potential contaminant rebound in both the vapor and aqueous phase. As mentioned previously, in situ biodegradation via reductive dechlorination of TCE occurs in areas within the Building 834 core area where sufficient amounts of silicon oils exist. However, it was demonstrated that this intrinsic microbial degradation is inhibited during periods of active soil vapor extraction because the soil vapor extraction system draws oxygen-rich vapors into the subsurface and the microbes become dormant. In essence, the SVE system acts like an on/off switch to control biodegradation. As such, allowing the system to remain off-line will promote biodegradation and will achieve some level of mass removal, although this mass is not easily quantified.

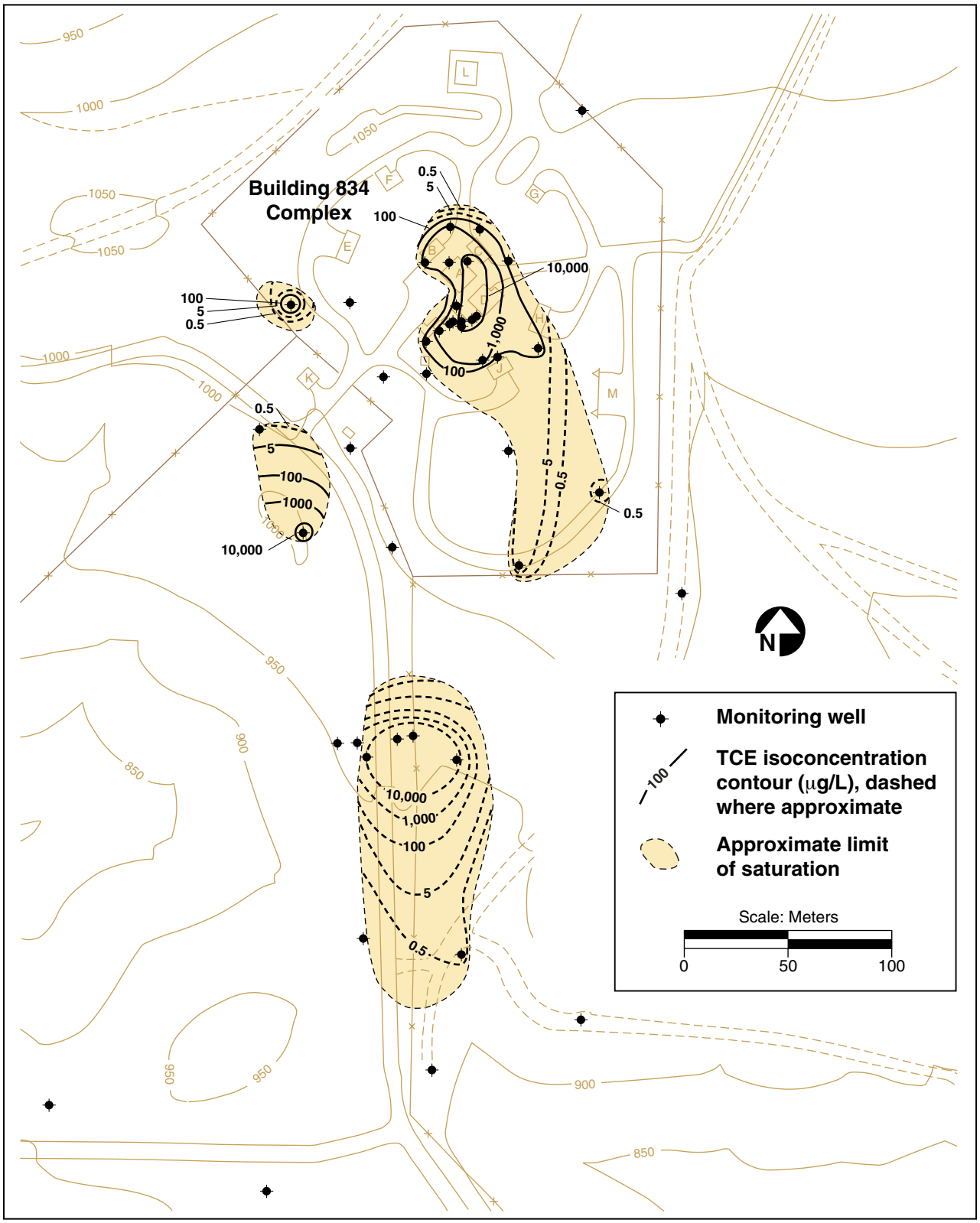


Figure 8-15. Isoconcentration contour map of TCE in groundwater in the Tpsg aquifer at the Building 834 complex (2nd quarter, 2002)

During 2001, the combined groundwater and soil vapor VOC mass removal at Building 834 was 31.96 kg. During 2002, the combined VOC mass removal at Building 834 was 6.0 kg. **Table 8-6** shows the volumes of water and soil vapor treated and masses of VOCs removed at Building 834. Quarterly reports for the Building 834 treatment facility were submitted to the EPA, CalEPA, and the CVRWQCB in accordance with the Substantive Requirements for Waste Discharge (Lamarre 2002e,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 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 perchorate was discharged to nine former unlined lagoons at concentrations high enough to impact groundwater.

A TCE hardstand, 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, perchlorate, and RDX occur in groundwater within two separate water-bearing zones. One of the zones occurs in the Pliocene Tps Formation and the other occurs in the $Tnbs_2$ sandstone aquifer within the late Miocene Neroly Formation. Depth to groundwater ranges from 2 to 76 m beneath the area. The VOC (principally TCE) plume in Tps strata is about 200 m long; the VOC plume in the $Tnbs_2$ 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 $Tnbs_2$ aquifer. The extent of nitrate above the MCL in the $Tnbs_2$ aquifer is about 700 m long. The maximum 2002 concentrations of TCE, RDX, nitrate, and perchlorate were 80 µg/L, 93 µg/L, 130 mg/L, and 30 µg/L, respectively.

The remedial strategy for groundwater cleanup in the High Explosives Process Area was presented in the *Interim Remedial Design for the High Explosives Process Area Operable Unit at Lawrence Livermore National Laboratory Site 300* report (Madrid et al. 2002). This report was finalized in August 2002.

The High Explosives 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 the area immediately downgradient (south) of the Building 815 Source Area to the vicinity of Buildings 818 and 823. The Distal Site Boundary Area is located in the southern part of the High Explosives Process Area, where the Site 300 boundary is located.

Contaminants, mainly the VOC TCE, the HE compound 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 $Tnbs_2$ aquifer resides beneath the Proximal Area. Distal Site Boundary Area contains TCE at low concentrations, generally below 30 µg/L; however, RDX and perchlorate are not present in this area at concentrations above EPA method detection limits for those chemicals.

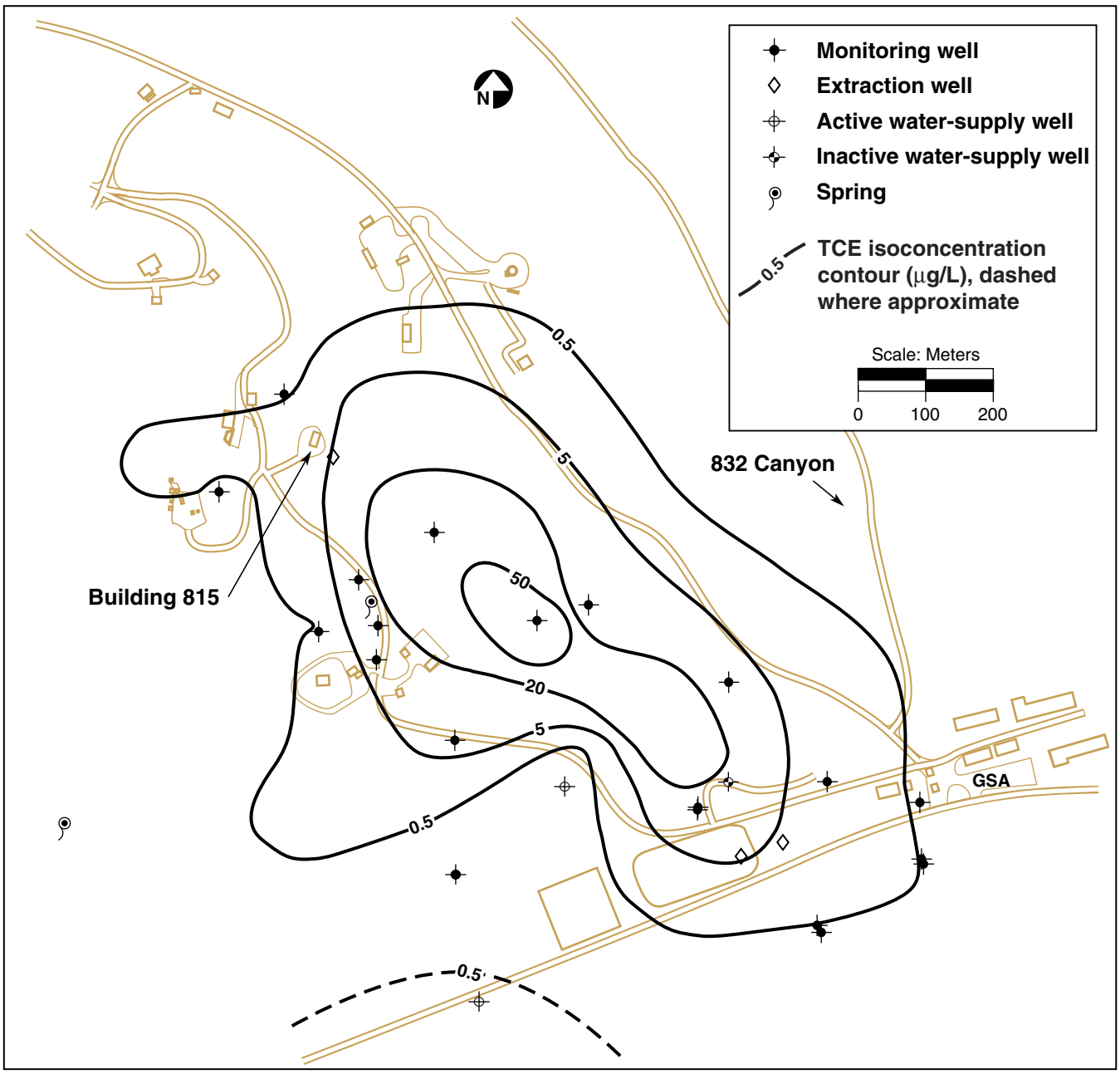


Figure 8-16. Isoconcentration contour map of trichloroethene (TCE) in groundwater in the $Tnbs_2$ aquifer in the High Explosives Process Area (2nd quarter, 2002)

The remediation strategy for the High Explosives 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 High Explosives 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.

In 2002, Phase 3 of the High Explosives Process Area remedial strategy was implemented with the installation of a third facility (B815-PRX). The extraction wells for this facility (W-818-08 and W-818-09) are located in the center of mass of the TCE plume and the primary objective of this facility is TCE mass removal. Extraction well W-818-08 is pumped at 3.8 L/min, while W-818-09, which has a higher sustainable yield, is pumped at 13 L/min. With the addition of the B815-PRX facility, the total number of groundwater extraction wells in the High Explosives Process Area is five and the total extraction flow rate is about 30 L/min.

In 2003, LLNL plans to expand the existing B815-SRC facility by connecting two additional wells (W-817-01 and W-815-04). These wells will be pumped at 3.8 L/min each for a total flow rate of 11 L/min at this facility. This additional pumping will increase the extraction well field capture zones in the Building 815 source area and significantly increase RDX mass removal. In addition to expanding the B815-SRC facility extraction well field, LLNL also plans to install an injection well upgradient of Building 815 to dispose of treated groundwater. Currently, treated effluent from the B815-SRC facility is discharged via a misting system located about 46 m south of Building 815. An alternative method for discharging treated groundwater is necessary because the ravine where Building 815 is located is not optimal for dispersing mist, especially under the increased flow rates planned for 2003.

Phase 4, which involves cleanup of fine-grained source areas, will begin in 2005 by using conventional pump-and-treat techniques to remediate shallow, perched groundwater beneath Building 815. If pump-and-treat proves impracticable, innovative techniques such as enhanced bioremediation will be considered. An enhanced bioremediation treatability test is planned for the Building 834 T2 area in 2003. If this test is successful, this technology will be considered for Building 815.

To date, more than 10 million liters of groundwater have been extracted and treated by the three existing facilities (B815-DSB, B815-SRC, and B815-PRX) in the High Explosives Process Area. As presented in **Table 8-6**, 4.5 million liters of groundwater were extracted and treated during 2002. In addition to removal of 0.027 kg of VOCs, 0.134 kg of RDX, and 0.034 kg of perchlorate have also been removed from extracted groundwater. Quarterly reports for the High Explosives Process Area treatment facilities were submitted to the EPA, CalEPA, and the CVRWQCB in accordance with the Substantive Requirements for Waste Discharge (Lamarre 2002 i,j,k,l).

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 landfills. 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

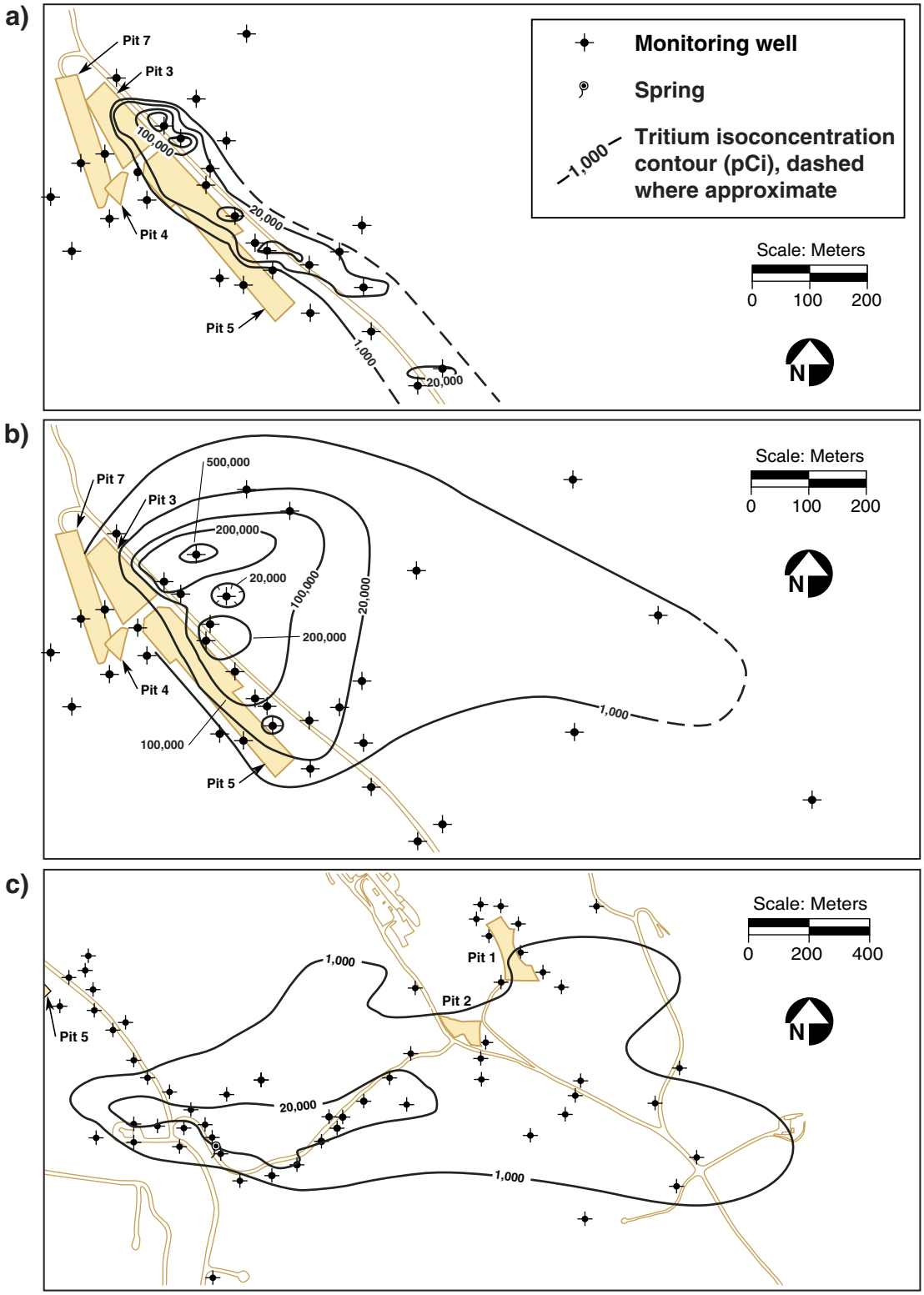


Figure 8-17. Distribution of tritium in groundwater in a) Pits 3 and 5 area alluvium, b) Pits 3 and 5 area bedrock ($Tnbs_0$), and c) Building 850/East Firing Area alluvium and bedrock (all for 2nd quarter, 2002).

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 $Tnbs_0$ and in the regional aquifer in the area east of the western limit of the Elk Ravine Fault zone. The water-bearing zone occurs at depths of 5 to 20 m below surface. There are three overlapping plumes of tritium in groundwater.

The maximum 2002 groundwater tritium activity was about 26,148 Bq/L (706,000 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 $Tnbs_1$ aquifer at the Elk Ravine Fault. Maximum 2002 groundwater tritium activities in this aquifer were about 878 Bq/L (23,700 pCi/L). There are two smaller plumes containing depleted uranium (predominantly uranium-238) emanating from the Pits 3, 5, and 7 area and the Building 850 area, with maximum measured 2002 total uranium activities of about 4366 Bq/L (118 pCi/L) and 377.4 Bq/L (10.2 pCi/L). The depleted uranium is confined principally to the alluvial portion of the perched water-bearing zone; the lengths of the two uranium plumes are about 390 m and 450 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 groundwater interceptor trench and surface and shallow subsurface water diversion. LLNL is testing reactive media, such as cow bone char and fish bones (apatite mineral sources) and other novel sorbents, 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 86 mg/L and 44 µg/L, respectively, in 2002. Trace amounts of TCE (less than 6.4 µg/L) are also present in groundwater near Pit 5.

To determine the appropriate remediation strategy for the Pits 3 and 5 landfills, LLNL is completing a water budget for the Pits 3 and 5 valley; continuing to build and calibrate a three-dimensional geological structural model and a finite element model of groundwater flow and contaminant transport; and evaluating several remediation strategies to keep water from entering the landfills. These techniques include subsurface groundwater interceptor trenches, shallow terraced drains, horizontal dewatering wells, landfill grouting, and other forms of permeability reduction, and in situ geochemical techniques using sorbents, such as bone apatite, to immobilize uranium in groundwater.

LLNL is also conducting field studies to determine how water recharges the perched water-bearing zone and enters the landfills. These studies included monitoring of wells completed at shallow depths, horizontal wells, and terraced drains, all completed in the hillslope west of the landfills

where much of the recharge that enters the landfills originates. Additionally, LLNL is conducting laboratory treatability tests of cow bone char and fish bone in removing uranium for Pits 3 and 5 groundwater. Cow bone char mixed with inert sand has been emplaced within a portion of the alluvial aquifer containing uranium at Pit 5 to test the in situ removal of uranium from area groundwater. Wells within and downgradient of this emplacement are being monitored to define the long-term chemical effectiveness and hydraulic characteristics of the emplaced material. If successful, this emplacement may be expanded as a long-term remedy for depleted uranium in groundwater. The Remedial Investigation/Feasibility Study for the Pits 3 and 5 area is scheduled for completion by March 2004.

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 $Tnbs_1$ strata at maximum 2002 concentrations of 270 µg/L, 57 mg/L, and 10 µg/L, respectively. The affected aquifer occurs at depths of 9 to 50 m below the surface. The TCE plume is about 1000 m long (**Figure 8-18**). TCE also occurs in underlying $Tnsc_0$ strata at a maximum concentration of 2.5 µg/L.

During 2002, LLNL continued to define the extent of TCE in groundwater and the conceptual hydrogeological model. Three new monitoring wells were installed within the central portion 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 wetland, a modular, mobile unit that implements phytoremediation technology to treat VOCs, nitrate, and perchlorate.

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 downgradient 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 source area 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 Building 854 proximal 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 3.8 L/min from one well (W-854-03). The groundwater is treated using a solar-powered aqueous-phase treatment unit 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

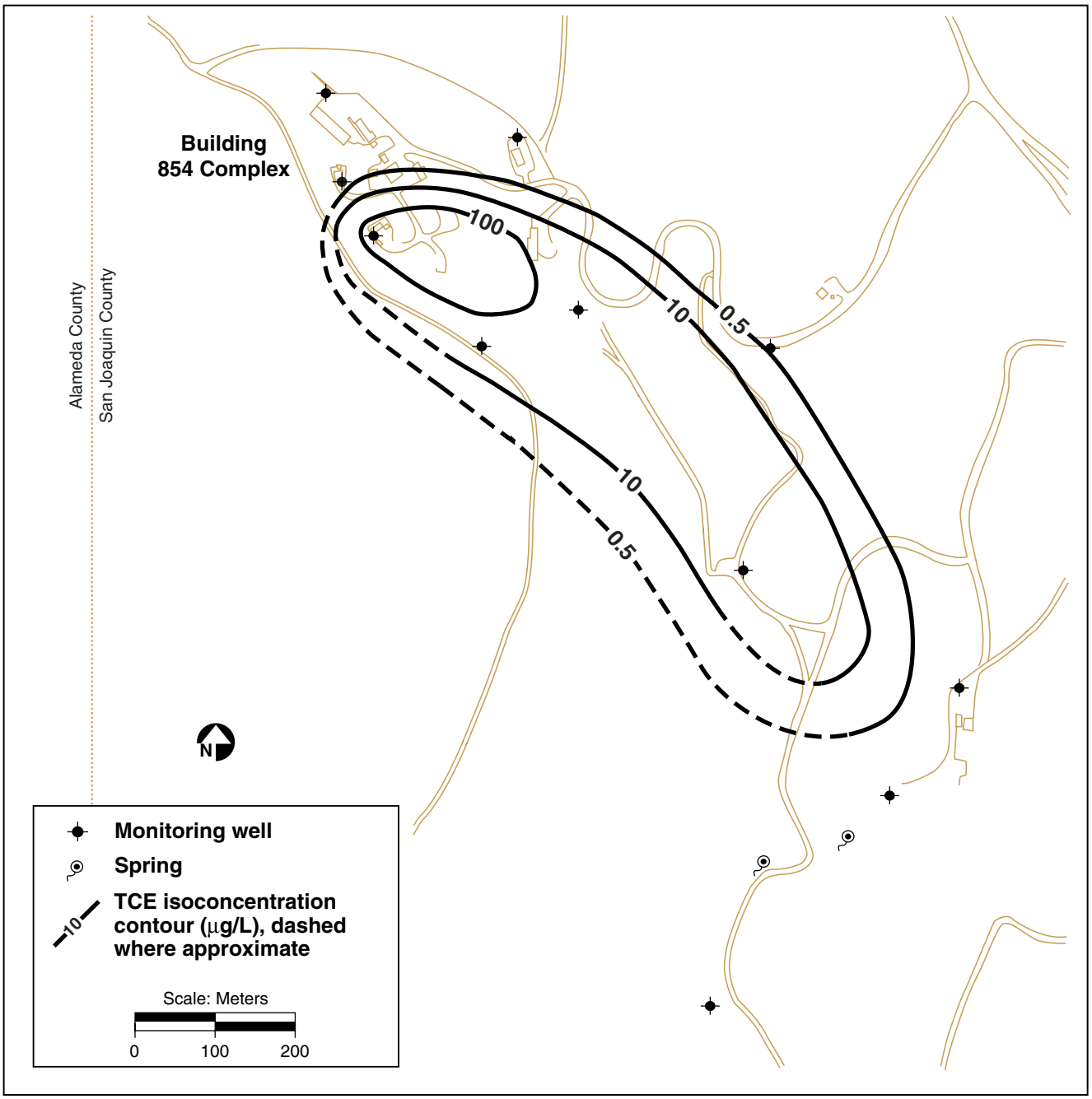


Figure 8-18. Distribution of trichloroethene (TCE) in groundwater in the $Tnbs_1$ aquifer in the Building 854 area (2nd quarter, 2002)

water is discharged to the ground via an infiltration trench located immediately south of the treatment facility. B854-PRX typically operates only a few hours per day based on solar power availability.

During 2002, 3.67 million L of groundwater were treated and discharged at the two treatment systems (**Table 8-6**). A mass of 780 g of VOCs, primarily TCE, was removed from this groundwater. The Building 854 OU discharges were in accordance with the Draft CVRWQCB Substantive Requirements for the Building 832 Canyon and Building 854 OUs. Analytical results from treatment system influent and effluent samples, monthly volumes of water treated and discharged, and total mass of contaminants removed at the two Building 854 OU treatment facilities are presented in quarterly Compliance Monitoring Reports for the Building 832 Canyon and the Building 854 OUs (Lamarre 2002m,n,o,p).

Pit 6 Operable Unit

A low concentration groundwater TCE plume occurs in a shallow water-bearing zone in terrace alluvium (Qt) and in the upper part of underlying $Tnbs_1$ sandstone (**Figure 8-19**).This shallow water-bearing zone occurs at depths of 0 to 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 2002 maximum groundwater TCE concentration was 5.2 µg/L, which is similar to the previous three years. Tritium (**Figure 8-19**) at a maximum activity of 73 Bq/L (1970 pCi/L) and perchlorate at a maximum concentration of 15 µg/L also occur in the shallow water-bearing zone. The length of the tritium plume is 345 m. The length of the perchlorate plume was as much as 175 m in early 2002, but shrank to 60 m by the 4th quarter. While low in activity, the tritium plume is 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 non-time-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 $Tnsc_1$ silty-sandstone strata at depths of 15 to 25 m. Groundwater TCE occurred at maximum 2002 concentration of 12,000 µg/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 2002 concentration of 11 µg/L. Nitrate concentrations in groundwater in 2002 reached a maximum of 190 mg/L. Well drilling conducted over the last four 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.

The *Treatability Study Report for the Building 832 Canyon Operable Unit at Lawrence Livermore National Laboratory Site 300* (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.

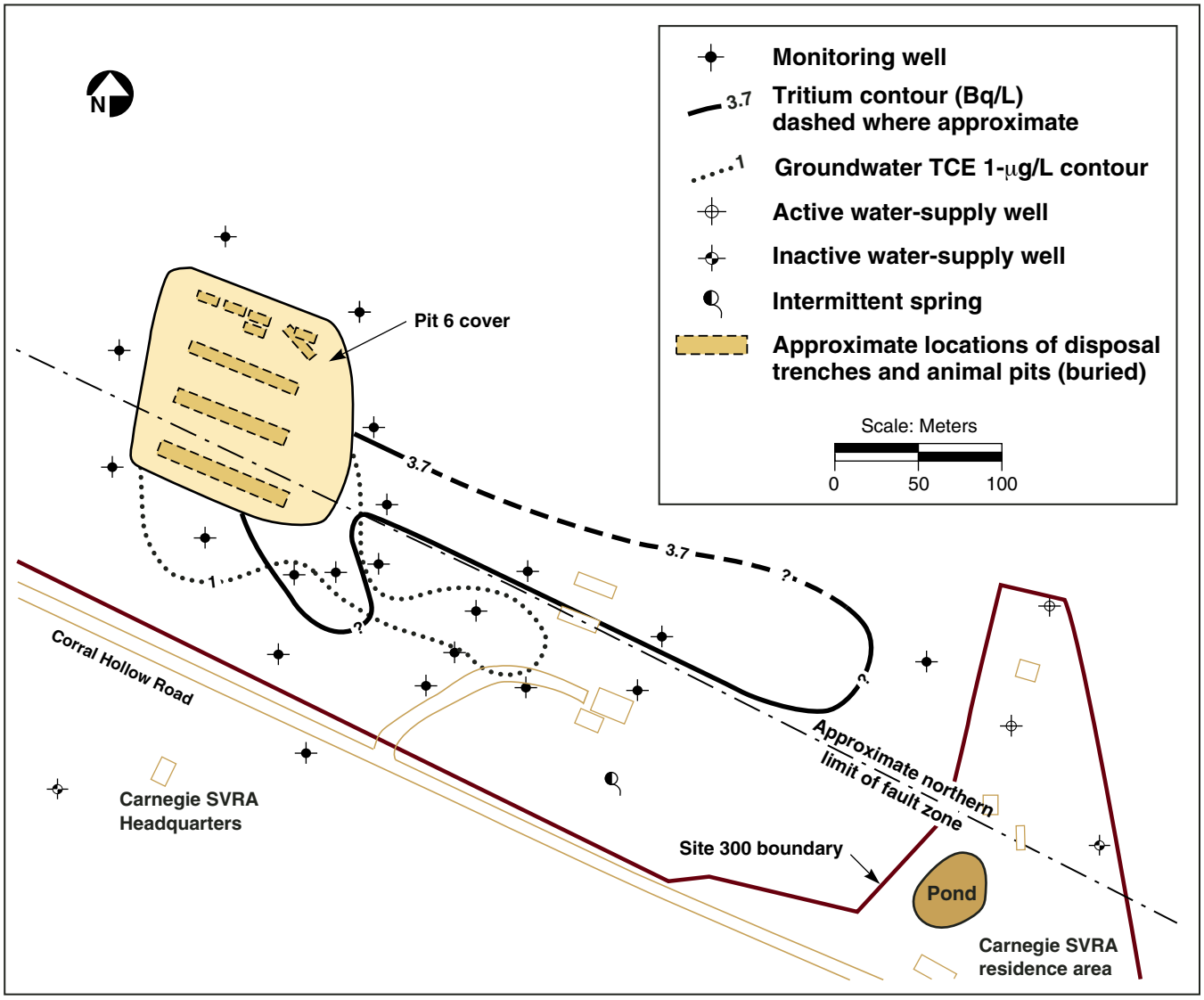


Figure 8-19. Distribution of TCE and tritium in groundwater in the Pit 6 area (4th quarter, 2002)

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 8-6 shows the volume of water treated and the mass of VOCs removed in the treatment systems. The B830-DISS treatment

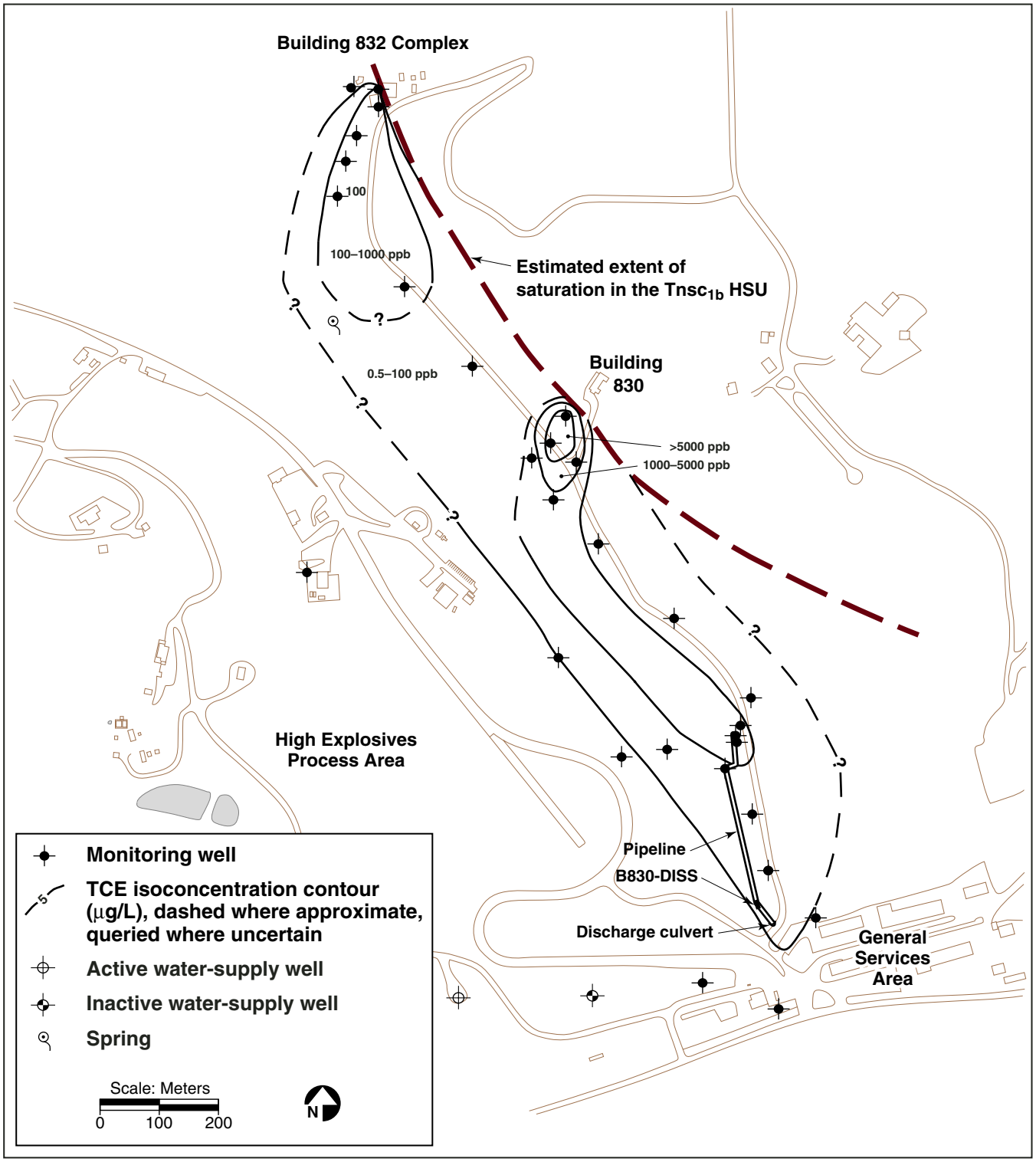


Figure 8-20. Distribution of TCE in groundwater in the Building 832 Canyon (4th quarter, 2002)

facility discharges to surface drainage courses; the B830-PRXN systems discharges to an infiltration trench; and the B830-SRC system discharges to air by misting. The Building 854 OU discharges were in accordance with the Draft CVRWQCB Substantive Requirements for the Building 832 Canyon and Building 854 OUs. Progress of the pump-and-treat systems and groundwater monitoring results are published quarterly (Lamarre 2002a,b,c,d).

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 µg/L). Debris from the Building 801 firing table was buried in the Pit 8 Landfill. No contaminants have been detected in groundwater downgradient of the landfill. Groundwater monitoring will continue in this area to monitor the VOC concentrations and to detect any potential 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 and rock with depleted 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 been impacted. The maximum 2002 total uranium groundwater activity was 14.06 Bq/L (0.38 pCi/L). Monitoring will continue to evaluate any future impacts to groundwater from soil contaminants.

There are eight monitor wells at Building 812, a firing table where depleted uranium and thorium were used in explosives experiments. The maximum 2002 uranium activity found in groundwater containing depleted uranium is 1136 Bq/L (30.7 pCi/L). Remedial investigation field work, including well drilling and soil and groundwater analysis, will be completed during 2003.

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 mg/L MCL for Freon 113.

From 1959 to 1960, 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 Impact

This section discusses the environmental impacts of the Livermore site GWP and the Site 300 CERCLA activities.

Livermore Site Ground Water Project

Environmental Impact

In 2002, the decrease in concentrations observed in the Livermore site VOC plumes reflects the 108 kg of VOCs removed by the groundwater extraction wells during the year. The decline in VOC concentrations is primarily attributed to active groundwater extraction and remediation. Notable results of VOC analyses of groundwater received from the third quarter 2001 to the fourth quarter 2002 are discussed below.

VOC concentrations on the western margin of the site either declined or remained unchanged during 2002, indicating continued effective hydraulic control of the western site boundary plumes in the TFA, TFB, and TFC areas. Concentrations in the TFA and TFB source areas increased slightly, however. While the areal extent of the off-site TFA HSU 1B total VOC plume remained largely unchanged in 2002, the entire off-site TFA HSU 2 plume dropped below 50 ppb for the first time. All off-site TFA HSU 3A wells remained below MCLs for all VOCs of concern.

In the TFB area, VOC concentrations were lower in HSU 1B close to Vasco Road, where TCE declined from 23 ppb in 2001 to 14 ppb in 2002. However, Freon 113 concentrations increased in the TFB source area (280 ppb in SIP-141-203 in April 2002, up from 6.5 ppb in May 2001).

In the central to northern TFC area, the lateral extent of HSU 1B total VOC concentrations above 50 ppb decreased significantly. Total VOC concentrations decreased along the western margin of the TFC area where well W-1116 decreased from 26 ppb to 5 ppb TCE in 2002, and well W-1102 decreased from 23 ppb to 5 ppb TCE.

HSU 2 Freon 11 concentrations in the northern TFD area continued to decline in response to pumping at TFD-W. Freon 11 in well W-423 declined from 420 ppb in 2001 to 150 ppb in 2002, and from 83 ppb to 54 ppb in well W-375.

Concentrations began to decline in 2002 in a mobile HSU 2 plume located in the western TFE area in response to pumping at TFE-W. TCE in extraction well W-305 declined from 220 ppb TCE in 2001 to 76 ppb in 2002, while concentrations further downgradient at SIP-331-001, located west of TFE-W, declined from 20 ppb in 2001 to 15 ppb in 2002. The leading edge of this plume should be hydraulically contained once TFG-N, which will be located near well W-1807, is activated in 2003. TCE in the more proximal part of this plume declined in 2002, from 171 ppb to 64 ppb in well W-271 in response to pumping in the source area at TFE-E. Total VOC concentrations in the Old Salvage Yard source area, located near SIP-ETS-601, also known as the TFE Hotspot source area, increased significantly from 521 ppb in 2001 to 1684 ppb in 2002 at SIP-ETS-601. Source area cleanup at the TFE Hotspot source area is scheduled to begin in 2005.

HSU 3A total VOC concentrations continued to decline in the T5475 area in 2002 due to a combination of soil vapor extraction at VTF5475 and regional dewatering of HSU 3A. VOCs in HSUs 3A, 3B, and 4 declined in the south-central TFD area in response to pumping at TFD-S and PTU4. TCE in HSU 3 well W-1504 declined from 400 ppb in 2001 to 180 ppb in 2002, and TCE in

HSU 4 well W-1418 declined from 290 ppb in 2001 to 200 ppb in 2002. HSU 4 TCE concentrations also declined in the southwestern TFE area due to ongoing pumping at TFE-SW. TCE in HSU 4 wells W-354 and W-1520 declined from 83 ppb and 394 ppb in 2001 to 35 ppb and 161 ppb in 2002, respectively.

Significant decreases in HSU 5 VOC concentrations were observed in the TF406 area in 2002 in response to groundwater extraction, particularly at Sandia/California south of East Avenue. TCE in well W-509, positioned at the leading edge of a TCE plume, declined from 27 ppb in 2001 to less than 0.5 ppb in 2002. Closer to TF406, TCE in well W-1112 declined from 31 ppb to 9 ppb over the same period. The relatively rapid cleanup of this area suggests that the TF406 South facility proposed for 2006 may not be needed to achieve timely cleanup.

During 2002, tritium activities in groundwater from all wells in the T5475 area remained below the MCL and continued to decrease by natural decay. Only one well, UP-292-007, located north of TFC-E, remains slightly above the 741 Bq/L (20,000 pCi/L) MCL in the Building 292 area (763 Bq/L [20,600 pCi/L] in October 2002).

Site 300 CERCLA Activities

Influent TCE concentrations to the eastern GSA OU were reduced from 64 µg/L in January 1992 to 2.2 µg/L in December 2002. No longer do any off-site wells in the eastern GSA yield groundwater TCE concentrations in excess of the cleanup standards (MCL) of 5 µg/L. LLNL estimates that two 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 the central GSA OU influent have been reduced from 9400 µg/L in 1993 to 153 µg/L in December 2002. From 1994 through the end of 2002, total VOC concentrations in the central GSA soil vapor extraction influent stream were reduced from 450 mg/L to 3.9 mg/L. VOC concentrations in the central GSA soil vapor extraction influent stream were reduced from 450 mg/L to 6.3 mg/L. VOC concentrations in individual central GSA soil vapor extraction wells have also been significantly reduced.

Because of mostly decreased operation at the Building 834 OU in 2002, overall mass removal was down about 89% from the previous year. However, additional VOC mass was destroyed during 2002 through in situ bioremediation although this mass was not quantified.

LLNL proceeded to implement the next phase of the High Explosives Process Area OU remedial strategy; to develop an RI/FS for the Pits 3 and 5 portion of the Building 850 OU; and to define the extent of groundwater contamination at the Building 854 OU.

At the Pit 6 OU, maximum TCE concentrations are similar to the previous three years. By the end of the year, the length of the perchlorate plume was a third the size it was at the beginning of the year. In 2002, maximum contaminant concentrations at the Building 832 Canyon OU were less than or similar to those for 2001.

Contributing Authors Acknowledgment

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Groundwater Monitoring

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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 Ground Water Protection Management Program (GWPMP). 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 GWPMP 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 GWPMP is described in Chapter 10. Additional LLNL programs address potential contaminant sources such as the sanitary sewer system (Chapter 6) and underground storage tanks (briefly discussed in Chapter 2).

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 at Site 300 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 the 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 the city of 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 such as nitrate and perchlorate are the objects of continuing study. Present-day administrative, engineering, and maintenance controls at both LLNL sites are specifically tailored to prevent 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 2-3** 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 semiannual 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, contain small amounts of HTO from natural sources, past worldwide atmospheric nuclear weapons tests, and atmospheric emissions from LLNL. (See Chapters 4 and 5 for further discussion of air emissions, and Chapter 7 for further discussion of rain and storm water runoff.)

Groundwater is recharged at the Livermore site, primarily from arroyos by rainfall (see also Chapter 7). Groundwater flow beneath the Livermore site is generally southwestward. Groundwater flow 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 in the annual *LLNL Ground Water Project* report (Dibley et al. 2003).

Groundwater samples were obtained during 2002 from 23 of 25 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 2002.

Livermore Site Perimeter

LLNL designed a surveillance monitoring program to complement the Livermore Site Ground Water Project (discussed in Chapter 8). The intent of the surveillance monitoring 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 upgradient (background) 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 groundwater Treatment Facilities A, B, and C (see **Figure 8-1**), meet the requirements of DOE Order 5400.1. The western perimeter wells are screened (that is, where groundwater is drawn from) 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 three times in 2002 for pesticide and herbicide compounds that are used on site and off site, for nitrate, and for certain radioactive constituents. They were also sampled and analyzed twice for hexavalent chromium (chromium(VI)) during 2002.

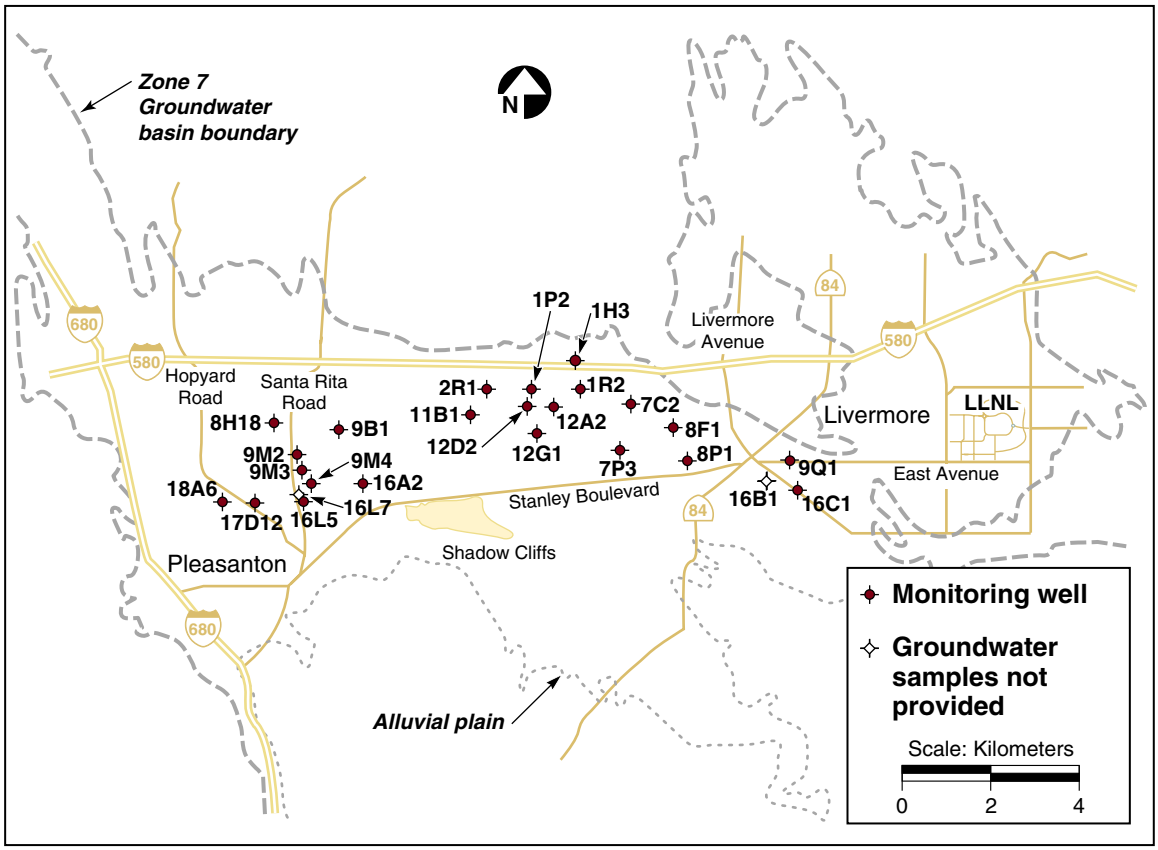

Figure 9-1. Locations of off-site tritium monitoring wells in the Livermore Valley, 2002

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.) These wells were sampled and analyzed at least once for pesticides, herbicides, radioactive constituents, nitrate, and chromium(VI).

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 downgradient 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 2002 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

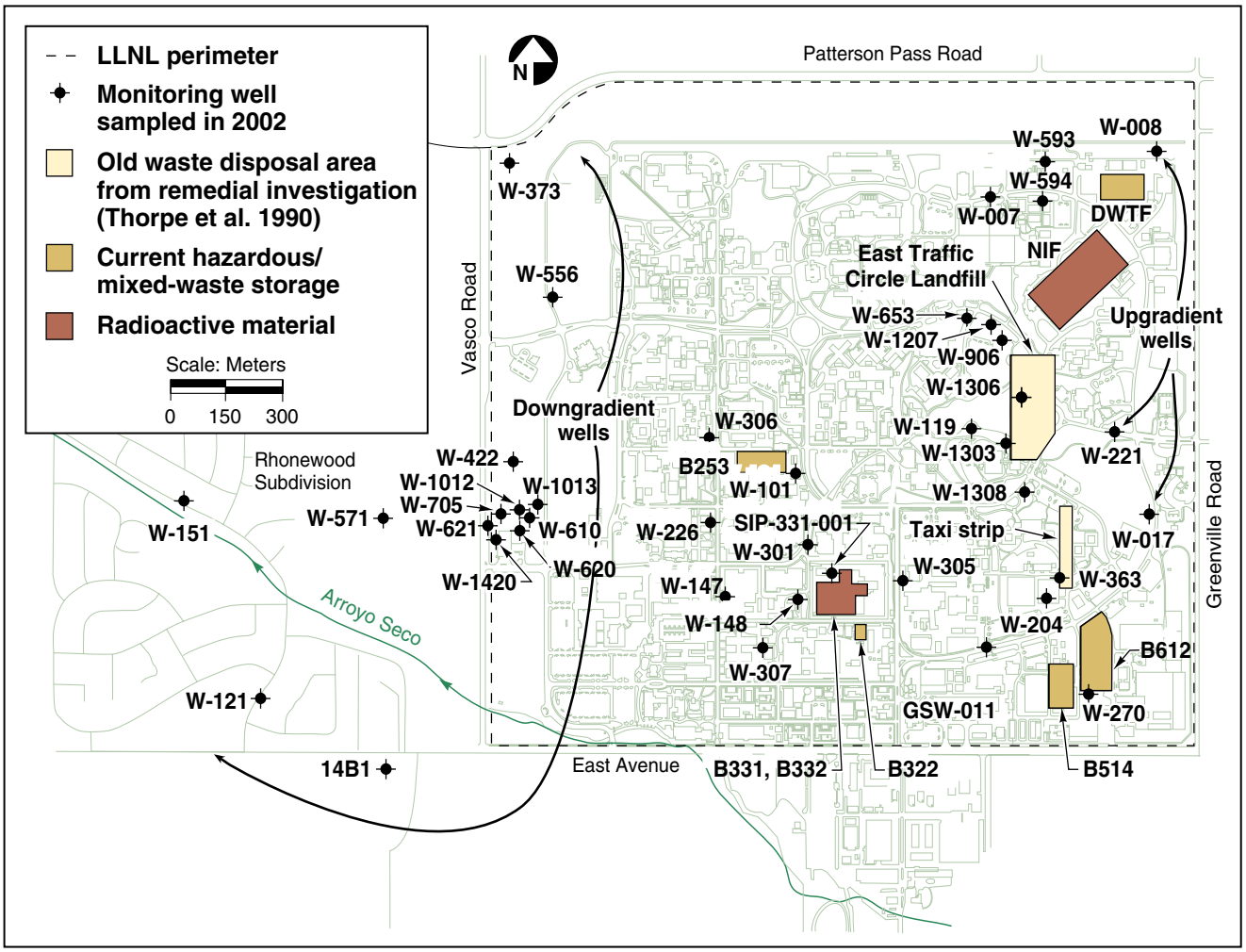

Figure 9-2. Locations of routine surveillance groundwater monitoring wells at the Livermore site

W-1308) within and downgradient from the East Traffic Circle Landfill were analyzed for the same elements as in the Taxi Strip Area. The locations of all of these wells are shown in **Figure 9-2**.

Although the National Ignition Facility (NIF, **Figure 9-2**) has not yet begun full operations, it is prudent to obtain a baseline of groundwater quality prior to start of operations. NIF operations will use significant quantities of tritium. Analyses were conducted on groundwater samples collected from wells W-653 and W-1207 (screened in HSUs 3A and 2, respectively) downgradient of NIF for minerals, selected metals, gross alpha and beta radiation, radium-226, and tritium.

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 wells W-007, W-593 (screened in HSU 3A), and W-594 during 2002 and were analyzed for minerals, selected metals, americium-241, plutonium-238, plutonium-239,

radium-226, and tritium. Monitoring wells W-007 and W-594 (screened in HSUs 2/3A and 2, respectively) were added to this monitoring network in 2002.

The hazardous waste/mixed waste storage facilities around Buildings 514 and 612 are a potential source of contamination. They are monitored by well GSW-011 (screened in HSU 3A). Groundwater from this well was sampled and analyzed for selected trace metals, general minerals, americium-241, plutonium-238, plutonium-239, radium-226, and tritium in 2002.

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 total 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 wells W-101, W-147, and W-148 are screened in HSU 1B; and SIP-331-001 and well W-301 are screened in HSU 2.

Surveillance and Compliance Monitoring of Site 300

For surveillance and compliance groundwater monitoring at Site 300, LLNL uses DOE CERCLA wells and springs on site and private wells and springs off site. Representative groundwater samples are obtained at least once per year at every monitoring location; 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 or near Site 300 that are used for groundwater surveillance monitoring. The locations of additional compliance monitoring wells are shown in **Figures 9-4** through **9-11**. 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. Deeper water-bearing zones are monitored at four locations (K1-02A, K2-01A, K2-02A, and K2-02B) by means of Barcad devices installed in the deeper zones.

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

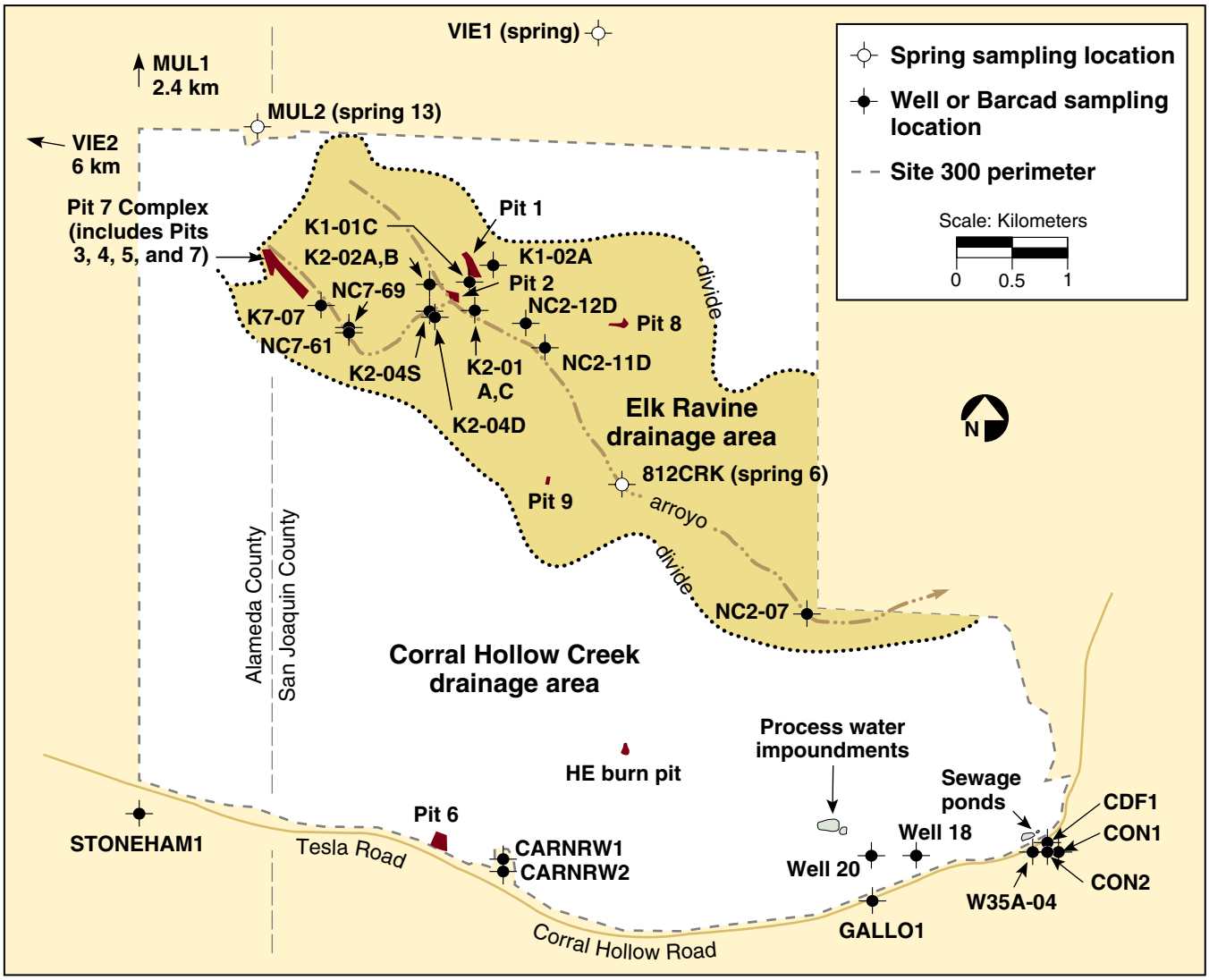

Figure 9-3. Locations of surveillance groundwater wells, Barcads, and springs at Site 300

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.

On-site wells, installed primarily 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 process water 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 2002 for compliance purposes and published elsewhere are not contained in the Data Supplement accompanying this report. Instead, the compliance reports containing those data tables and data graphs have been copied onto the CD that contains this Environmental Report. Active links to these reports 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 eight closed landfills known as Pits 1 through 5 and 7 through 9 and firing tables where explosives tests are conducted. None of the closed landfills has a liner, which is consistent with disposal practices in the past when the landfills were constructed. 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) in 1993, are specified in Waste Discharge Requirements Order No. 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 m^3 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 every three months (quarterly) during 2002 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

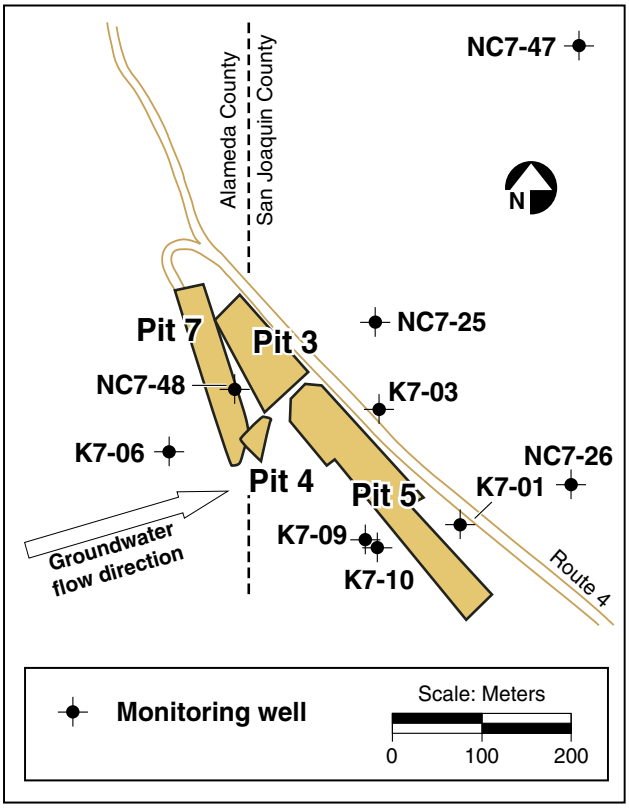

Figure 9-4. Locations of Pit 7 compliance groundwater monitoring wells

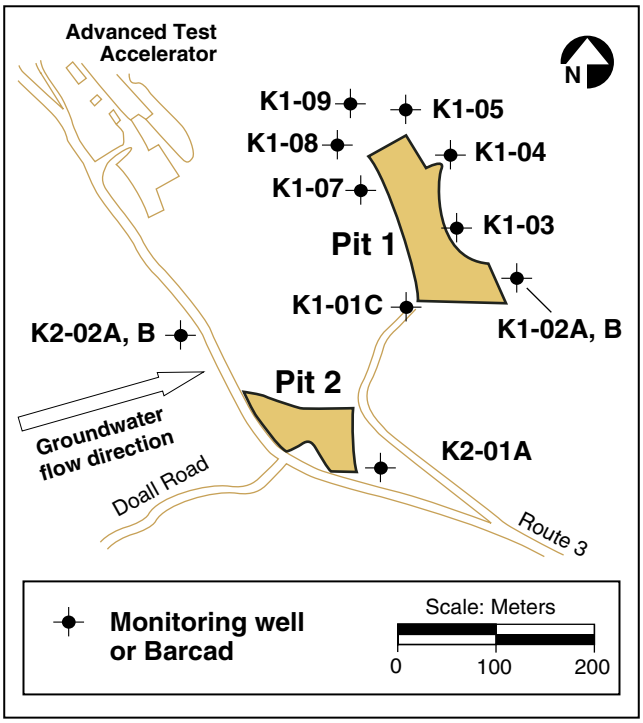

Figure 9-5. Locations of Pit 1 compliance and Pit 2 surveillance groundwater monitoring wells

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 2002 from the widespread Elk Ravine surveillance monitoring network. Samples were analyzed for inorganic constituents (mostly metallic elements), VOCs (EPA method 601), general radioactivity (gross alpha and beta), tritium and uranium activity, and explosive compounds (HMX and RDX).

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 2002 from the Pit 2 monitoring network (comprising 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 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 2002 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 an even larger set of COCs were made on the groundwater samples obtained from well K1-01C during the fourth quarter of 2002. These additional analyses included common 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) in 1993, are also specified in 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 2002 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.

Approximately 40 m^3 of untreated debris from the firing table were placed in the pit until 1974 when the pit was covered with a layer of native soil. 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 five 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).

Construction and other operations in the vicinity of Pit 8 limited access to the monitoring wells during 2002, and well K8-05 was dry throughout the year. Groundwater samples obtained in June from well K8-01 were analyzed for inorganic COCs (mostly metallic elements), VOCs (EPA method 601), general radioactivity (gross alpha and beta), activity of certain radioisotopes (tritium and uranium), and explosive compounds (HMX and RDX). Groundwater samples from well K8-03B obtained in July

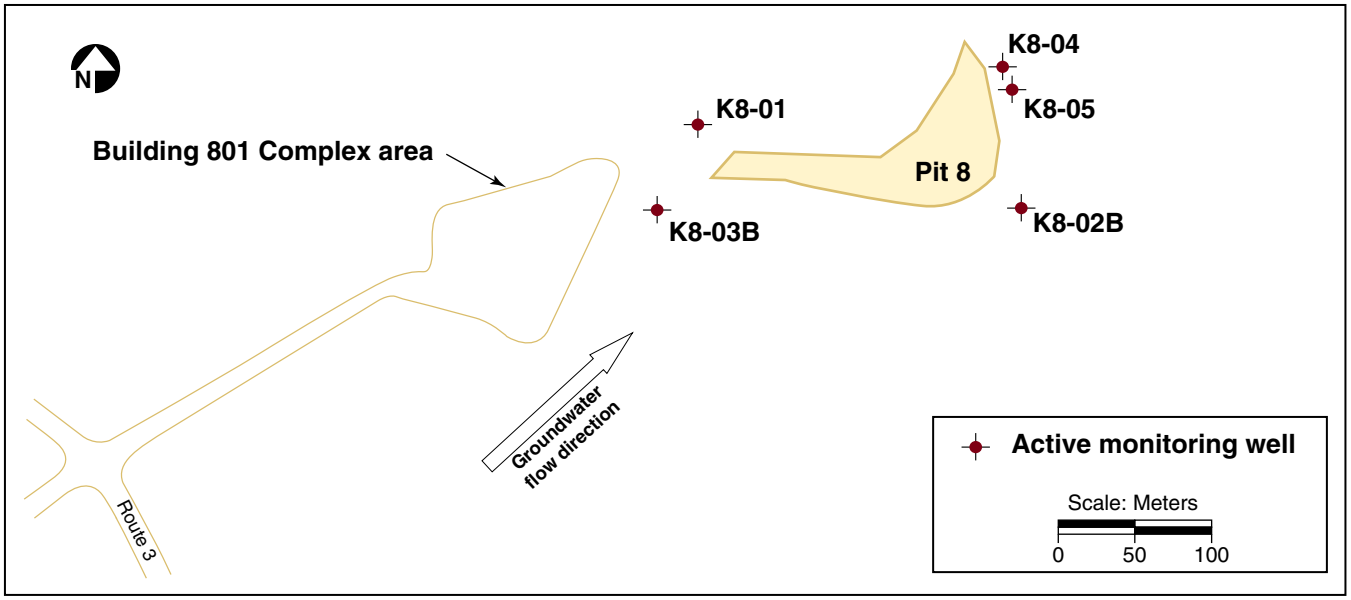

Figure 9-6. Locations of Pit 8 surveillance groundwater monitoring wells

were analyzed for VOCs (EPA method 601), general radioactivity (gross alpha and beta), activity of certain radioisotopes (tritium and uranium), and explosive compounds (HMX and RDX). Groundwater samples from well K8-04 obtained in June were analyzed for VOCs (EPA method 601) and tritium activity.

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 east-northeasterly beneath Pit 9 in the Neroly lower blue sandstone unit ($Tnbs_1$). 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

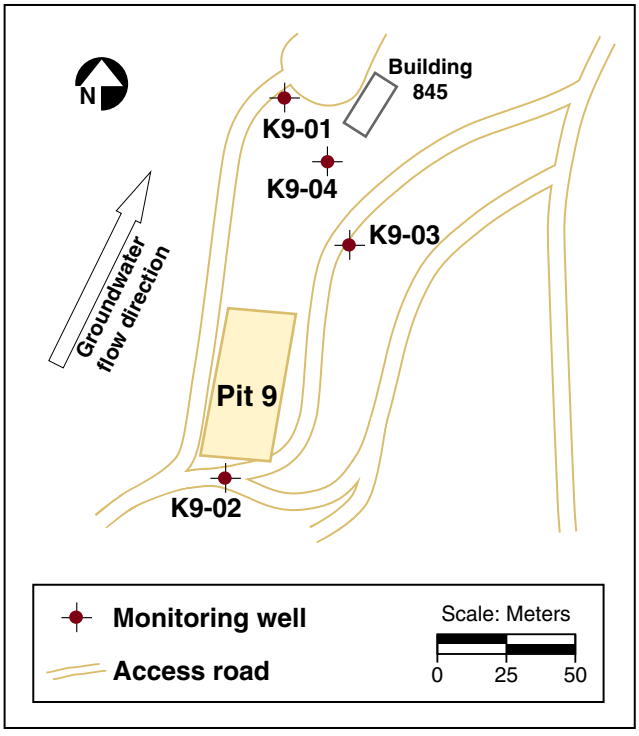

Figure 9-7. Locations of Pit 9 surveillance groundwater monitoring wells

As planned for surveillance purposes, LLNL obtained groundwater samples once (annually) during 2002 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.)

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 m^3 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 m^3 of solid waste that includes empty drums, glove boxes, lumber, ducting, and capacitors. Six smaller trenches contain 230 m^3 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, 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 historical 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 2002 from the Pit 6 monitoring well network. Samples were analyzed for inorganic COCs (mostly metals), general radioactivity (gross alpha and beta), activity of certain radioisotopes (tritium and uranium), VOCs (EPA method 624), extractable organics (EPA method 625), pesticides (EPA method 608), and PCBs (EPA method 8082A). Field measurements of groundwater depth,

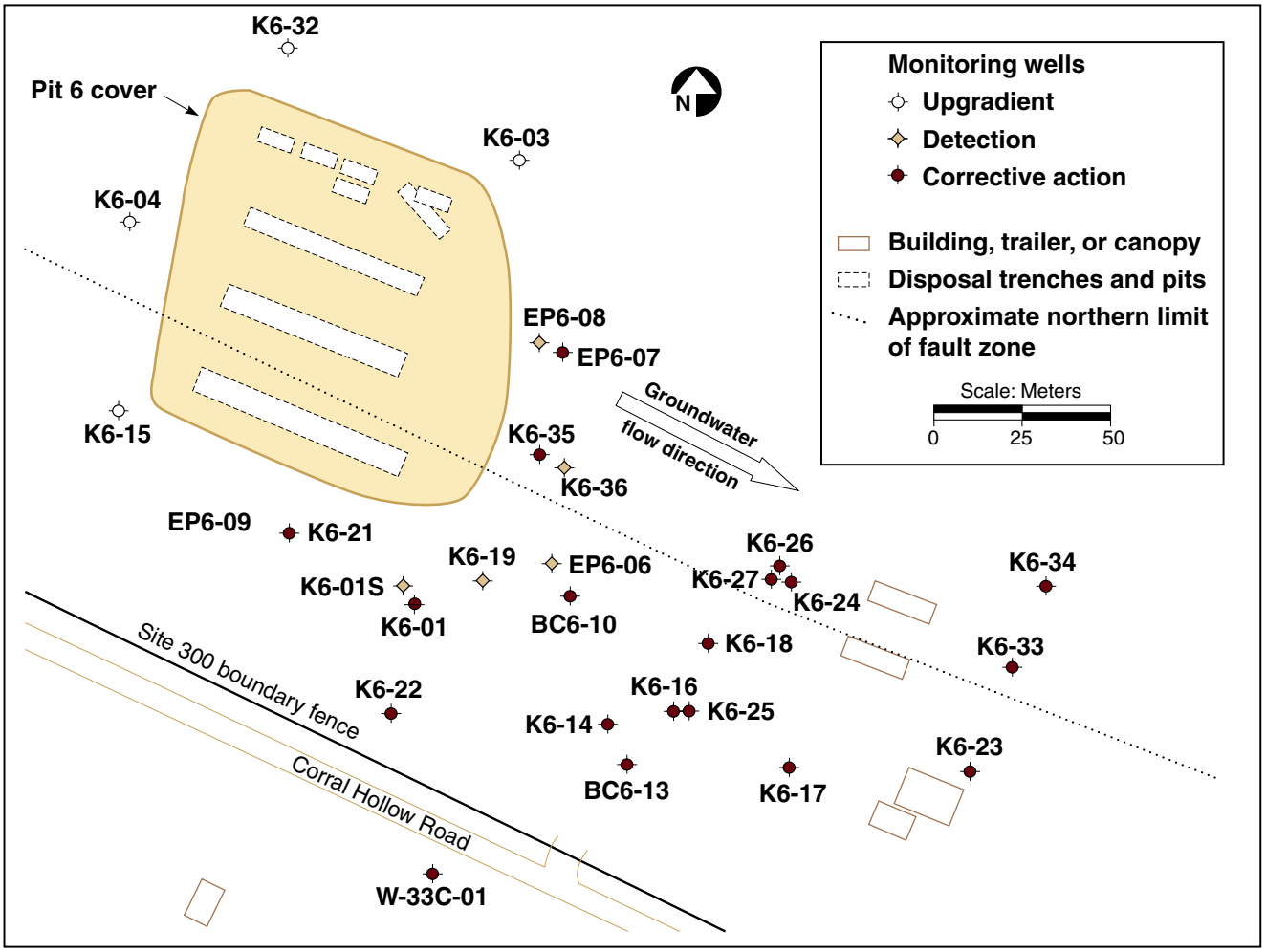

Figure 9-8. Locations of Pit 6 compliance groundwater monitoring wells

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 2001).

The former 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 shallow unlined pits constructed in unconsolidated sediments that cap

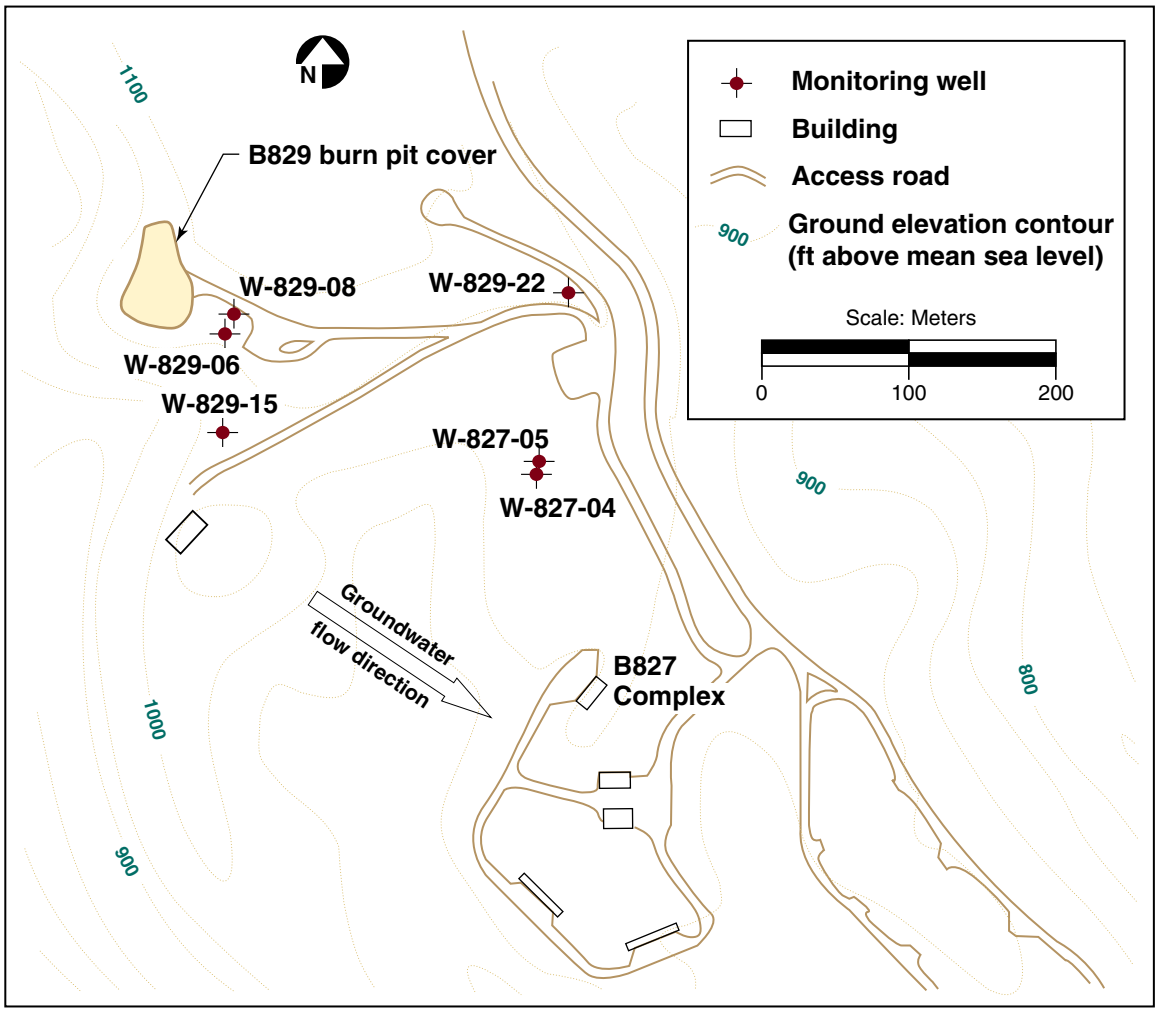

Figure 9-9. Locations of Building 829 closed burn pit compliance groundwater monitoring wells

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 ($Tnsc_2$). The deeper zone, at a depth of about 120 m, represents a regional aquifer within the Neroly upper sandstone member ($Tnbs_2$). (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 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 2002 from the Building 829 monitoring well network. As in past years of this monitoring program, deep well W-827-04 remained dry throughout 2002. 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. During the first two quarters of 2002, however, well W-829-08 appeared to be dry. This condition was initially attributed to a gradually lowering water table in the perched zone, consistent with similar observations at other Site 300 locations. Further examination revealed an obstruction in the pump line, and well W-829-08 was returned to service for the third and fourth quarters of 2002.

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 2002, while well 18 was maintained as a standby water supply well. Both wells are screened in the Neroly lower sandstone aquifer ($Tnbs_1$). 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 2002 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: Waste Discharge Requirements Order No. 96-248 (WDR 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.

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

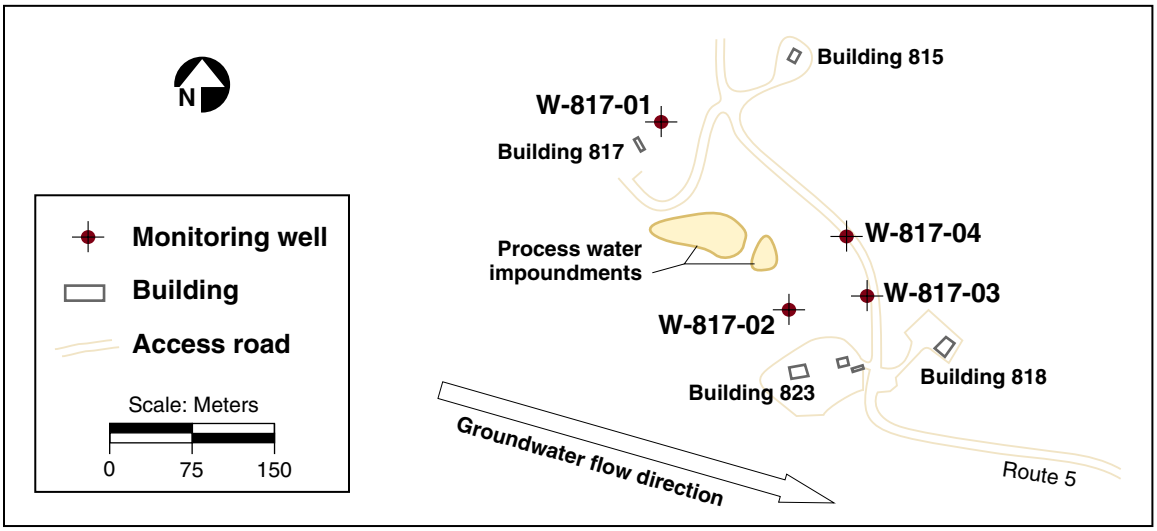

Figure 9-10. Locations of compliance groundwater monitoring wells in the Explosives Process Area

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 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 the MRP for WDR 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, $Tnbs_1$, and $Tnsc_1$ (see Chapter 8). $Tnbs_1$ (Neroly Formation lower blue sandstone unit) is the regional aquifer.

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 2002. 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**). Well W35A-04 is a DOE CERCLA well that was installed off site for monitoring purposes only. The

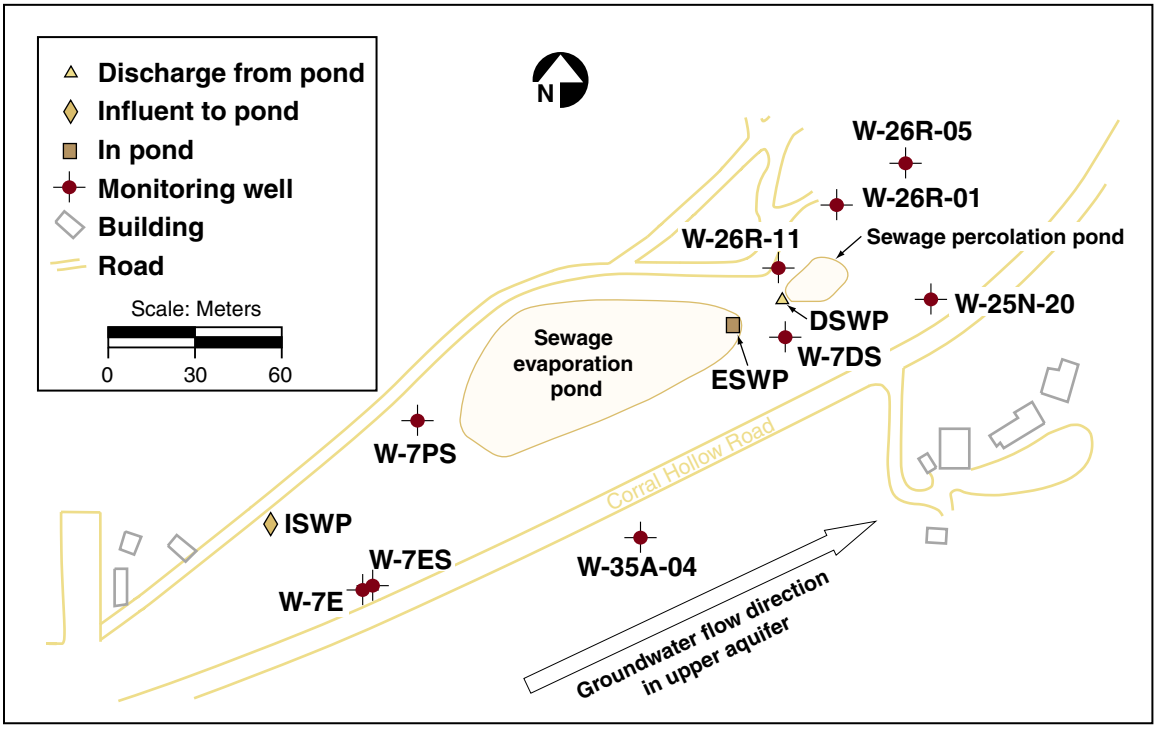

Figure 9-11. Sewage evaporation and percolation ponds, compliance groundwater monitoring wells, and wastewater monitoring locations

remaining seven wells south of Site 300 are privately owned and were constructed to supply water either for human consumption, stock watering, or fire suppression. They are monitored to determine the background contents of the groundwater beneath the Corral Hollow Creek flood plain.

Groundwater samples were obtained quarterly during 2002 at six of the 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 2002 from the remaining 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 2002). 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 U.S. Environmental Protection Agency (EPA) are used to measure dissolved constituents in water because they are both accurate and sensitive. (See Data Supplement Tables 9-1a, 9-1b, and 9-1c for the U.S. EPA or other standard analytical methods used to measure chemicals and radioactivity in groundwater.) All the chemical and radioactivity analyses of groundwater samples were performed during 2002 by California-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 ± 2°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 with the exception of 2002. 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 3.4 Bq/L in 2002, which is equal to 0.5% of the MCL. **Figure 9-12** shows the history since 1988 of the maximum tritium activity measured in the Livermore Valley wells sampled. Continuing monitoring will determine future needs.

Livermore Site Perimeter

Constituent measurements for the Livermore site background wells and 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 2002. The inorganic compounds detected include dissolved trace metals and minerals, which occur naturally in the groundwater at variable concentra-

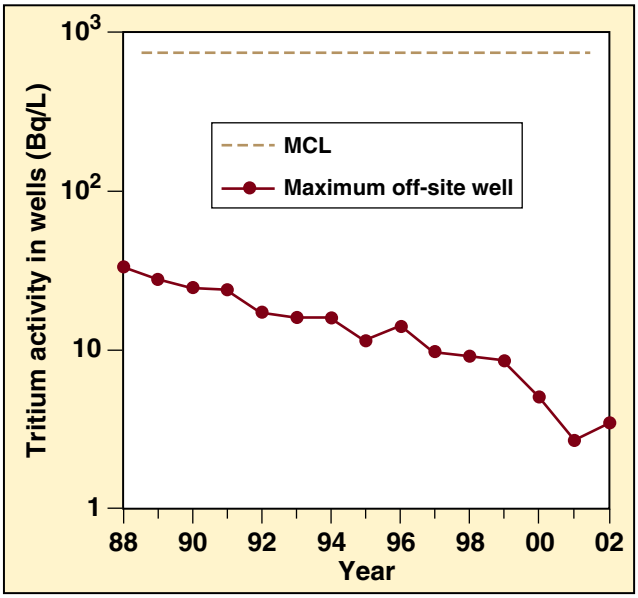

Figure 9-12. Trend of tritium activity in Livermore Valley wells, 1988 to 2002. The drinking water MCL of 740 Bq/L is also shown.

tions. The concentrations detected in the groundwater samples from the background wells represent background values for 2002.

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; concentrations of nitrate detected in groundwater samples from this well since 1996 have exceeded 45 mg/L. Concentrations of nitrate detected in samples from this well in 2002 were 78 to 80 mg/L. Those are the highest nitrate concentrations measured in any surveillance monitoring well during 2002.

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 40 mg/L, in downgradient monitoring well W-571 (see Data Supplement Table 9-4). Monitoring well W-571 is off site and downgradient to the west, and is screened in HSU 1B. During 2002, concentrations of nitrate in on-site shallow background wells W-008 and W-221 ranged from 23 mg/L to 30 mg/L. Detected concentrations of nitrate in western perimeter wells, with the exception of well W-1012, ranged from 13 to 40 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 2002. 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).

Nitrate concentrations were also analyzed in groundwater samples collected from seven additional monitoring wells (**Figure 9-2**), screened in HSUs 1B and 2. Nitrate results from those seven wells and from wells W-1012 and W-571 are listed in Data Supplement, Table 9-6. Other than well W-1012, no groundwater sample had a nitrate concentration exceeding the MCL.

Of the selected trace metal analytes, no concentration analyzed in any groundwater sample collected in 2002 exceeded its California or federal MCL. Since monitoring began in 1989, concentrations of chromium(VI) in groundwater samples collected from western perimeter well W-373 in previous years had exceeded the California MCL of 50 µg/L. 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. The concentration of

48 µg/L for chromium(VI) in the January 2002 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 2002. Activities of total uranium in those wells were measured as 0.17 ± 0.01 Bq/L to 0.24 ± 0.02 Bq/L (32% 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 0.025 ± 0.004 Bq/L (in well W-121) to 0.12 ± 0.01 Bq/L (16% 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 exceeding the MCL.

Livermore Site

Constituent measurements for the Livermore site wells are contained in the Data Supplement, Tables 9-7 through 9-14. No concentrations of americium or plutonium radioisotopes were detected above the radiological laboratory's minimum detectable activities. Concentrations of tritium and radium isotopes remain well below drinking water MCLs. The trace metals copper, lead, and zinc were not detected in samples from any of these monitoring wells in 2002.

Monitoring results from the wells near NIF and DWTF show very little concentrations of tritium present and only minor concentrations of gross alpha and gross beta radiation in the groundwater samples collected. Monitoring will continue near these facilities to determine baseline conditions.

No significant contamination was detected in the sample collected from well GSW-011 downgradient from Buildings 514 and 612 in 2002.

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 15 µg/L, greater than 10 µg/L, the highest concentration of chromium(VI) measured in any background well from 1996 through 2002. Dissolved chromium was also detected at elevated concentrations in groundwater samples from well W-306, which is downgradient from the Building 253 catch basin. Concentrations were measured as 10 µg/L at well W-226 and 40 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 chromium(VI) exceeded the MCL of 50 µg/L for total chromium in drinking water.

In August 2002, the tritium activity was 110 ± 11 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 reduced to 98 ± 11 Bq/L or less, by December 2002 in all of the wells sampled downgradient of Building 331. The relatively elevated tritium activity in the groundwater sampled at well W-148 in August 2000 (115 ± 5.0 Bq/L) was concluded to be most likely related to local infiltration of storm water containing elevated tritium activity. Tritium activities in groundwater of this area have been cyclic since that time. 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.

Site 300

The following are summaries of Site 300 groundwater surveillance and compliance monitoring results for 2002. Site 300 compliance monitoring

results for 2002 have been published previously (Brown 2002a,b,c, 2003; Christofferson and MacQueen 2002a,b,c, 2003; Christofferson et al. 2002a,b,c, 2003; Revelli 2003). Compliance monitoring results for Site 300 are discussed again in the following summaries. Surveillance monitoring data for 2002 have not been published elsewhere and are listed in the Data Supplement, Tables 9-15 through 9-27.

Elk Ravine Drainage Area

Pit 7: No new release of COCs to groundwater from Pit 7 is evident in the chemical data obtained during 2002. The COCs detected in groundwater include several metals, depleted uranium, tritium, and several VOCs. These are associated with releases that occurred prior to 2002. 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 arsenic, barium, uranium, and, possibly nitrate 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 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 2002, including tables and graphs of groundwater COC analytical data, see Christofferson and MacQueen (2003).

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 2002. The major source of contaminated groundwater beneath Elk Ravine is from historical operations in the Building 850 firing table area (Webster-Scholten 1994, Taffet et al. 1996). Constituent measurements for the Elk Ravine drainage area surveillance monitoring network are listed in the Data Supplement, Table 9-15.

The arsenic concentration in the groundwater monitored beneath the Elk Ravine drainage area is generally above the MCL of 10 µg/L for arsenic in drinking water. Concentrations range up to 42 µg/L (well NC2-07). Earlier CERCLA characterization studies determined that the arsenic is from natural sources, particularly from the dissolution of the mineral arsenopyrite, which is a component of the underlying volcanogenic sediments and sedimentary rocks (Raber and Carpenter 1983). It should be noted that there are no wells in this area that are used for potable domestic, livestock, or industrial water supply. However, a perennial spring in Elk Ravine, which is utilized by the indigenous wildlife there, contains concentrations of arsenic up to 33 µg/L (location 812CRK).

Tritium activity was above background level in many of the shallow groundwater surveillance samples obtained during 2002 from Elk Ravine. Tritium, as HTO, has been released in the past in the vicinity of Building 850 (see **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 1700 Bq/L at well NC7-61, which

samples the shallowest water-bearing zone, and the tritium activity of 1.8 Bq/L at well NC7-69, which samples the next deeper water-bearing zone in this area.

The majority of the Elk Ravine surveillance network tritium measurements made during 2002 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 1700 Bq/L in 2002. CERCLA modeling studies indicate that the tritium will decay to background levels before it can reach a site boundary. Note that the tritium plume has not reached the perennial spring location 812CRK.

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 2002. Constituent measurements for the Pit 2 surveillance monitoring network are contained in Data Supplement Tables 9-16a and 9-16b.

Several metals were detected at low concentrations. Most were below analytical reporting limits, which are in the parts per billion (ppb) range. Arsenic exceeded its MCL but was within the range of background level concentrations for this area of 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 15 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 2002. A detailed account of Pit 1 compliance monitoring during 2002, including tables and graphs of groundwater COC analytical data, appears in a separate report; see Christofferson and MacQueen (2003).

Tritium activity measured above background level (about 4 Bq/L) in the groundwater at Pit 1 monitoring wells K1-01C (15 Bq/L), K1-02B (170 Bq/L), K1-03 (25 Bq/L), and K1-08 (11 Bq/L) during 2002 (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 2002 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 57 µg/L in 2002 in groundwater at Pit 1 monitoring wells K1-05 (17 µg/L), K1-08 (19 µg/L), and K1-09 (57 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 to the west of 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 2002. Constituent measurements for the Pit 8 surveillance monitoring network are contained in Data Supplement Table 9-17.

The VOC TCE was detected below the 5 µg/L MCL for TCE in wells K8-01, K8-03B, and K8-04. 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. The nitrate concentration of 64 mg/L in the groundwater monitored at well K8-01 exceeded the MCL of 45 mg/L for nitrate (as NO_3) in drinking water. The nitrate source is unknown. A site-wide CERCLA study of nitrate in groundwater continued through 2002.

Pit 9: As in past years, no evidence for a release from Pit 9 is indicated by the surveillance monitoring data obtained during 2002. Constituent measurements for the Pit 9 surveillance monitoring network are contained in the Data Supplement, Table 9-18. 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 2002. For a detailed account of Pit 6 compliance monitoring during 2002, including tables of groundwater analytical data and map figures showing the distribution of COC plumes, see *LLNL Experimental Test Site 300 Compliance Monitoring Program for the CERCLA-Closed Pit 6 Landfill, Annual Report for 2002* (Christofferson et al. 2003).

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). All contaminant plumes associated with Pit 6 are relatively small and are confined to shallow depths. None has been detected 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 2002. For a detailed account of compliance monitoring of the closed HE burn pit during 2002, including tables and graphs of groundwater COC analytical data, see *LLNL Experimental Test Site 300—Compliance Monitoring Program for the Closed Building 829 Facility—Annual Report 2002* (Revelli 2003).

The well network used to monitor the Building 829 facility samples two zones containing groundwater: a shallow perched water-bearing zone, which is not present directly below the capped burn pits, 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 was not in service the first two quarters of 2002, well W-829-06 provided a sufficient quantity of groundwater throughout 2002 for the required analyses. The primary contaminant in the perched groundwater is TCE. The maximum TCE concentration measured during 2002 was 240 µg/L. The other contaminant, 1,2-dichloroethene (1,2-DCE), was measured at a maximum concentration of 2.8 µg/L during 2002.

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 are generally typical of the values seen in previous years. The postclosure plan inorganic constituents that were detected during 2002 show concentrations that represent background level concentrations of substances dissolved from natural sources in the underlying rocks. Only arsenic and molybdenum were detected at 1-to-4 ppb above the previously determined background concentrations for the deep aquifer beneath the HE Burn Area. However, these constituents (found at Site 300 in naturally occurring minerals) are present in other uncontaminated Site 300 wells at background levels above those reported for the HE Burn Area. (A fourth deep well, W-827-04, was dry during 2002.)

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 9-19 and 9-20.

As in past years, TCE was detected during 2002 at low concentrations in the groundwater at standby well 18. The maximum concentration measured was 0.3 µg/L, which is equal to 6% 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. A detection of the explosive compound HMX at a concentration of 13 µg/L occurred first quarter, but three subsequent quarterly analyses showed no HMX above the reporting level concentration of 5 µg/L. 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 2002. Two releases of wastewater containing minor concentrations of metals to ground occurred in 2002. For a detailed account of compliance monitoring of the Site 300 surface impoundments, including tables of groundwater measurements, see *LLNL Experimental Test Site 300 Compliance Monitoring Report for Waste Discharge Requirements 96-248, Annual/Fourth Quarter Report 2002* (Brown 2003).

The two leachate collection and removal systems were monitored weekly for the presence of liquids to identify potential leaks. None was observed during 2002. 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 2002. Concentrations of arsenic continue to be detected at concentrations at or near its drinking water MCL in these same wells during 2002. 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 2002, 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 2002. 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 (2003).

Percolation Pits: During 2002, 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 2003).

Sewage Evaporation and Percolation Ponds: All wastewater parameters for the sewage evaporation and percolation ponds complied with permit provisions and specifications throughout 2002. There was one continuous overflow to the percolation pond during 2002. This was sampled and reported to the CVRWQCB. For details, see Brown (2003).

All of the groundwater monitored constituents were also in compliance with permit 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 9-21 through 9-27.

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 are probably related to metals used in pumps and supply piping. This is particularly true of the upgradient STONEHAM1 well, which was used little during 2002, because its private owner had departed the area. The grab sample from the well showed considerable concentrations of arsenic, barium, chromium, copper, nickel, selenium, and zinc (see Data Supplement, Table 9-27).

As in past years, TCE was detected at concentrations up to 0.63 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 2002, 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 3.4 Bq/L (74 pCi/L), in well 11B1 (see Data Supplement Table 9-2).

Of the Livermore on-site monitoring wells, no inorganic data exceeded primary MCLs with the exception of nitrate in monitoring well W-1012 (see **Figure 9-2**).

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 2002 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 at the Livermore site made in 2002 do not indicate that LLNL activities have an adverse impact on groundwater or public health (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, nitrate, and perchlorate from the groundwater adjacent to several source areas within Site 300 (see Chapter 8 for locations).

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

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Introduction

The soil and sediment surveillance monitoring that Lawrence Livermore National Laboratory performed in 2002 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. U.S. 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 (GWPMP). 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 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 to 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 aboveground 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.

There are 19 soil sampling locations in the Livermore Valley, including 6 sampling locations at the Livermore Water Reclamation Plant (LWRP), an area of known plutonium contamination (**Figure 10-1**) and 14 locations at or near Site 300 (**Figure 10-2**). In 2002, all of the Livermore Valley locations were sampled; at Site 300 all locations except 812N were sampled. (Location 812N was inaccessible during the sampling campaign.)

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 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.

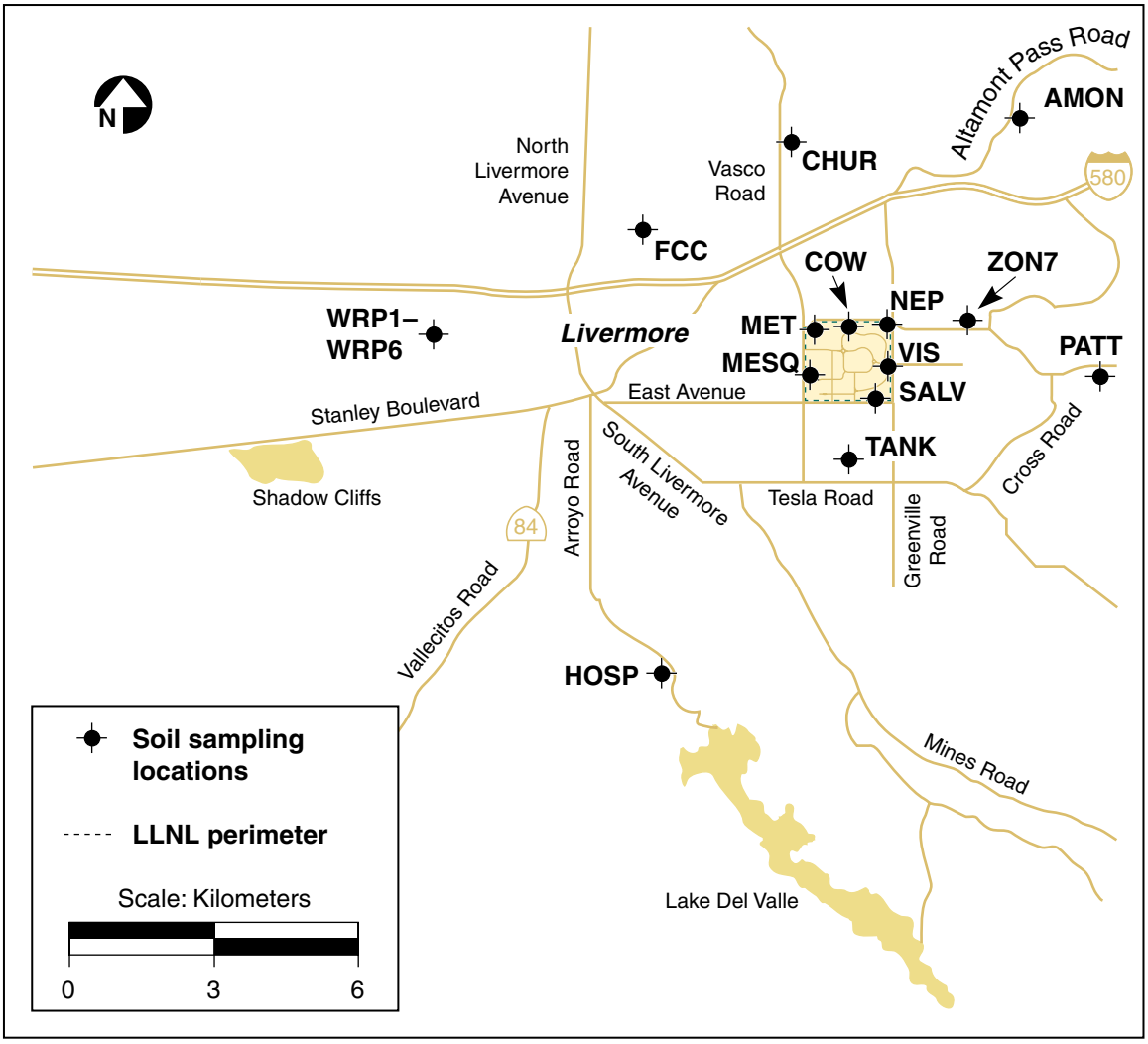


Figure 10-1. Surface soil sampling locations, Livermore Valley, 2002

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.

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

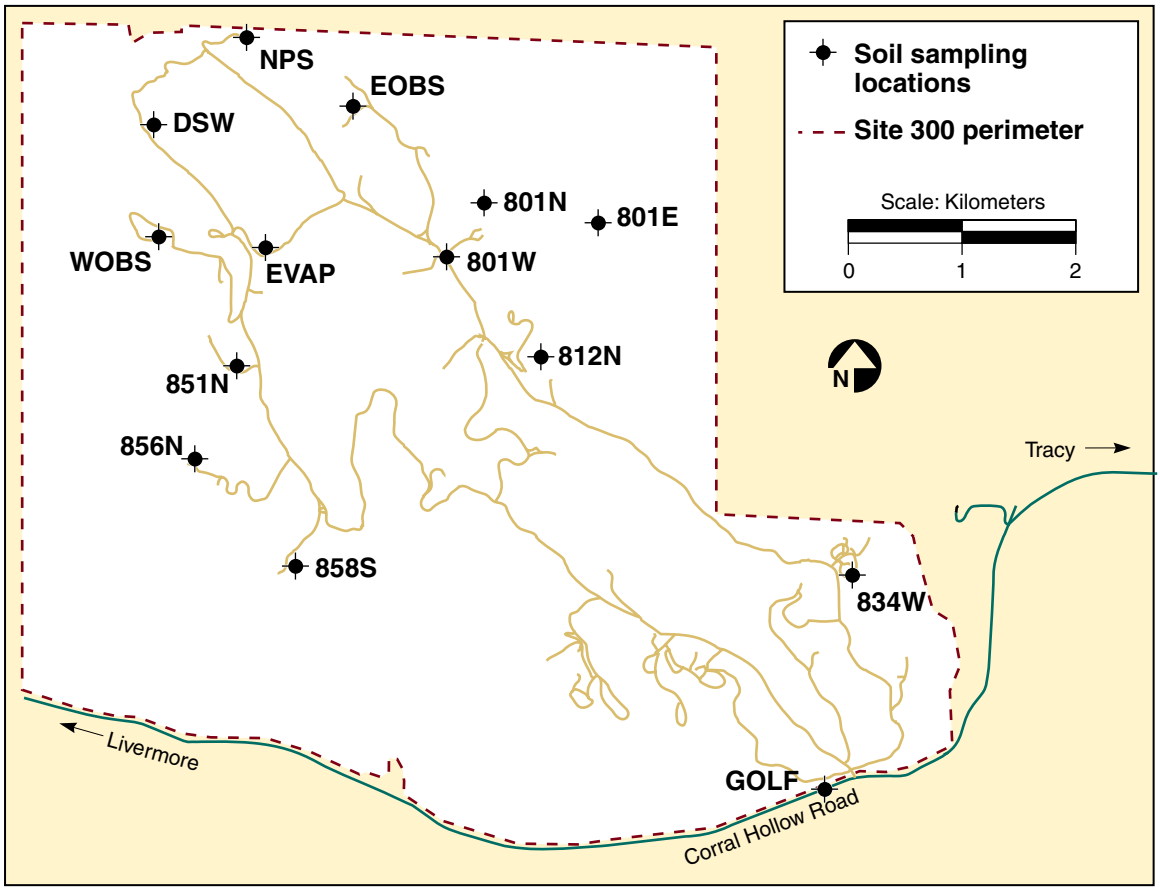


Figure 10-2. Site 300 surface soil sampling locations, 2002

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 and at 45–65 cm deep for analysis of soluble volatile organic compounds and for polychlorinated biphenyls (PCBs).

In 2002, 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 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 Monitoring Radiological Laboratory (EMRL). The plutonium content of a 100-g sample aliquot is determined by alpha spectroscopy. Other sample aliquots (300-g) are analyzed for more than

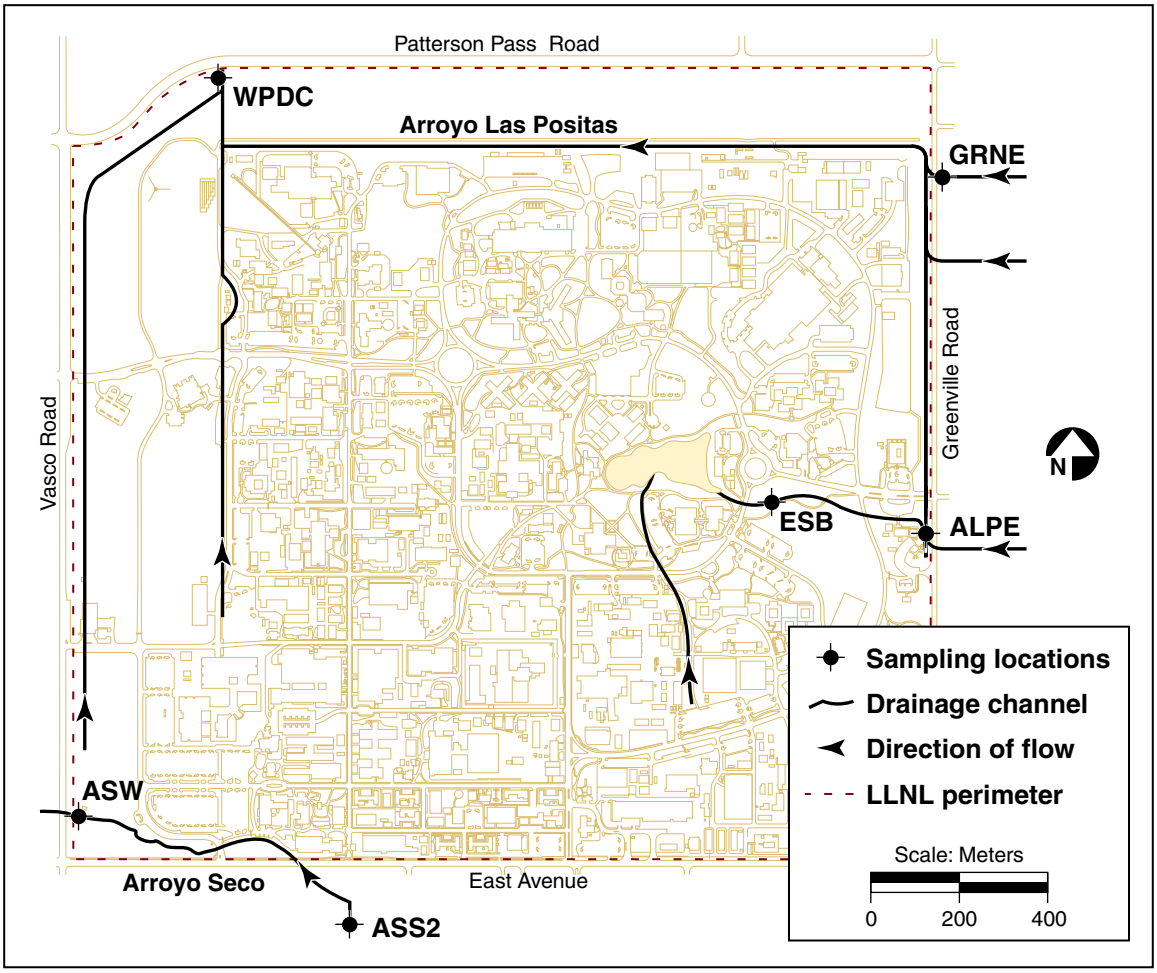


Figure 10-3. Sediment and vadose zone sampling locations on or near the Livermore site, 2002

150 radionuclides by gamma spectroscopy using a high-purity germanium (HPGe) detector. The 10-g subsamples for beryllium analyses are sent to a contract analytical laboratory and are analyzed by atomic emission spectrometry (EPA Method 200.7). For sediment samples collected for tritium analyses, EMRL 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 determining soluble metals includes the California Waste Extraction Test, followed by the same analytical methods for metals applied to the leachates. In 2002, as in the previous two years, 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 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 2002 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. In 2002, the measured plutonium-239+240 value for VIS was 0.48 mBq/dry g (1.3×10^{-2} pCi/dry g), a value that is equal to the 95% upper confidence level for the 95th percentile calculated for background data (LLNL 1998,

Table 10-1. Plutonium activity concentrations in Livermore Valley soil, 2002

Location identifier	Plutonium-238 mBq/dry g	Plutonium-239+240 mBq/dry g
L-AMON-SO	0.0049 ± 0.00096	0.085 ± 0.0041
L-CHUR-SO	0.0042 ± 0.00090	0.11 ± 0.0051
L-COW-SO	0.0015 ± 0.0010	0.019 ± 0.0033
L-FCC-SO	0.0017 ± 0.00053	0.027 ± 0.0020
L-HOSP-SO	0.0024 ± 0.00060	0.048 ± 0.0027
L-MESQ-SO	0.0015 ± 0.00047	0.028 ± 0.0019
L-MET-SO	0.0037 ± 0.00074	0.044 ± 0.0025
L-NEP-SO	0.0020 ± 0.00056	0.054 ± 0.0027
L-PATT-SO	0.00085 ± 0.00041	0.028 ± 0.0019
L-SALV-SO	0.011 ± 0.0012	0.074 ± 0.0034
L-TANK-SO	0.0099 ± 0.0012	0.12 ± 0.0044
L-VIS-SO	0.024 ± 0.0018	0.48 ± 0.012
L-ZON7-SO	0.0015 ± 0.00093	0.018 ± 0.0027
Median	0.0024	0.048
IQR[a]	0.0034	0.057
Maximum	0.024	0.48

Note: Radioactivities are reported as the measured concentration and either an uncertainty (±2σ 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

Appendix D). 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 and 2001, americium-241 was detected in at least one LWRP sample; 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 2002 included sampling locations VIS, PATT, NEP, COW, AMON, and ZON7, compared with the upwind data. Notable variability in plutonium-239+240 is also seen in samples from

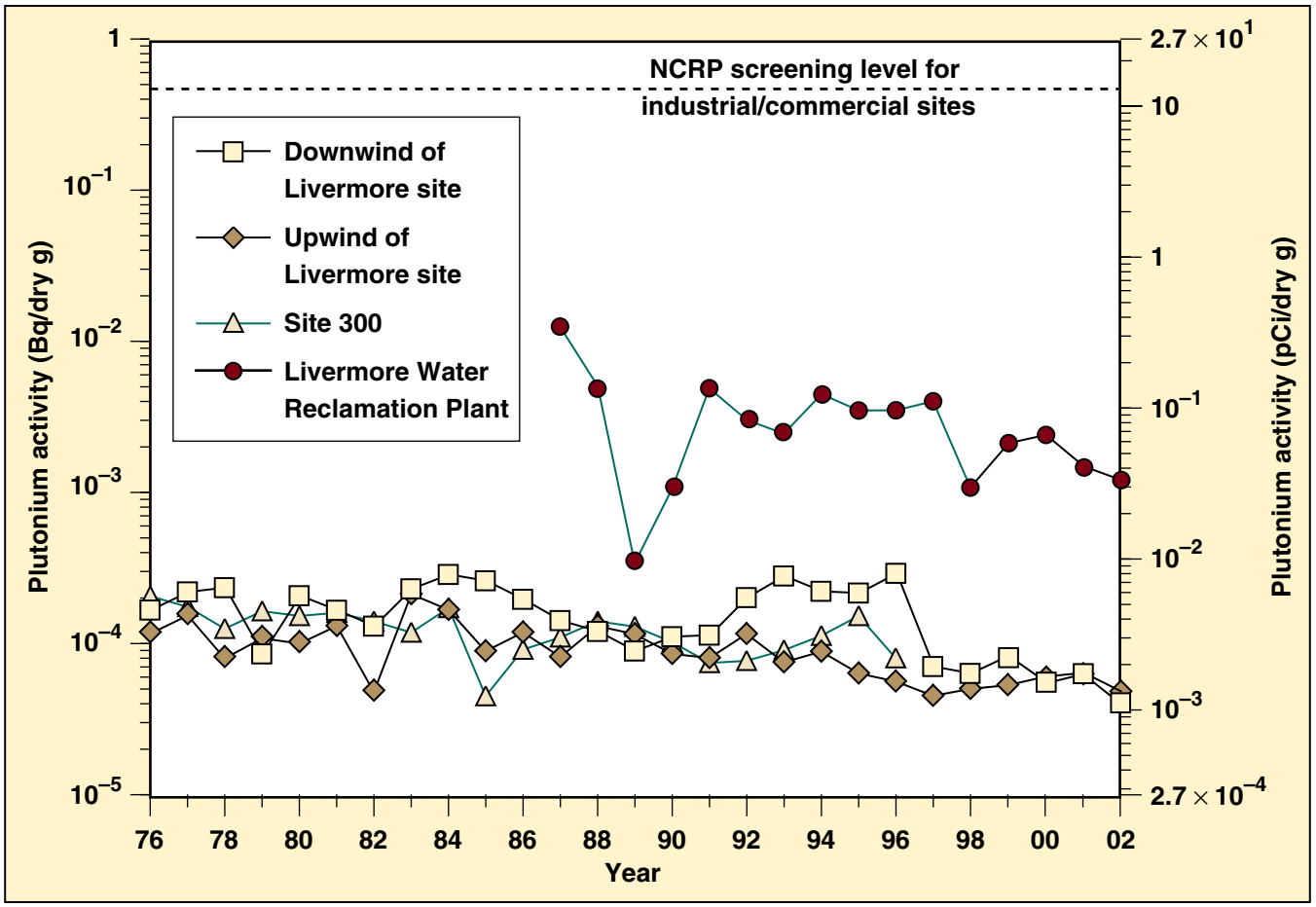
Table 10-2. Plutonium and americium activity concentrations in LWRP soil, 2002

Location identifier	Plutonium-238 mBq/dry g	Plutonium-239+240 mBq/dry g	Americium-241 mBq/dry g
L-WRP1-SO	0.40 ± 0.020	6.9 ± 0.25	5.4 ± 3.5
L-WRP2-SO	0.16 ± 0.011	2.7 ± 0.10	<0.68
L-WRP3-SO	0.051 ± 0.0053	0.90 ± 0.038	<0.41
L-WRP4-SO	0.040 ± 0.0048	0.60 ± 0.028	<0.54
L-WRP5-SO	0.080 ± 0.0069	1.5 ± 0.058	<0.67
L-WRP6-SO	0.035 ± 0.0022	0.64 ± 0.014	<0.69
Median	0.066	1.2	<0.68
IQR[a]	0.097	1.7	Not calculated[b]
Maximum	0.40	6.9	5.4

Note: Radioactivities are reported as the measured concentration and either an uncertainty (±2σ 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.



NCRP = National Council on Radiation Protection and Measurements

Figure 10-4. Median plutonium-239+240 activities in surface soils, 1976–2002. Upwind and downwind designations are relative to the center of the Livermore site.

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.

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, 9.6 Bq/L (260 pCi/L), was at location WPDC; the second highest detected value, 9.4 Bq/L (250 pCi/L) was at location ESB. Locations ESB

Table 10-3. Plutonium and tritium activity concentrations in surface sediment, 2002

Location identifier	Plutonium-238 mBq/dry g	Plutonium-239+240 mBq/dry g	Tritium Bq/L
L-ALPE-SD	0.0016 ± 0.00046	0.017 ± 0.0015	4.7 ± 2.1
L-ASS2-SD	0.0020 ± 0.0011	0.0077 ± 0.0020	3.4 ± 2.6
L-ASW-SD	0.0027 ± 0.0012	0.013 ± 0.0028	7.9 ± 7.8
L-ESB-SD	0.17 ± 0.011	1.8 ± 0.071	9.4 ± 2.3
L-GRNE-SD	0.0026 ± 0.0012	0.025 ± 0.0037	2.0 ± 1.9
L-WPDC-SD	0.0038 ± 0.0015	0.0089 ± 0.0022	9.6 ± 2.3
Median	0.0027	0.015	6.3
IQR[a]	0.0014	0.013	5.3
Maximum	0.17	1.8	9.6

Note: Radioactivities are reported as the measured concentration and either an uncertainty (±2σ 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

and WPDC are located in the influent and effluent, respectively, of the Drainage Retention Basin (DRB). The DRB contains water with similar concentrations of tritium (see Chapter 7). The measured values at ESB and WPDC are less than 2% 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 surface soil, the concentrations and distributions of all observed radionuclides in surface sediment for 2002 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 de minimis concentrations for organic compounds and tritium developed by LLNL and approved by the San Francisco Bay Regional Water Quality Control Board (SFBRWQCB) (Folks 1997; Marshack 2000), and with background concentrations for metals developed by LLNL. 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. Since 2000, Aroclor 1260 (a PCB) has been detected at location ESB. In 2002, it was again detected at location ESB at a concentration of 4 mg/kg. 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; 2002 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

Table 10-4. Uranium and beryllium concentration in Site 300 soil, 2002

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	0.016 ± 0.0091	1.6 ± 0.87	0.010 ± 0.0079	<0.5
3-801N-SO	0.037 ± 0.020	7.9 ± 2.4	0.0047 ± 0.0029	0.70
3-801W-SO	0.026 ± 0.0091	4.5 ± 0.90	0.0058 ± 0.0023	<0.5
3-834W-SO	0.016 ± 0.0096	2.0 ± 1.4	0.0080 ± 0.0074	0.60
3-851N-SO	0.024 ± 0.011	2.5 ± 1.0	0.0096 ± 0.0058	0.60
3-856N-SO	0.017 ± 0.0086	1.9 ± 1.2	0.0089 ± 0.0072	<0.5
3-858S-SO	0.024 ± 0.012	2.1 ± 0.95	0.011 ± 0.0077	<0.5
3-DSW-SO	0.026 ± 0.011	3.5 ± 1.2	0.0074 ± 0.0040	<0.5
3-EOBS-SO	0.021 ± 0.014	2.0 ± 1.6	0.011 ± 0.011	<0.5
3-EVAP-SO	0.029 ± 0.013	3.6 ± 1.2	0.0081 ± 0.0045	<0.5
3-GOLF-SO	0.020 ± 0.014	2.0 ± 1.3	0.010 ± 0.0096	<0.5
3-NPS-SO	0.020 ± 0.012	1.8 ± 1.1	0.011 ± 0.0095	<0.5
3-WOBS-SO	0.025 ± 0.0069	6.3 ± 1.0	0.0040 ± 0.0013	<0.5
Median	0.024	2.1	0.0089	<0.5
IQR[c]	0.0060	1.6	0.0026	Not calculated[d]
Maximum	0.037	7.9	0.011	0.70

Note: Radioactivities are reported as the measured concentration and either an uncertainty (±2σ 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 µg/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 µg/dry g by specific activity of uranium-238, i.e., 0.01245 Bq/µg, or 0.3367 pCi/µg.

c IQR = interquartile range

d Interquartile range not calculated because of high incidence of nondetections.

Site 300 soil for 2002 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**. The highest values at Site 300 result from the use of depleted uranium in explosive experiments. The measured beryllium values for 2002 at Site 300 are lower than in previous years. This is most likely due to a change in analytical method from a method based on atomic absorption spectroscopy (EPA method 7091) to one based on atomic emission spectrometry (EPA method 200.7). The latter method has fewer matrix interferences, and it is expected that the results would be somewhat lower.

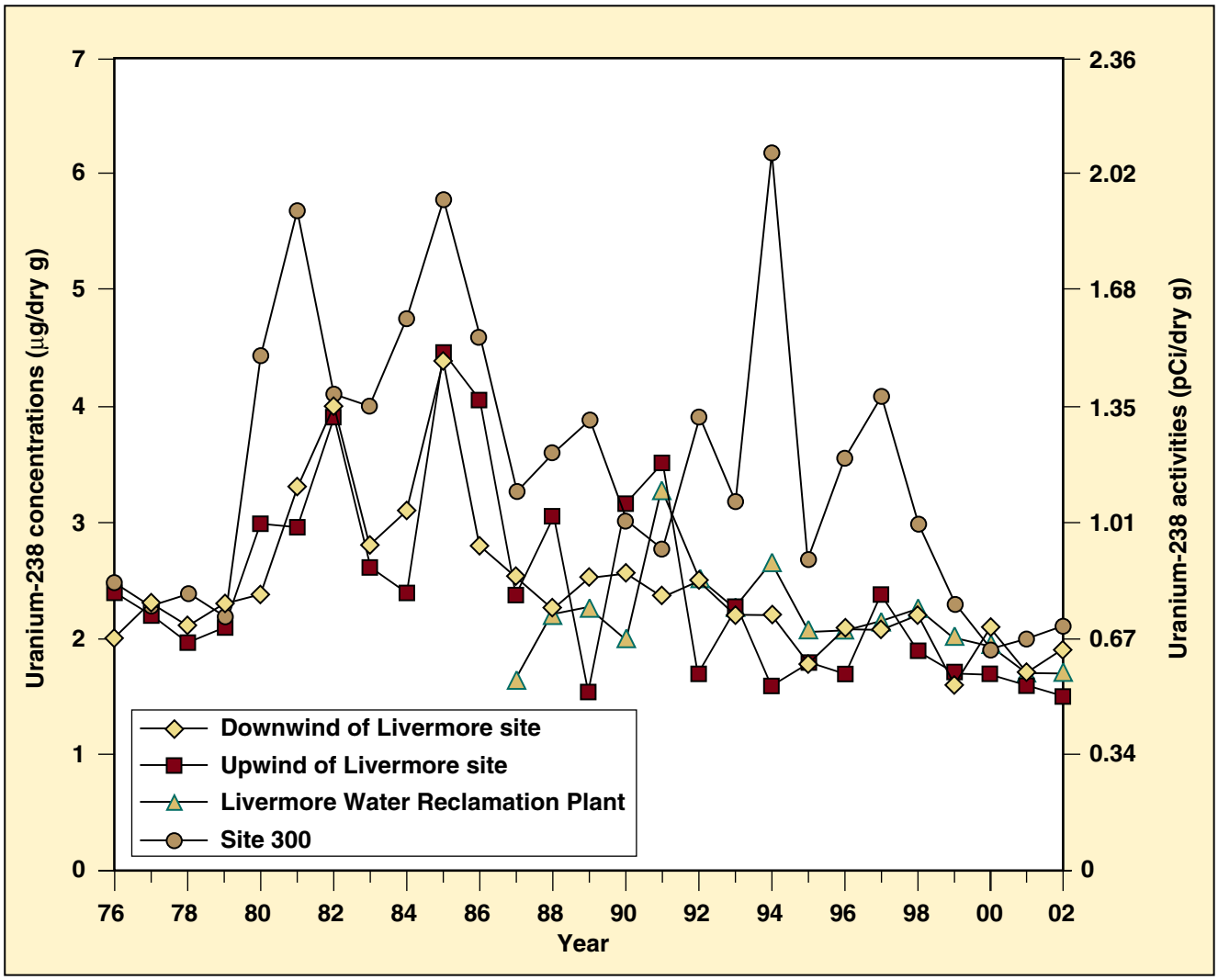


Figure 10-5. Median uranium-238 concentrations in surface soils, 1976–2002. Upwind and downwind designations are relative to the center of the Livermore site.

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 2002 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 6.9 mBq/dry g (0.19 pCi/dry g) for plutonium-239+240 measured at LWRP is 1.5% of the National Council on Radiation Protection and Measurements (NCRP) recommended screening limit of 470 mBq/g (12.7 pCi/g) for property used for commercial purposes (NCRP 1999). Regression analysis of the annual medians of the upwind and downwind data groups shows a slight 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.

Table 10-5. Special soil studies

Year	Subject[a]	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	ATSDR 2000
2002	Livermore Big Trees Park:1998 Results	MacQueen et al. 2002
2003	ATSDR Draft Public Health Assessment Plutonium 230 in Sewage Sludge Used as a Soil or Soil Amendment in the Livermore Community	ATSDR 2003

a See Acronyms and Abbreviations for list of acronyms.

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 result from the fraction of the firing table operations that disperse depleted uranium. The uranium-238 concentrations are below the NCR 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. A CERCLA remedial investigation is underway at the Building 812 firing table area to define the nature and extent of contamination. Depleted uranium has been detected in soil and groundwater in the area.

Vegetation and Foodstuff Monitoring

S. Ring Peterson

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 are exposed to a tritiated environment.

LLNL has been monitoring tritium in vegetation to some extent since 1966 and has performed routine vegetation sampling in the vicinity of the Livermore site and Site 300 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 on average less than 0.2% of the EPA's drinking water standard, 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, honey and milk are no longer produced in the vicinity of LLNL, so tritium concentrations in only vegetation and wine are used to assess potential ingestion dose from tritium emitted during LLNL operations.

During 2002, 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 presented in Appendix C. In addition, as part of a continuing study, LLNL determined the potential tritium dose to the maximally exposed individual from a particular 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 from this tree (Location PINI in **Figure 11-1**) 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 2002, 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 approximately equal size from the same location was also collected for archiving. Samples, delivered to LLNL's Chemistry and Materials Science Environmental Monitoring Radiological 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. All sampling locations were the same as those in 2001.

The routine vegetation sampling locations are designated with permanent location markers. Consistent use of the same 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.

Wine

In 2002, 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

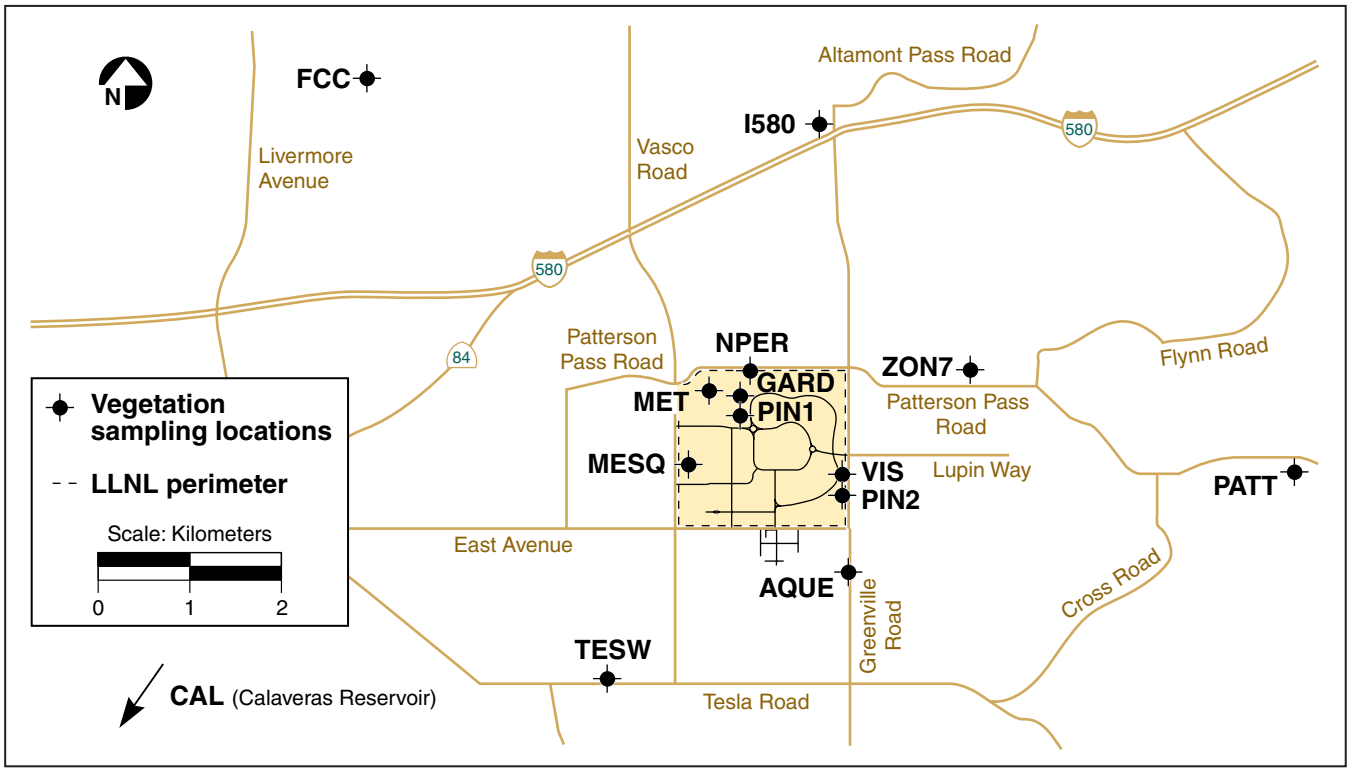


Figure 11-1. Livermore site and Livermore Valley vegetation sampling locations, 2002

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 2002. Approximately 10% of the total complement of wines was sampled in duplicate to comply with quality assurance protocols.

LLNL analyzed wines for tritium using helium-3 mass spectrometry in the Analytical and Nuclear Chemistry Division's Noble Gas Mass Spectrometry Laboratory in the 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.

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.

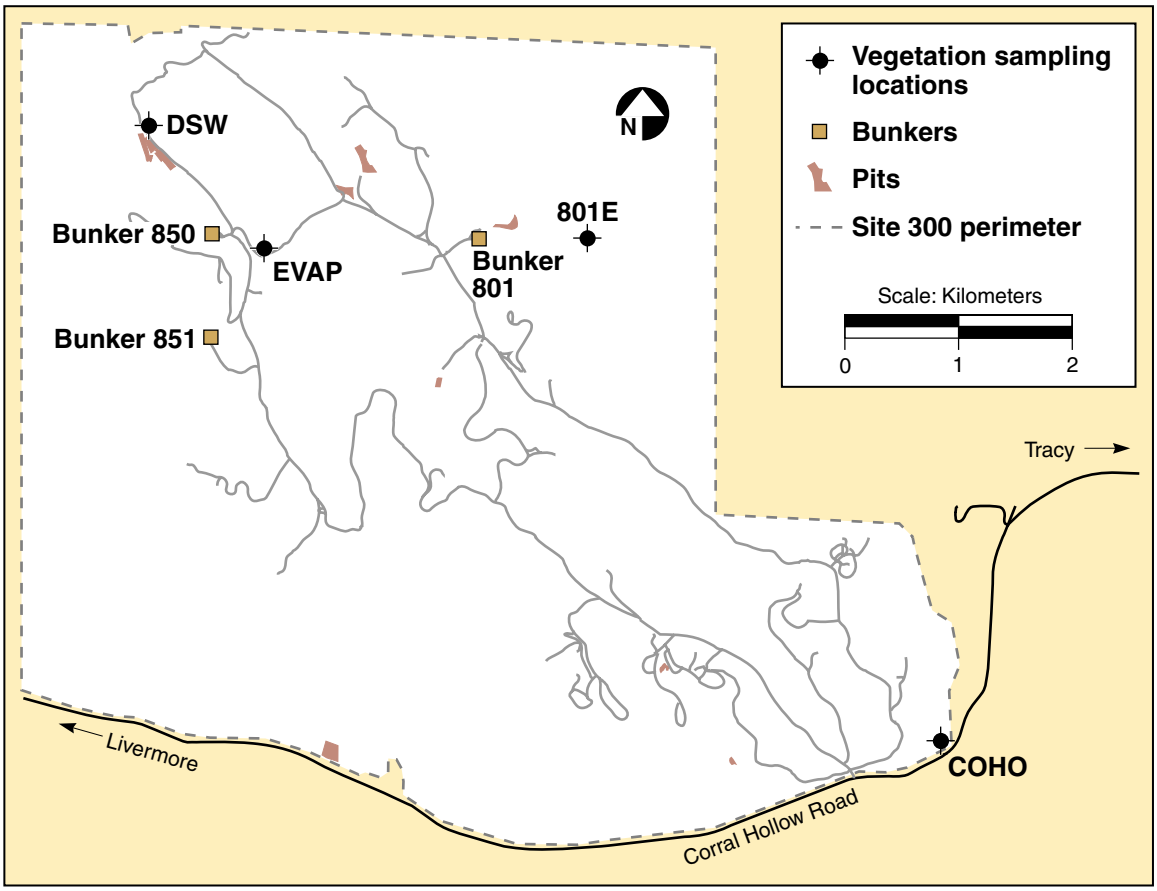


Figure 11-2. Site 300 vegetation sampling locations, 2002

Livermore Site

Vegetation

The Livermore site and Livermore Valley vegetation locations are divided into four groups for statistical evaluation:

- **Near:** locations on-site or 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 11-1 shows tritium concentrations for all vegetation collected for the LLNL vegetation monitoring program in 2002. For 2002, the data for tritium in vegetation were compared using Scheffé's *F* and Games/Howell multiple comparisons (Scheffé 1953; Games and Howell 1976). 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. Both the lowest and the highest concentrations were found in the Near locations, and two values for the Intermediate samples were higher than all but two of the Near samples.

Figure 11-3 shows the 2002 medians of the tritium concentrations for PIN1, Near, Intermediate, and Far Livermore locations as a continuation of historic median concentrations from 1971 to 2001. The upturn in median values for the Intermediate group (**Figure 11-3**) is due to high values at ZON7. In general, the trend loosely linked to a small increase in emissions from the Tritium Facility (see Chapter 4), is towards slightly higher concentrations in vegetation in 2002 than in 2001. This is most noticeable in the Intermediate locations probably by chance, because quarterly vegetation sampling is insufficient to define annual average concentrations.

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 Emission Standards for Hazardous Air Pollutants (NESHAPs) (See **Chapter 13**). 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 (with the exception of PIN1), are from air and soil water in quasi-equilibrium with air. When samples from PIN1 were compared with samples from each Near location for 2002 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 2002 represent vintage years 1997, 1998, 1999, and 2001, the 2002 sampling data cannot be used to indicate how LLNL's operations affected concentrations of tritium in wines produced from grapes grown in 2002. 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.

The results from the 2002 wine tritium analyses are shown in **Table 11-2**. Tritium concentrations of Californian and European wines are within the range of those reported in previous years; the concentrations in Livermore wines are distinctly lower, on average. The data for the 2002 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 concen-

Table 11-1. Concentrations of tritium in plant water (Bq/L) collected quarterly and estimated annual ingestion doses for each sampling location, 2002

	First Quarter	Second Quarter	Third Quarter	Fourth Quarter	Median	IQR[a]	Mean	Dose (nSv/y)[b]	
								Mean[c]	Maximum
Sampling locations within 1 km of the Livermore site perimeter									
AQUE	0.88 ± 2.0	2.5 ± 2.0	0.48 ± 2.0	2.1 ± 2.2	1.5	1.4	1.5	7.4	12
GARD	2.3 ± 2.0	0.58 ± 1.9	–0.75 ± 1.9	1.4 ± 2.2	0.99	1.4	0.88	4.3	11
MESQ	2.5 ± 2.0	–0.54 ± 1.9	0.34 ± 2.0	2.4 ± 2.3	1.4	2.3	1.2	5.9	12
MET	0.46 ± 2.0	0.88 ± 1.9	0.67 ± 2.0	7.4 ± 2.5	0.78	1.9	2.4	12	36
NPER	3.6 ± 2.1	1.6 ± 2.0	2.5 ± 2.1	5.7 ± 2.4	3.1	1.9	3.4	17	28
PIN2	5.5 ± 2.2	7.5 ± 2.2	4.8 ± 2.2	3.5 ± 2.3	5.2	1.5	5.3	—[d]	—[d]
VIS	4.8 ± 2.2	4.9 ± 2.1	4.4 ± 2.2	4.5 ± 2.3	4.7	0.35	4.7	23	24
PIN1	52 ± 3.7	77 ± 4.2	290 ± 7.5	12 ± 2.7	65	89	110	0.0089[e]	0.024[e]
Sampling locations 1–5 km from the Livermore site perimeter									
I580	2.3 ± 2.0	1.2 ± 2.0	2.3 ± 2.1	–0.19 ± 2.2	1.8	1.4	1.4	6.9	11
PATT	1.4 ± 2.0	1.3 ± 2.0	2.3 ± 2.1	0.77 ± 2.2	1.4	0.46	1.4	6.9	11
TESW	0.38 ± 2.0	–0.10 ± 1.9	2.2 ± 2.1	3.8 ± 2.3	1.3	2.3	1.6	7.8	19
ZON7	4.5 ± 2.1	2.7 ± 2.0	5.8 ± 2.2	6.7 ± 2.4	5.2	2.0	4.9	24	33
Sampling locations more than 5 km from the Livermore site perimeter									
CAL	0.26 ± 1.9	0.60 ± 1.9	0.91 ± 2.0	–1.3 ± 2.1	0.43	0.81	0.12	0.59	4.5
FCC	0.22 ± 1.9	2.0 ± 2.0	–0.44 ± 1.9	0.43 ± 2.2	0.33	0.77	0.55	2.7	9.8
Sampling locations at Site 300									
COHO	2.4 ± 2.1	–0.025 ± 1.9	0.58 ± 2.0	–0.31 ± 2.1	0.28	1.1	0.66	3.2	12
801E	0.58 ± 2.0	–0.13 ± 1.9	–0.77 ± 1.9	1.40 ± 2.3	0.23	1.1	0.27	1.3	6.9
DSW[f]	45 ± 3.5	23 ± 3.0	2500 ± 21	2.3 ± 2.3	34	640	640	3100	12,000
EVAP[f]	37 ± 3.3	43 ± 3.3	120 ± 5.0	–0.41 ± 2.2	40	35	50	250	590

Note: Radioactivities are reported as the measured concentration and an uncertainty (±2σ 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 C.

c Doses are calculated based on mean rather than median concentrations because ingesting an equal mass of food quarterly is represented by the mean.

d Doses were not calculated because pine needles 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 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.

f These plants are rooted in areas of known subsurface contamination.

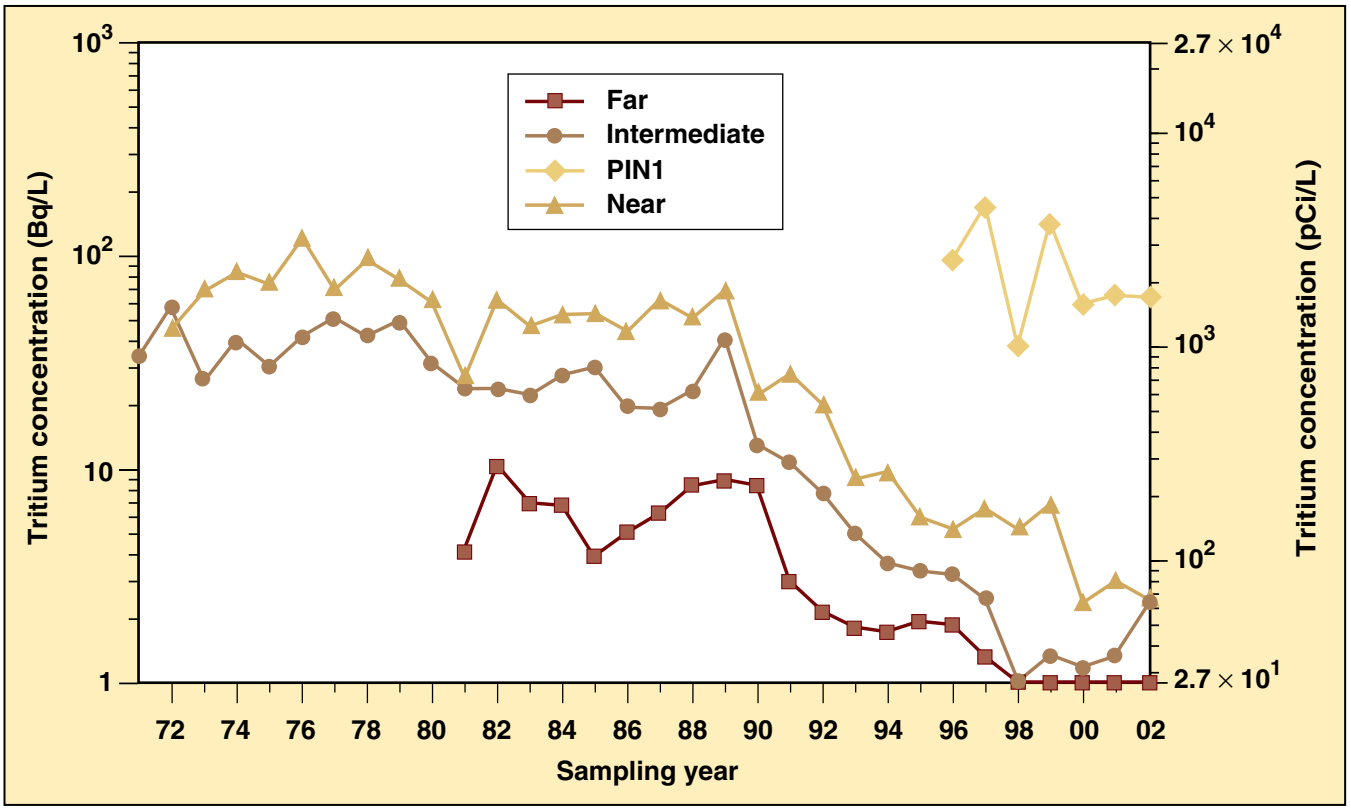


Figure 11-3. Median tritium concentrations in Livermore site and Livermore Valley plant water samples, 1971–2002. When median values are below 1 Bq/L (well below detection limits), values are plotted as 1 Bq/L to eliminate meaningless variability.

trations 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 more variability in the concentrations of Livermore Valley wines collected for 2002 than there has been in recent years. For 2002, the concentrations in Livermore Valley wines are both lower and higher than in 2001. The lower concentrations seen in wines collected in 2002 are all from grapes harvested in 2001; the higher concentration is from a bottle from grapes harvested in 1999.

Concentrations of tritium in wine corrected to vintage year are plotted in **Figure 11-4**. The downward trend for Livermore Valley wines continues. Using the Scheffé's F test, there is no significant difference in concentrations of California wines from 1991 through 2001.

Table 11-2. Tritium in retail wine (Bq/L), 2002[a]

Sample	Area of production		
	Livermore Valley	California	Europe
1	0.71 ± 0.20	0.34 ± 0.19	0.88 ± 0.20
2	0.72 ± 0.20	0.42 ± 0.19	1.2 ± 0.22
3	0.75 ± 0.20	0.45 ± 0.19	1.3 ± 0.23
4	0.75 ± 0.20	0.50 ± 0.19	3.9 ± 0.43
5	0.83 ± 0.20	0.57 ± 0.19	
6	1.2 ± 0.22	0.76 ± 0.20	
7	1.2 ± 0.22		
8	1.3 ± 0.22		
9	1.4 ± 0.23		
10	2.1 ± 0.28		
11	2.6 ± 0.32		
12	2.9 ± 0.35		
Median; IQR[b]	1.2; 0.83	0.48; 0.13	1.3; 0.83
Mean ± standard deviation	1.4 ± 0.76	0.51 ± 0.15	1.8 ± 1.4
Dose (nSv/y)[c]			
Mean[d]	1.3	0.46	1.6
Maximum	2.6	0.68	3.9

Note: Radioactivities are reported here as the measured concentration and an uncertainty (±2σ 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 2002. The concentrations reported are those at the time the bottle was opened.

b IQR = interquartile range

c This dose is calculated based on consumption of 52 L wine per year (see Appendix C).

d Doses are calculated on mean concentrations because ingestion intake is better represented by a mean than by a median.

Site 300

Vegetation

There are four monitoring locations for vegetation at Site 300 (**Figure 11-2**). Of these, 801E and COHO have the potential to demonstrate changes in atmospheric tritium concentrations. Vegetation from locations DSW and EVAP grows in areas of known groundwater contamination.

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 concentration in the plant water will be somewhat lower than that of soil water, but it will be much higher than the concentration in air moisture.

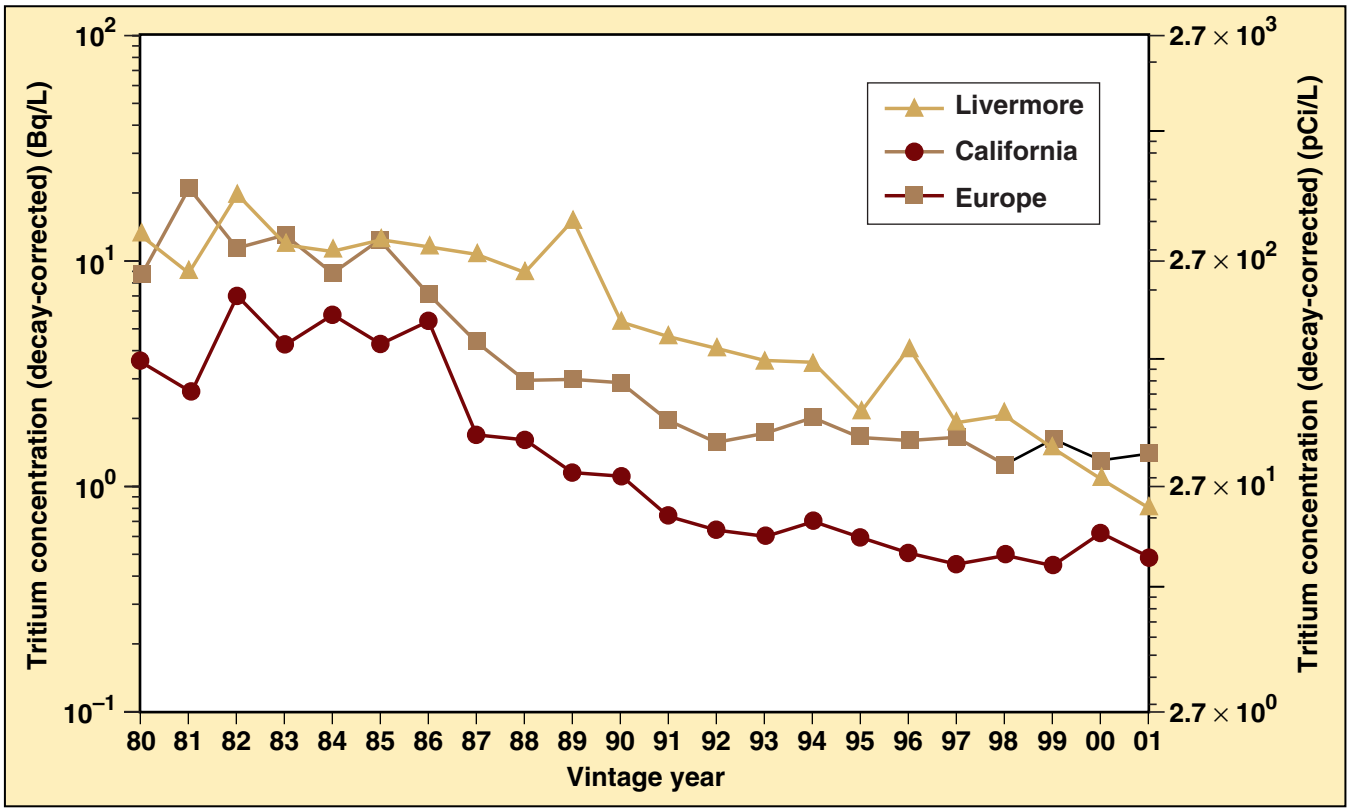


Figure 11-4. Median tritium concentrations in retail wines decay-corrected from the sampling year to the vintage year

Table 11-1 shows all tritium data for vegetation collected at Site 300 during 2002. Historic median concentrations for tritium at Site 300 sampling locations are shown in Figure 11-5. Results from 801E and COHO for 2002 were close to or below detection limits. Concentrations at locations EVAP and DSW were above detection limits for the first three quarters. The median concentrations at DSW and EVAP are similar; both are below those of 2001. As shown in Figure 11-5, median concentrations below 1 Bq/L (well below the limits of detection) are assumed equal to 1 Bq/L to avoid plotting meaningless differences.

The highest tritium result (2500 Bq/L) 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 environmental restoration study areas of the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) (see Chapter 8).

Relatively high concentrations of tritium in plants at DSW and EVAP are observed only sporadically when the roots of the vegetation come in contact

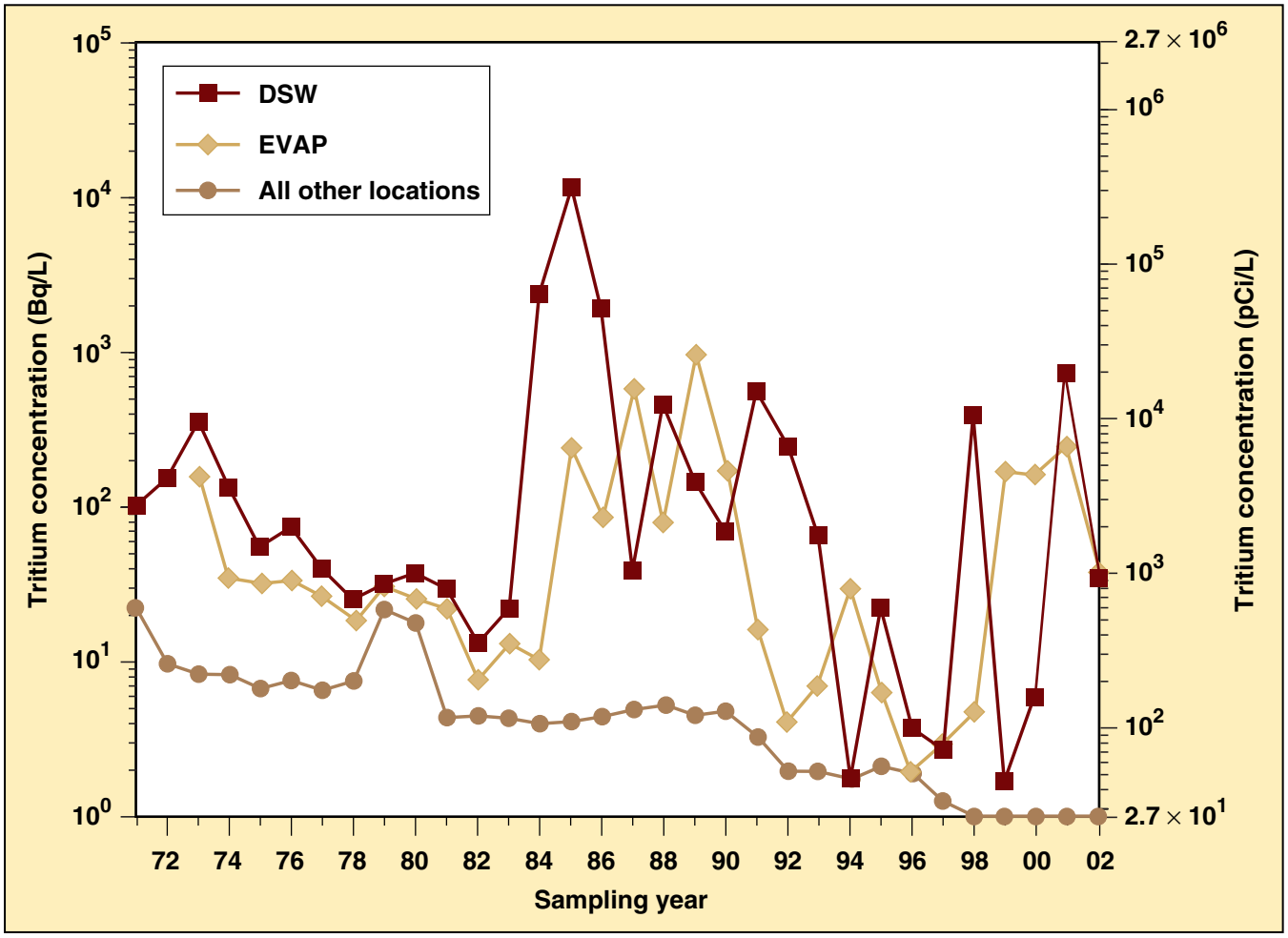


Figure 11-5. Median tritium concentrations in plant water at Site 300 sampling locations, 1971–2002. When median values are below 1 Bq/L (well below detection limits), values are plotted as 1 Bq/L to eliminate meaningless variability.

with contaminated groundwater. Evaluation of the 2002 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, DSW was determined to be different from 801E and COHO at the 5% significance level.

Environmental Impact

In 2002, 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 2002. 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 C 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 C-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 2002 for the Livermore Valley is 36 nSv/y (0.036 μSv/y or 0.0036 mrem/y).

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 2002 cannot exceed 110 nSv/y (0.11 μSv/y or 0.011 mrem/y), which is well below any level of regulatory 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 emitted by the tree that is 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 0.024 nSv/y (2.4×10^{-5} µSv/y or 2.4×10^{-6} mrem/y) 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 (2.9 Bq/L or 78 pCi/L) represents only 0.39% 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 C.

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 2002 Livermore Valley tritium value in wine is 19 nSv (1.9 µrem). Assuming a more realistic, yet high,* average wine consumption (52 L/year or 1 L/week), and the mean tritium values from the three sampling areas, the annual doses from Livermore, European, and California wines would be 1.3 nSv (0.13 µrem), 1.6 nSv (0.16 µrem), and 0.46 nSv (0.046 µrem), 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 2002 that accounts for contributions from HTO and OBT in vegetables, milk, meat, and wine will realistically be less than 110 nSv (0.11 µSv or 0.011 mrem). This estimate is similar to dose estimates calculated using other assumptions (see Appendix C). This estimate is a factor of 27,000 lower than an annual background dose (~3000 µSv or 300 mrem) and a factor of 900 lower than the dose from a typical chest x-ray (100 µSv or 10 mrem) (Shleien and Terpilak 1984). Therefore, although tritium levels are slightly elevated near the Livermore site, doses from tritium ingestion are negligible.

In general, LLNL impacts on tritium concentrations in vegetation at Site 300 for 2002 were insignificant. With the exception of vegetation from previously identified sites of contamination, the tritium levels at Site 300 were 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 DSW (**Figure 11-2**), based on the maximum value of 2500 Bq/L (68,000 pCi/L), is 12 µSv (1.2 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.

*. 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

Nicholas A. Bertoldo

Introduction

In accordance with federal regulations and applicable portions of U.S. 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 the 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. Should a significant deviation from the expected values occur, an action level investigation of possible sources for the deviation is implemented.

As previously mentioned, the variability of the naturally occurring radioisotopes present in the soil due to 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 12 of the Data Supplement.

Monitoring Locations

In 2002, 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 were monitored at 13 monitoring locations in the first two quarters at Site 300 (**Figure 12-3**); the number of monitoring locations was reduced to 9 in the 3rd and 4th quarters of 2002. The locations that were removed (3-123-TD, 3-124-TD, 3-125-TD, 3-126-TD) were added in the 3rd and 4th quarters of 2000 for monitoring accessibility following a vehicle fire that occurred in the 2nd quarter and resulted in the loss of several samples in that year. Additionally, the Site 300 data had previously been compared to 4 near–Site 300 locations and 2 locations in nearby Tracy. Two of the near–Site 300 locations have been removed this year due to private property access issues. Summary dose calculations for all gamma-monitoring locations are presented in **Table 12-1**. These site locations are depicted in **Figure 12-3**.

Results of Gamma Monitoring

Figure 12-4 shows gamma doses for the Livermore site perimeter, Livermore Valley, and Site 300 from 1988 through 2002. 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

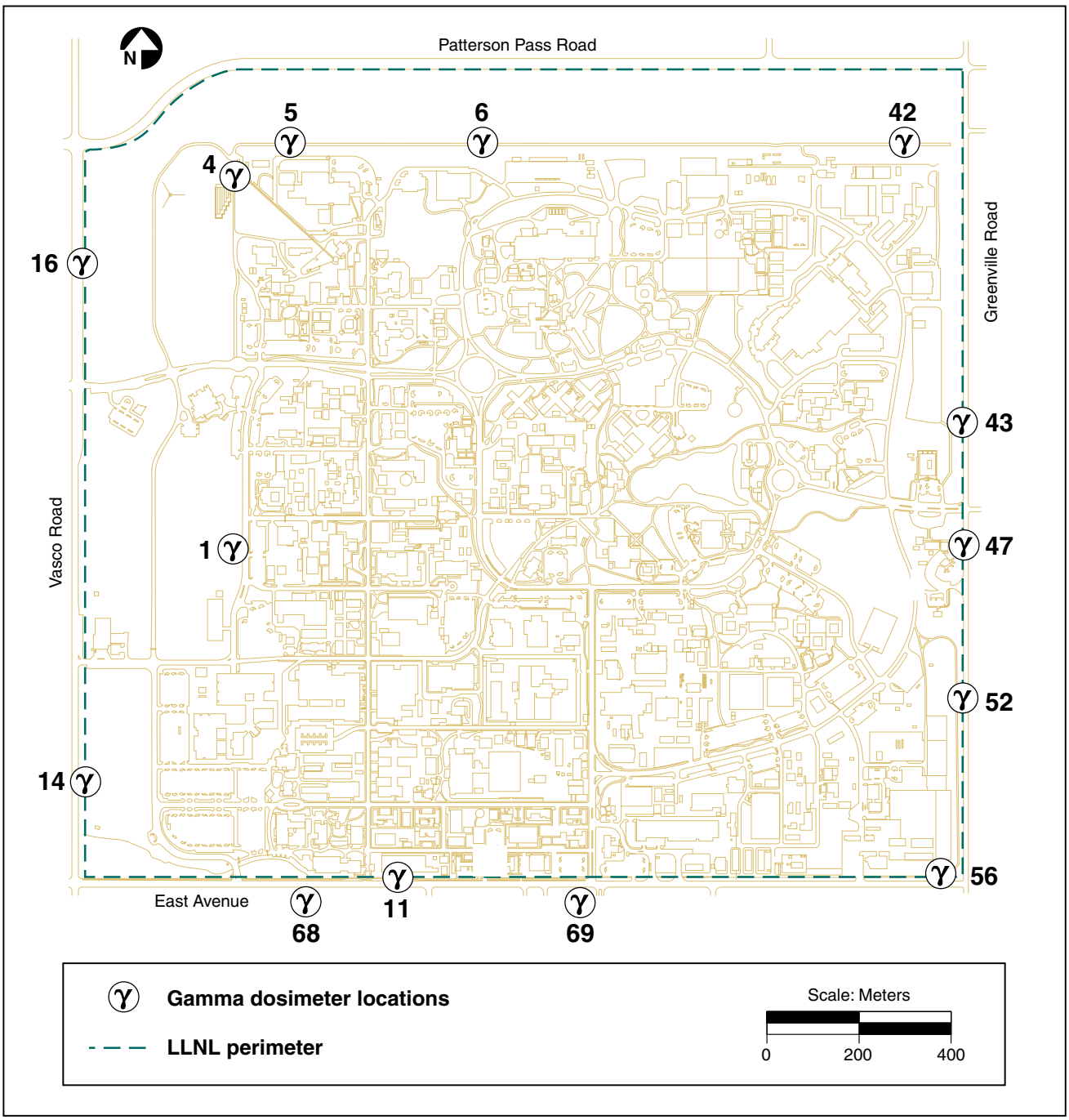


Figure 12-1. Gamma dosimeter locations, Livermore site, 2002

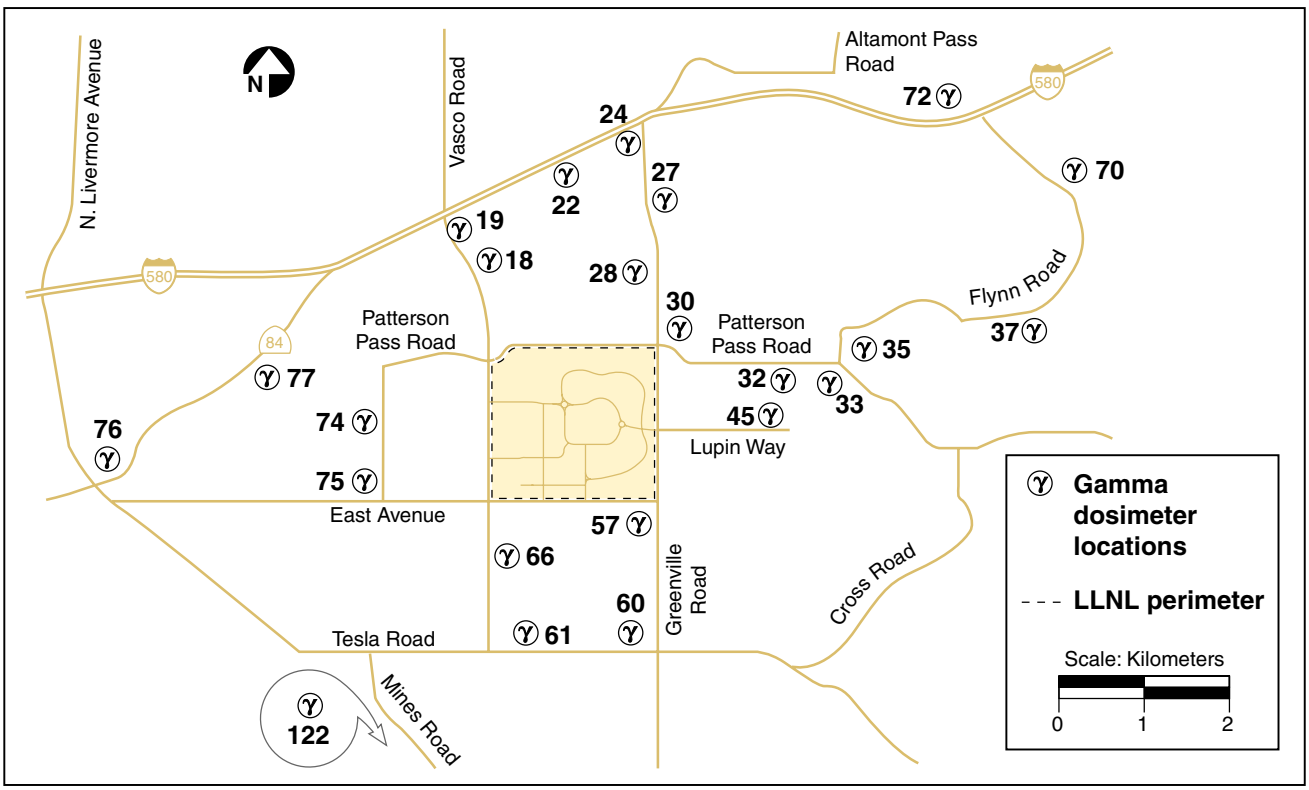


Figure 12-2. Gamma dosimeter locations, Livermore Valley, 2002

data by this method normalizes the data for comparison and reduces the data variability due to field duration.

Livermore Site

The quarterly and annual 2002 TLD gamma radiation dose for the Livermore site perimeter is summarized in **Table 12-1**. The annual dose from external radiation exposure at the Livermore site perimeter is 0.646 ± 0.028 mSv (64.6 ± 2.8 mrem). The quarterly means that produce the annual total are reported in Table 12-1 of the Data Supplement.

Site 300

The summary dose reported in **Table 12-1** for the Site 300 perimeter in 2002 is 0.755 ± 0.025 mSv (75.5 ± 2.3 mrem). The measured dose at the off-site locations near Site 300 was 0.751 ± 0.068 mSv (75.1 ± 6.8 mrem). The annual dose measured for Tracy is 0.679 ± 0.060 mSv (67.9 ± 6.0 mrem).

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

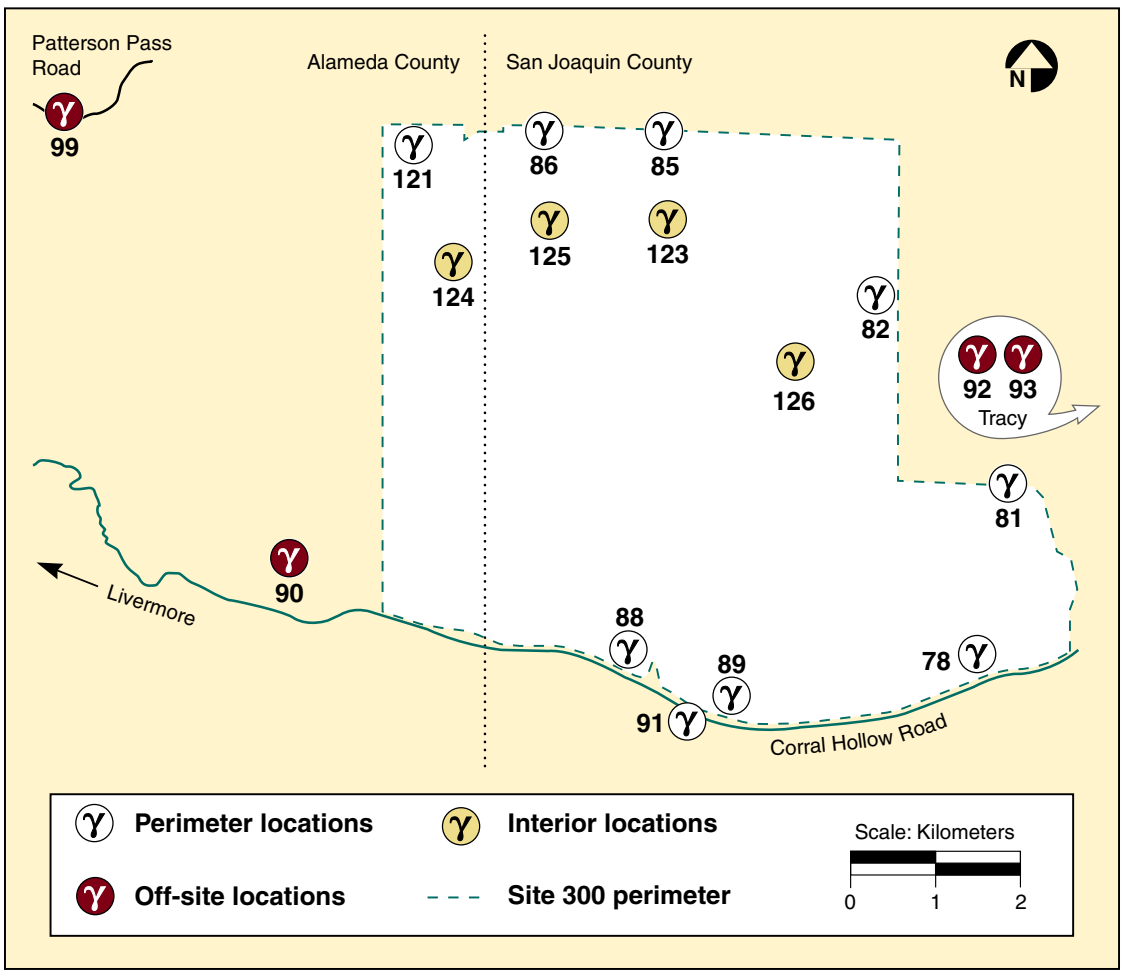


Figure 12-3. Gamma dosimeter locations, Site 300 and vicinity, 2002

of clays, sands, and silts overlying bedrock. The difference in the doses can be directly attributed to the difference in geologic substrates.

The data represented in **Figure 12-5** show a slight increase for the 4th quarter for both the Livermore site and Livermore Valley data. Additionally, the data for Site 300, Tracy, and the near–Site 300 locations show a similar trend. Although the data does not suggest a serious impact on either health or the environment, it falls within the action level of investigation. There are no plausible explanations at this time.

Table 12-1. Summary of dose calculations for gamma-monitoring locations (mSv)[a] at all LLNL sites, 2002

Quarter	Location				
	Livermore site	Livermore Valley	Site 300	Tracy	Near Site 300
	Mean 2 SE[b]	Mean 2 SE[b]	Mean 2 SE[b]	Mean 2 SE[b]	Mean 2 SE[b]
First	0.161 ± 0.007	0.161 ± 0.006	0.182 ± 0.010	0.167 ± 0.040	0.188 ± 0.038
Second	0.151 ± 0.006	0.150 ± 0.008	0.172 ± 0.011	0.147 ± 0.034	0.181 ± 0.019
Third	0.151 ± 0.007	0.153 ± 0.008	0.188 ± 0.010	0.153 ± 0.025	0.180 ± 0.029
Fourth	0.183 ± 0.008	0.182 ± 0.007	0.213 ± 0.018	0.212 ± 0.014	0.202 ± 0.045
Annual dose[c]	0.646 ± 0.028	0.646 ± 0.015	0.755 ± 0.025	0.679 ± 0.060	0.751 ± 0.068

a 1 mSv = 100 mrem

b SE = Standard Error (standard deviation of the mean)

c Annual dose is reported as the summation of the quarterly doses. The reported error is the root mean square of the quarterly errors.

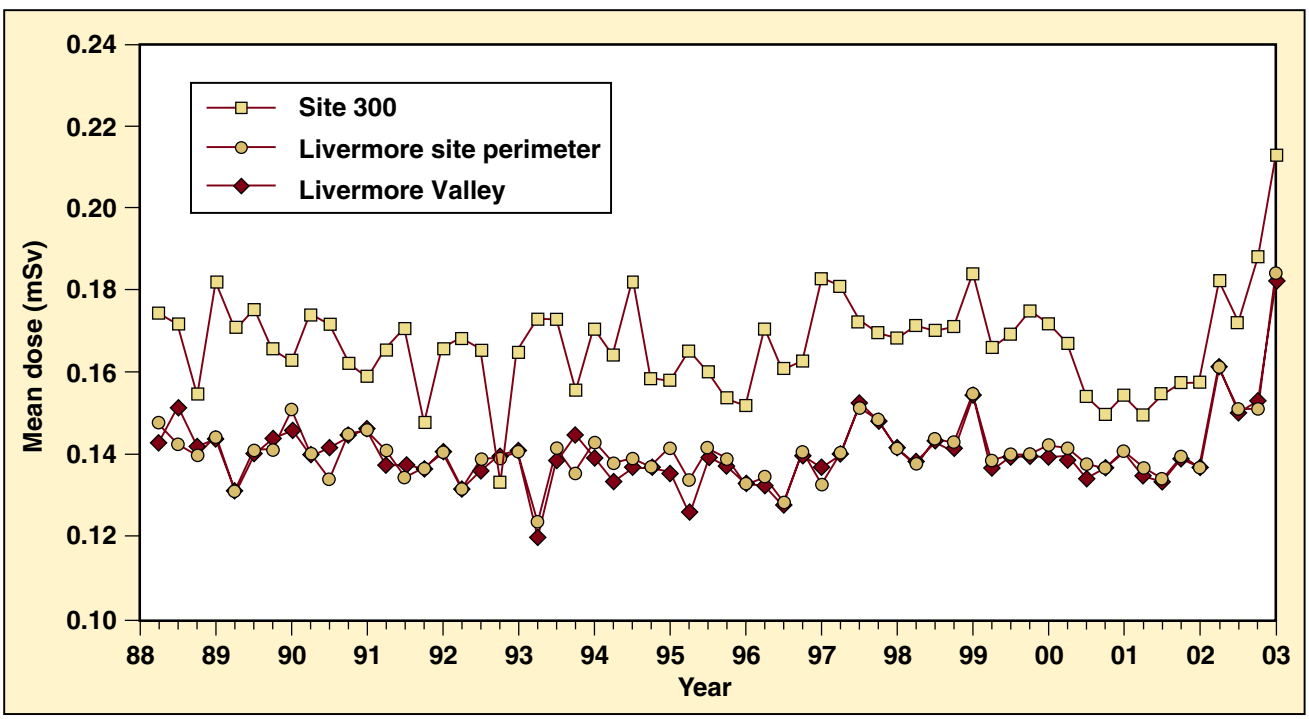


Figure 12-4. Quarterly gamma dose measurements at the Livermore site perimeter, Livermore Valley, and Site 300, 1988–2002

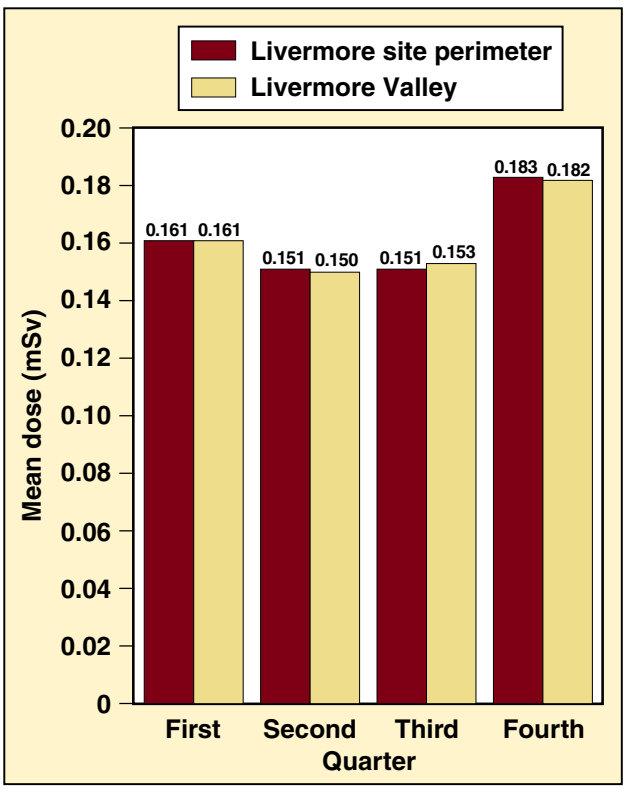


Figure 12-5. Comparison of the 2002 LLNL site perimeter and the Livermore Valley TLD quarterly mean dose (mSv)

Environmental Impact

Although the contribution of cosmic radiation may vary due to the sun cycle, the sum of the measured terrestrial and cosmic radiation dose has been observed to range from 0.55 to 0.65 mSv/y (55 to 65 mrem). 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 2002 are at or near these predicted values and are statistically equivalent to the Livermore Valley doses, which are considered to be reference natural background levels for this area. Although measured gamma exposure at Site 300 and the local vicinity are slightly higher than that 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 annual gamma radiation measured by the TLD network indicates that the exposure level is not elevated significantly above natural background for any of the monitoring sites due to LLNL operations and more importantly remains an adequate indicator of exposure risk.

13

Radiological Dose Assessment

Robert J. Harrach
S. Ring Peterson
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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. It also 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 2002.

Wilhelm Conrad Röntgen discoverer of x-rays in 1885, recipient of first Nobel prize in physics, 1901.

Readers desiring to go directly to these principal new results can turn to the section "Results of 2002 Radiological Dose Assessment."

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 case of this type from several years ago concerned the potential dose to the public from inhalation and ingestion of soil that had been contaminated by sewage sludge containing radioactivity (MacQueen et al. 2002). 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 rain water, soil, vegetation, and wine, and measures environmental (gamma) radiation.

Monitoring has been described extensively since 1971 in LLNL's environmental reports (e.g., Gallegos et al. 2002; see also Chapters 4 through 12 in the present report) and in LLNL's *Environmental Monitoring Plan* (Tate et al. 1999) and its companion volume on procedures and guidance documents.

Air Dispersion and Dose Models

Theoretical/computational models are needed to describe the transport and dispersion in air of contaminants and the doses received by exposed persons. Various factors dictate a need for modeling: (1) because the amounts of LLNL-generated radioactive material dispersed into the atmosphere cause doses thousands of times smaller than those caused by natural background radiation (see Appendix D, Part D-1), it is difficult to demonstrate compliance with standards through monitoring (radioisotope-specific measurements are required); (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, the 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 codes 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.

The EPA's radiation dose standard, which applies only to air emissions, limits the EDE to members of the public to 100 µSv/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 µSv/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, 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

Nearly a hundred different radioisotopes are used at LLNL for research purposes, including tritium, mixed fission products, transuranic isotopes, biomedical tracers, and others (see **Table 13-1**). 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. Work places 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 without abatement devices, to direct dispersal of depleted uranium during explosives testing at Site 300, 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 regulatory compliance: point sources (including stacks, roof vents, and explosive experiments conducted on firing tables at Site 300) and diffuse area sources (including dedicated waste accumulation areas and other areas of known contamination). Detailed information on releases of radioactivity from LLNL's operations during 2002 is given in *LLNL NESHAPs 2002 Annual Report* (Harrach et al. 2003).

2002 Air Monitoring

This section briefly describes continuous stack-effluent sampling systems at selected LLNL facilities and ambient air monitors in place at numerous

Table 13-1. Radionuclides used at LLNL during 2002

Hydrogen-3	Manganese-54	Technetium-99	Gadolinium-148	Thorium-229	Plutonium-240
Beryllium-7	Iron-55	Rhodium-103	Promethium-151	Thorium-230	Americium-241
Beryllium-10	Cobalt-57	Ruthenium-106	Samarium-151	Protactinium-231	Plutonium-241
Nitrogen-13	Cobalt-58	Cadmium-109	Europium-152	Thorium-232	Curium-242
Carbon-14	Nickel-59	Tin-113	Europium-154	Uranium-232	Plutonium-242
Oxygen-15	Cobalt-60	Iodine-125	Europium-155	Uranium-233	Americium-243
Sodium-22	Nickel-63	Antimony-125	Hafnium-172	Uranium-234	Curium-244
Phosphorus-32	Selenium-75	Iodine-131	Lutetium-174	Uranium-235	Plutonium-244
Phosphorus-33	Strontium-85	Barium-133	Gold-195	Plutonium-236	Curium-246
Sulfur-35	Yttrium-88	Cesium-134	Platinum-195m	Uranium-236	Curium-248
Chlorine-36	Strontium-90	Cesium-137	Bismuth-207	Neptunium-237	Californium-249
Potassium-40	Yttrium-90	Barium-140	Polonium-209	Uranium-237	Californium-250
Argon-41	Niobium-94	Cerium-141	Lead-210	Plutonium-238	Californium-252
Calcium-41	Niobium-95	Cerium-144	Radium-223	Uranium-238	
Scandium-46	Zirconium-95	Neodymium-147	Radium-226	Neptunium-239	
Chromium-51	Molybdenum-99	Promethium-147	Thorium-228	Plutonium-239	

locations on and off LLNL sites. More complete information is provided in Chapters 4 and 5 of this report and in *LLNL NESHAPs 2002 Annual Report* (Harrach et al. 2003).

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 2002, there were seven buildings (Buildings 175, 177, 235, 251, 331, 332, and 491) at the Livermore site and one building (Building 801A) at Site 300 that 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.

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 (HT), tritiated water vapor (HTO), 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 monitoring systems with alarm systems.

Air Surveillance Monitoring for Radioactive Particles and Gases

Surveillance air monitoring for tritium and radioactive particles has been in place since the 1970s. LLNL currently maintains seven continuously operating, high volume, air particulate samplers on the Livermore site, nine in the Livermore Valley, eight at Site 300, and one in Tracy. LLNL also maintains twelve continuously operating tritiated water vapor samplers on the Livermore site, six samplers in the Livermore Valley and one at Site 300. The samplers are located to ensure reasonable probability that any significant airborne concentration of particulate or 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, air surveillance information can be used to estimate and/or confirm the emissions from the associated diffuse sources. Also included is an air particulate monitor positioned at the location of the hypothetical maximally-exposed member of the public (defined in the section "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.

Radionuclide Usage Inventory Update

A partial accounting of LLNL's radiological emission sources was made in 2002 (as was done in 2001), in accordance with the allowance by EPA that a 100% accounting need be made only every third year. The last 100% accounting was made in 2000.

The partial accounting focused on radiological emission 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 2001 assessment; (2) all "new" sources that commenced emissions in 2002, or sources that showed significantly elevated releases over 2001 levels; (3) all monitored sources; and (4) all sources in the major LLNL waste stream dealt with by Radioactive and Hazardous Waste Management (RHWM) Division in the Environmental Protection Department (EPD).

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 the partial accounting. The forms were completed by experimenters and certified by facility managers. In particular, 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. An LLNL-modified version of this code (designated CAP88-PC-T) that contains an improved tritium model (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 μSv). Separate doses for Livermore site and Site 300 emissions are evaluated below.

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 U.S. Nuclear Regulatory Commission's Regulatory Guide 1.109 (U.S. NRC 1977), which incorporate dose conversion factors consistent with those in the ICRP's Publication 30 (ICRP 1979 et seq.). This approach, outlined in Appendix C 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 (SW-MEI; defined below) member of the public. 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 100 μSv/y (10 mrem/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 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.

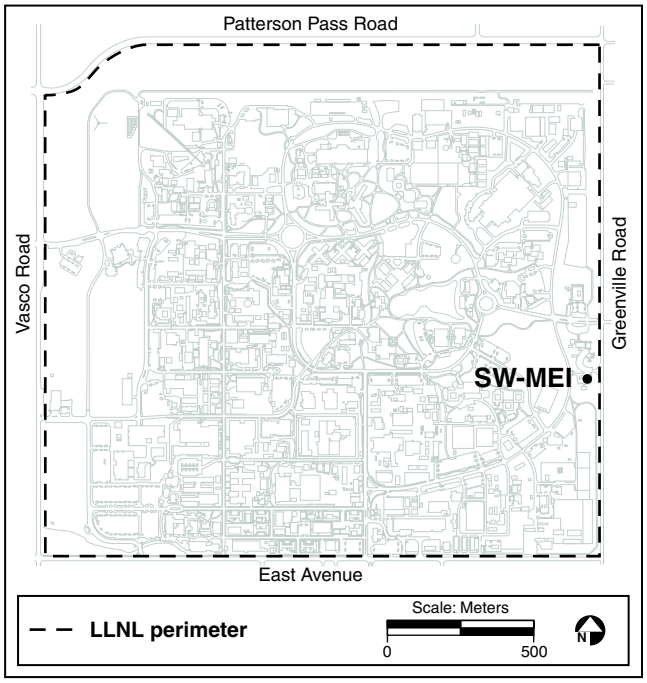

Figure 13-1. Location of the sitewide maximally exposed individual (SW-MEI) at the Livermore site, 2002

At the Livermore site, the SW-MEI in 2002 was, as usual, 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**.

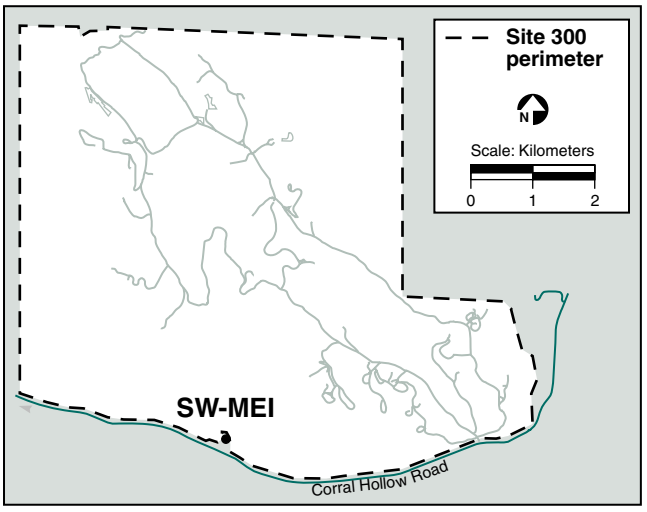

Figure 13-2. Location of the sitewide maximally exposed individual (SW-MEI) at Site 300, 2002

While the SW-MEI location is determined 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 2002 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. The *LLNL NESHAPs 2002 Annual Report* (Harrach et al. 2003) 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 2002 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 2002. 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.

The U.S. EPA has granted approval for LLNL to use alternative physical state factors for elemental uranium, uranium/niobium alloy, and elemental plutonium as described in Table 3 in *LLNL NESHAPs 2002 Annual Report* (Harrach et al. 2003). The physical-state-dependent release fraction and the time factor are used to adjust 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 conduct 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 consideration.

Site 300 Explosives Experiments: Some of the assemblies for Site 300 explosives experiments contain depleted uranium 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. The modeling methodology LLNL uses for compliance purposes for modeling these short duration explosive events is discussed in the *LLNL NESHAPs 2002 Annual Report* (Harrach et al. 2003).

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 vary based on radionuclide usage inventory data, environmental surveillance monitoring data, samples of contaminated materials, and other methods. The doses from principal diffuse sources in 2002 are described in the *LLNL NESHAPs 2002 Annual Report* (Harrach et al. 2003).

Modeling Dose from Tritium

Tritium (^{3}H) emissions account for the major dose from operations at the Livermore site. These emissions exist in two major chemical forms: tritium oxide or HTO and 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 (see Appendix C).

Doses from inhalation of unit concentration of HT in air are a factor of 15,000 times lower than those from inhalation and absorption through skin of 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 readily converted to HTO by microorganisms in soil (McFarlane, Rogers, and Bradley 1978) 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). In 2000, LLNL began using 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 the *LLNL NESHAPs 2000 Annual Report* (Gallegos et al. 2001).

In late 2002, the EPA had NEWTRIT coded into GENII-NESHAPs, a version of GENII (Napier et al. 1988) that the EPA intends to approve as a regulatory model for compliance with radionuclide NESHAPs (40 CFR 61 Subpart H). GENII-NESHAPs is being peer reviewed.

Results of 2002 Radiological Dose Assessment

This section summarizes the doses to the most exposed public individuals from LLNL operations in 2002, 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.

Total Dose to Site-Wide Maximally Exposed Individuals

The total dose to the SW-MEI from Livermore site operations in 2002 was 0.23 µSv/y (0.023 mrem/y). Of this, the dose calculated for the SW-MEI from diffuse emissions totaled 0.13 µSv (0.013 mrem) or 57% of the total SW-MEI; the dose due to point sources was 0.10 µSv (0.010 mrem) or 43% of the total SW-MEI. The point source dose includes Tritium Facility HT emissions modeled as HTO, as directed by EPA Region IX. Using NEWTRIT to calculate the dose

for tritium emissions reduced the tritium component of the total dose from 0.20 µSv (0.020 mrem) to 0.15 µSv (0.015 mrem).

The total dose to the Site 300 SW-MEI from operations in 2002 was 0.21 µSv (0.021 mrem). Point source emissions from firing table explosives experiments accounted for 0.18 µSv (0.018 mrem), or 85%, of this total, while 0.033 µSv (0.0033 mrem), or about 15%, was contributed by diffuse sources.

Table 13-2 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 2002. Although LLNL has nearly 200 sources with potential for releasing radioactive material to air according to NESHAPs prescriptions, most are very minor. Nearly the entire radiological dose to the public from LLNL operations comes from no more than a dozen sources. In April 2003, EPA granted LLNL permission to use surveillance monitoring in place of inventory-based modeling to account for dose contributions from the numerous minor sources (see *LLNL NESHAPs 2002 Annual Report* [Harrach et al. 2003]).

Dominant radionuclides at the two sites were the same as in recent years. Tritium accounted for about 87% of the Livermore site's calculated dose. 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 of exposure, 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 80% to 20%, respectively. 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 13-2. 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 2002

Facility (source category)	CAP88-PC dose (µSv/y)	CAP88-PC percentage contribution to total dose
Livermore site		
Building 612 Yard (diffuse source)	0.11[a]	48
Building 331 stacks (point source)	0.081[a]	35
Building 514 Evaporator (point source)	0.012	5.2
Building 612, R102 (point source)	0.011	4.8
Building 331 outside (diffuse source)	0.0087[a]	3.8
Site 300		
Building 851 Firing Table (point source)	0.18	85
Soil resuspension (diffuse source)	0.033	15

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, Building 331stacks, and Building 331 outside become 0.083 µSv, 0.056 µSv, and 0.0065µSv, respectively, and their percentages of the total dose from Livermore site operations each drop by about 2%.

The trends in dose to the SW-MEI from emissions at the Livermore site and Site 300 over the last 13 years are shown in **Table 13-3**. The general pattern, particularly over the last decade, shows year-to-year fluctuations around a 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.

Table 13-4 shows the Site 300 SW-MEI dose values attributed to firing table experiments for 1990 through 2002; the table also shows 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 2002 total dose was indicative of decreased firing table activity compared to the previous year but still typical of levels in the past decade.

Doses from Unplanned Releases

There were no unplanned atmospheric releases of radionuclides at the Livermore site or Site 300 in 2002.

Population Doses

Population doses, or collective EDEs, for both LLNL sites were calculated out to a distance of 80 km in all directions from the site centers using CAP88-PC. As noted earlier, CAP88-PC evaluates the four principal exposure pathways: ingestion through food and water consumption, 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 two years and described in *LLNL NESHAPs 2000 Annual Report* (Gallegos et al. 2001).

The CAP88-PC result for potential population dose attributed to 2002 Livermore-site operations was 0.0050 person-Sv (0.50 person-rem); the corresponding collective EDE from Site 300 operations was 0.025 person-Sv (2.5 person-rem). These values are both within the normal range of variation seen from year to year.

Doses to the Public Placed in Perspective

As a frame of reference to gauge the magnitude of these LLNL doses, **Table 13-5** compares LLNL doses to average doses received in the United States from exposure to natural background radiation and medical tests. Population doses from LLNL operations in 2002 are about 750,000 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 2002 are more than 13,000 times smaller than ones received from background radiation in the natural environment.

Comparison of 2002 Modeling Results with Tritium Air Surveillance Monitoring Data

Every two weeks throughout the year at eighteen locations on the Livermore site and in the Livermore Valley, air tritium concentrations were monitored and reported (Chapter 5). From these

Table 13-3. Doses (μSv) calculated for the sitewide maximally exposed individual (SW-MEI) for the Livermore site and Site 300, 1990 to 2002

Year	Total dose	Point source dose	Diffuse source dose
Livermore site			
2002	0.23[a]	0.10[a]	0.13
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			
2002	0.21	0.18	0.033
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	0.053
1997	0.20	0.11	0.088
1996	0.33	0.33	0.0045
1995	0.23	0.20	0.03
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 an 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 evaluated and reported at Site 300 before 1993.

Table 13-4. Annual dose to the SW-MEI from explosives experiments on firing tables at Site 300, 1990 to 2002, 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		
2002	0.18	0.018	45	77
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

Table 13-5. Comparison of background (natural and man-made) and LLNL radiation doses, 2002

Location/source	Individual dose[a]		Population dose[b]	
	(μSv)	(mrem)	(person-Sv)	(person-rem)
Livermore site sources				
Atmospheric emissions	0.23	0.023	0.0050	0.50
Site 300 sources				
Atmospheric emissions	0.21	0.021	0.025	2.5
Other sources[c]				
Natural radioactivity[d,e]				
Cosmic radiation	300	30	1,900	190,000
Terrestrial radiation	300	30	1,900	190,000
Internal (food consumption)	400	40	2,500	250,000
Radon	2,000	200	12,500	1,250,000
Medical radiation (diagnostic procedures)[e]	530	53	3,300	330,000
Weapons test fallout [e]	10	1.0	68	6,800
Nuclear fuel cycle	4	0.4	25	2,500

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.

data, an annual mean concentration of tritium in air at each monitoring location was calculated for comparison with air tritium concentrations predicted by CAP88-PC (**Table 13-6**). The model runs for CAP88-PC used source terms of HTO that represent the three principal tritium sources at the site: Building 331 (Tritium Facility) stacks, the Building 612 Yard waste storage area, and an area outside Building 331. Only released HTO is used as a source term because the air tritium monitors only collect HTO. However, HT as well as HTO is released from Building 331, and a small fraction of HT will be converted to HTO in the environment. What HT is converted will be picked up by the air tritium monitors in addition to the HTO that was released as HTO. Thus, the measured concentrations include a small fraction of HTO derived from HT that is not taken into account by CAP88-PC.

The source term for HTO released from the Tritium Facility was determined from stack air effluent monitoring (Chapter 4); the source term for the area outside B331 was determined from facility operator knowledge and ambient air tritium monitoring. In contrast, the Building 612 Yard emission rate was indirectly inferred from a self-consistent back-calculation, in which the HTO release rate from the Building 612 Yard was adjusted to force agreement with the data provided by the nearest air tritium monitor (the B624 monitor). The ratio of modeled-to-measured concentrations for the B624 monitor is therefore 1.0 by design (**Table 13-6**). The other air tritium samplers include the on-site locations B292, B331, and B514; the perimeter locations CAFE, COW, DWTF, MESQ, MET, POOL, SALV, and VIS; and one off-site location, ZON7 (see Chapter 5). ZON7 is notable because it is in the prevailing downwind direction from the sources and is the site of a drinking water supply for the area.

CAP88-PC's predicted air concentrations equaled or exceeded all observed annual mean concentrations except at B292. This under-prediction at sampler B292 is due to its proximity to a pine tree that is evapotranspiring HTO from the ground (see Chapter 11); this source was omitted from the model runs since it was not one of the principal sources of tritium at LLNL. All but one of the other predictions were within a factor of 1.7 of the observed air tritium concentrations. Even for the lone exception, sampler B514, the over-prediction (2.7) falls within the 90% confidence interval for the accuracy of the CAP88-PC dispersion model, which ranges from a factor of 0.3 to 4.4, based on 51 samples (Jack Faucett Associates 1987). A recent test of CAP88-PC's predicted air concentrations compared with annual mean observed air tritium concentrations at 13 perimeter and off-site locations for 1986 through 2001 (Peterson 2003) showed that ninety-six percent of all predictions fall within a factor of three of the observations, and the fraction of predicted air concentrations greater than observed is slightly greater than one-half.

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 2002, the DOE's standards for protection of the natural environment from the effects of ionizing radiation were approved. The guidance document, "DOE Standard: A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota" (DOE 2002), and the RAD-BCG (Biota Concentration Guides) Calculator (Version 2) were made available. DOE sites are requested to calculate dose to biota based upon this guidance. The guidance includes a manual, spreadsheets, and a database of BCGs. Cases where human access to an area of exposure is restricted or exposure pathways favor biota exposure are especially important to consider.

Table 13-6. Comparison of measured and modeled annual mean concentrations of tritiated water vapor (HTO) in air at selected Livermore locations, 2002

Air monitor (name)	Mean measured concentration (Bq/m^3)	Modeled[a] average concentration (Bq/m^3)	Ratio of modeled-to-measured concentrations	Modeled concentration of tritium in air contributed by the indicated source (Bq/m^3)		
				B331 Stacks	B612 Yard	B331 Outside
B624	2.09	2.1	1.0	0.052	2.1	0.0044
B331	0.370	0.53	1.4	0.0019	0.052	0.48
POOL	0.119	0.13	1.1	0.044	0.044	0.041
B514	0.116	0.31	2.7	0.021	0.29	0.0041
B292	0.0648	0.028	0.43	0.0085	0.012	0.0081
VIS	0.0636	0.098	1.5	0.044	0.048	0.0052
CAFE	0.0619	0.083	1.3	0.025	0.044	0.013
DWTF	0.0536	0.057	1.1	0.044	0.0089	0.0037
COW[b]	0.0452	0.050	1.1	0.037	0.0089	0.0043
SALV[b]	0.0344	0.058	1.7	0.015	0.041	0.0023
MESQ[b]	0.0279	0.036	1.3	0.0074	0.013	0.016
ZON7[b]	0.0245	0.025	1.0	0.019	0.0052	0.0012
MET[b]	0.0169	0.018	1.1	0.0056	0.0070	0.0056
CRED[c]		0.13		0.048	0.074	0.0059

a This result takes into account the three most significant tritium sources; it is the annual-average concentration comprising the sum of the three contributions shown in the far right columns.

b At these locations, more than 25% of the samples were below detection limits. The annual mean includes negative concentrations for all except COW. MET has the lowest percentage of detections (17%).

c The CRED location does not have a tritium surveillance air monitor, but it marks the location of the SW-MEI.

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 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 2002 using the RAD-BCG Calculator. Each radionuclide in each medium (soil, sediment, surface water) is assigned a derived concentration limit in the guidance. For each measured maximum concentration entered in 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 and riparian animals, 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 animals. If the sums of the fractions for the aquatic and terrestrial systems are both less than 1 (i.e., the dose to the biota does not exceed the limit), 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 2002, whether measured on the Livermore site, offsite in the Livermore Valley, or at Site 300, was entered into the screening calculation. This approach results in an assessment that is unrealistically conservative, given that the maximum concentrations in the media are spread over a very large area, and no animal could possibly be exposed to them all. It does indicate that no form of biota is put at risk by LLNL operations. Other conservative assumptions provide further reinforcement. For example, only gross alpha and gross beta are measured in water, but, for the biota assessment, it has been assumed that gross alpha is represented by plutonium-239 and gross beta by strontium-90. Furthermore, although biota would most likely live in and near permanent bodies of water (i.e., surface water), measurements of storm water runoff were used for the assessment because the surface water concentrations were below the limit of detection (Table 7-14, Data Supplement). Finally, when measurements were available for both water and sediment, the value (always from sediment) that gave the highest fraction of the BCG was used. (In the software, if a concentration is entered for sediment, a corresponding conservative concentration is calculated by the software, and vice versa.)

Measured radionuclides above the detection limit that might have been contributed by LLNL operations were americium-241, cesium-137, tritium, plutonium-239, thorium-232, uranium-234, uranium-235, and uranium-238. In addition, plutonium-239 and strontium-90 have been used to conservatively represent measurements of gross alpha and gross beta, respectively. The input to the RAD-BCG Calculator is given in **Table 13-7**. For LLNL, the sum of the fractions for the aquatic system was 0.22, and the sum for the terrestrial system was 0.00095. These results are very similar to those in 2001. In 2002, the sum of the fractions of the aquatic system was 5% higher than for 2001; for the terrestrial system, the sum of fractions in 2002 was 59% that of 2001. Both are indicative of doses to aquatic and terrestrial biota from LLNL operations that are well below allowable dose limits.

Dose Summary and Conclusion on Environmental Impact

The annual radiological dose from all emissions at the Livermore site and Site 300 in 2002 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 µSv/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 2002 were:

- Livermore site: 0.23 µSv (0.023 mrem)—43% from point-source emissions, 57% 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.

Table 13-7. Maximum concentrations of radionuclides in water, sediment, and soil on the Livermore site, in the Livermore Valley, and at Site 300 used as input to the RAD-BCG Calculator to assess the effect of LLNL operations on biota

Location	Reference table[a]	Analyte	Maximum concentration
Water (Bq/m^3)			
Site 300: CARW	7.3 DS	Gross alpha[b] (plutonium-239)	370
Livermore site: ASS2	7.1 DS	Gross beta[c] (strontium-90)	850
Site 300; GEOCRK	7.3 DS	Uranium-234	140
Sediment (Bq/kg)			
Livermore site: ESB	10.1 DS	Cesium-137	1.1
Livermore site: WPDC	10.3 MV	Tritium	2.5[d]
Livermore site: WPDC	10.1 DS	Thorium-232[e]	33
Livermore site: WPDC	10.1 DS	Uranium-235[e]	1.5
Livermore site: WPDC	10.1 DS	Uranium-238[e]	24
Soil (Bq/kg)			
LWRP; L-WRP1	10.2 MV	Americium-241	5.4
Site 300; DSW	10.2 DS	Cesium-137	5.0
LWRP; L-WRP1	10.2 MV	Plutonium-239	6.9
Site 300; 851N	10.2 DS	Thorium-232[e]	61
Livermore Valley; ZON7	10.1 DS	Uranium-235[e]	3.3
Livermore Valley; ZON7	10.1 DS	Uranium-238[e]	57

a DS refers to the Data Supplement of this report; MV refers to the main volume.

b It is conservatively assumed that all alpha in the sample is plutonium-239.

c It is conservatively assumed that all beta in the sample is strontium-90.

d Sediment concentrations for tritium are reported by the analytical laboratory both in pCi/L (Table 10-3) and pCi/g soil (shown here).

e Concentrations in the tables referenced are in μg/g dry weight soil or sediment.

- Site 300: 0.21 μSv (0.021 mrem)—85% from explosive experiments, which are classified as point-sources, 15% 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 2002 was estimated to be 0.0050 person-Sv (0.50 person-rem) for the Livermore site and 0.025 person-Sv (2.5 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 2002 were below one-quarter of one percent (0.25%) of the federal standard and were more than 13,000 times smaller than the dose from background radiation. The population doses from LLNL operations in 2002 were more than 750,000 times smaller than those caused by natural radioactivity in the environment.

Potential doses to aquatic and terrestrial biota from LLNL operations were assessed and found to be well below DOE allowable dose limits.

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 2002.

Quality Assurance

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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 2002 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 41 NCRs and 12 Analytical Lab Problem Reporting Forms related to environmental monitoring in 2002. These 53 reported problems can be compared to 50 in 2001 and 76 in 2000. The primary reason for the decrease in reported problems in 2002 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.

Twenty-three of the 53 problems reported in 2002 were due to problems with analytical laboratories; 13 were due to documentation, procedural, or sampling errors. The remaining 17 issues were related to equipment malfunction.

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 2002 for the Livermore site and Site 300

Environmental medium	Number of analyses planned	Number of analyses completed	Complete-ness (%)	Reason(s) for lost samples
Air particulate				
Radiological parameters (Livermore site)	1188	1175	99	Power off/GFI tripped (8), possible leak (2), unit replaced (1), wind blew unit over (1), no access (1)
Beryllium (Livermore site)	96	96	100	
Radiological parameters (Site 300)	728	722	99	Power off (4), no access (2)
Beryllium (Site 300)	48	48	100	
Air tritium				
Livermore site	520	500	96	Insufficient flow (13), broken flask (6), broken pump (1)
Site 300	26	25	96	Broken flask (1)
Soil and Sediment				
Livermore site	42	42	100	
Site 300	30	28	93	Area inaccessible for programmatic reasons (2)
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	97	97	TLD missing at pick up (3)
Site 300	72	68	94	TLD missing at pick up (3); no access (1)
Rain				
Livermore site	68	66	97	Bucket on ground (2)
Site 300	12	8	67	Buckets found on ground (3), bucket missing (1)

Table 14-1. Sampling completeness in 2002 for the Livermore site and Site 300 (continued)

Environmental medium	Number of analyses planned	Number of analyses completed	Complete-ness (%)	Reason(s) for lost samples
Storm water runoff				
Livermore site	397	387	97	One location not sampled at the discretion of the analyst (10)
Site 300	188	145	77	No flow (28), could not access area (15)
Drainage Retention Basin				
Field measurements	896	856	96	Meter problems (34), interference from vegetation (6)
Samples	82	81	99	Analytical lab error (1)
Releases	63	63	100	
Groundwater				
Livermore site	352	340	97	Two wells had insufficient water for sampling during third quarter (12).
Livermore Valley	29	27	93	These wells are sampled at the discretion of the local water agencies. Some wells go dry, some are exchanged for new wells. (2)
Site 300				
Building 829 network	186	182	98	Pump line obstruction (4)
Barcads	65	44	68	Three barcads inoperable (21)
Elk Ravine	122	95	78	Staff shortage (20), well dry (7)
Pit 1	335	335	100	
Pit 6	378	378	100	
Pit 7	342	342	100	
Pit 8	32	5	16	Staff shortage (19), electrical hazard (8)
Pit 9	32	32	100	
Offsite surveillance (annual)	61	61	100	
Offsite surveillance (quarterly)	153	153	100	
Sewage				
B196	910	906	99.6	Technologist error (2), clogged flow line (2)

Table 14-1. Sampling completeness in 2002 for the Livermore site and Site 300 (continued)

Environmental medium	Number of analyses planned	Number of analyses completed	Complete-ness (%)	Reason(s) for lost samples
C196	340	340	100	
LWRP[a] effluent	48	48	100	
Digester sludge	80	80	100	
WDR-96-248				
Surface impoundment wastewater	34	34	100	
Surface impoundment groundwater	116	116	100	
Sewage ponds wastewater	55	55	100	
Sewage ponds ground-water	72	64	89	Well was dry (4), well had bad equip-ment that was later replaced (4)
Miscellaneous aqueous samples				
Other surface water (Livermore Valley only)	58	58	100	
Cooling towers (Site 300 only)	24	24	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 23 of 28 results reported by EMRL and 10 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 2002. Fourteen of 22 analytes reported fell within acceptable limits. Further discussion of unacceptable results and corrective actions taken is presented in the Data Supplement.

Although contract laboratories are also required to participate in laboratory intercomparison programs, permission to publish their results for comparison purposes was not granted for 2002.

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 either of the results in a pair is a nondetection, then the other result should be a nondetection or less than two times the detection limit. **Table 14-4** identifies the sample media and analytes for which at least one pair failed this criterion. Media and 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

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]	11	34.3	0.784	0.68	6.24×10^{-6} Bq/m^3
	Gross beta	95	23.4	0.91	0.90	2.95×10^{-5} Bq/m^3
	Tritium	18	15.6	0.9	0.98	0.0225 Bq/m^3
Dose	Radiological dose, raw[e]	31	2.55	0.805	0.79	3.02 mR
	90-day radiological dose	31	2.75	0.87	0.84	2.02 mrem
Groundwater	Gross alpha[e]	9	29	0.676	0.76	0.0204 Bq/L
	Gross beta[e]	22	22.6	0.268	0.47	0.143 Bq/L
	Arsenic	17	17.7	1.08	0.96	0.000495 mg/L
	Barium	9	3.58	1.01	1.00	–0.00201 mg/L
	Nitrate (as NO_3)	19	5.31	0.987	0.99	0.992 mg/L
	Potassium	27	2.61	0.929	0.99	0.35 mg/L
	Trichloroethene[e]	12	7.77	1.78	0.87	–9.17 μg/L
	Tritium	14	14	0.977	1.00	2.13 Bq/L
	Uranium-234+233	19	11.7	0.965	0.98	–0.00176 Bq/L
	Uranium-235+236	15	23.5	1.05	0.89	–0.000208 Bq/L
	Uranium-238	19	16.6	0.963	0.99	–0.00161 Bq/L
Sewer	Gross alpha[d]	28	38.4	0.108	0.007	0.000227 Bq/mL
	Gross beta	52	8.14	0.968	0.89	2.75×10^{-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 of r^2 because of scatter

e Outside acceptable range of slope or r^2 because of outliers

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 with collocated sample pairs in LLNL environmental monitoring sampling. Different criteria are sometimes used in special studies when more than one agency is involved.

Routine and collocated sample results show reasonably good agreement: 90% of the pairs have a precision of 33% or better. 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 18 data sets reported in **Table 14-2**, four did not meet the

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

Media	Analyte	N[a]	Mean ratio	Minimum ratio	Maximum ratio
Air	Uranium-234+233 (pCi/m^3)[b]	5	0.99	0.83	1.1
	Uranium-235 ($\mu g/m^3$)[b]	7	0.98	0.76	1.1
	Uranium-235+236 (pCi/m^3)[b]	4	0.82	0.7	0.95
	Uranium-238 (pCi/m^3)[b]	5	1.1	0.91	1.2
	Uranium-238 ($\mu g/m^3$)[b]	7	0.97	0.73	1.1
Aqueous	Gross alpha	1	0.62	0.62	0.62
	Gross beta	2	0.96	0.72	1.2
	Tritium	1	3.1	3.1	3.1
Groundwater	Radium 226	5	0.72	0.35	0.92
Runoff (from rain)	Gross alpha	3	2.3	1.1	3.9
	Gross beta	3	1.2	0.9	1.4
	Uranium-234+233	2	0.82	0.75	0.9
	Uranium-235+236	1	0.36	0.36	0.36
	Uranium-238	2	0.9	0.71	1.1
Soil	Cesium 137	2	1.1	1	1.1
	Potassium-40	3	1	0.98	1.1
	Plutonium-238	3	0.67	0.2	1.1
	Plutonium-239+240	3	0.83	0.72	1
	Radium 226	3	1	0.93	1.1
	Radium 228	3	1	0.93	1.1
	Thorium 228	3	0.96	0.88	1.1
	Uranium-235	3	1	0.8	1.3
	Uranium-238	3	1.2	0.82	1.6
Sewer	Tritium	2	1	0.95	1.1
Vegetation	Tritium	7	1	0.11	2.3
Wine	Tritium	3	0.87	0.82	0.98

a Number of samples

b The analytical method changed during 2002, so results in units of pCi/m^3 are listed separately from the results in $\mu g/m^3$.

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	Gross alpha	2	92	2.2
	Gross beta	4	8	50
	Plutonium-238	1	7	14
	Plutonium-239+240	1	12	8.3
Groundwater	2-Amino-4,6-dinitrotoluene	3	6	50
	Perchlorate	1	11	9.1
Sewer	Gross alpha	4	24	17
	m- and p-Cresol	1	4	25
	o-Cresol	1	6	17
Vegetation	Tritium	1	5	20

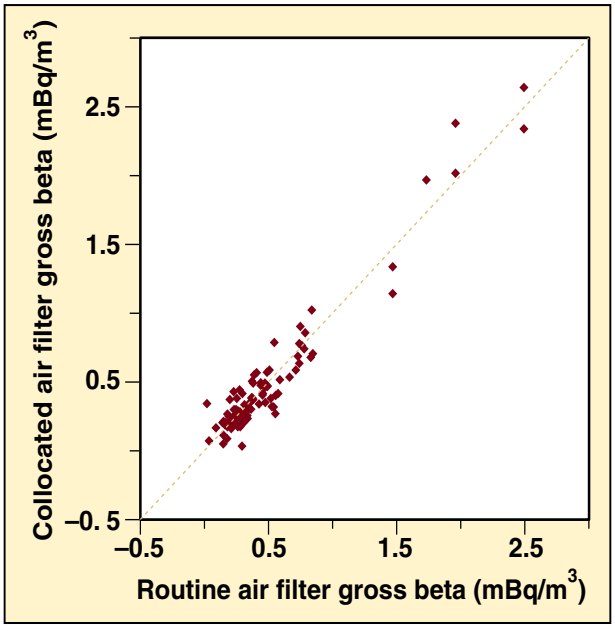

Figure 14-1. Example of data points that lie close to a line with slope equal to 1 and intercept equal to 0 using air filter gross beta concentrations from collocated samples

criterion for acceptability because of outliers. Figure 14-2 illustrates a set of collocated pairs with one outlier.

The second category are data sets that do not meet the criterion for acceptability because 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 18 data sets in Table 14-2, two show sufficient variability in results to make them fall outside the acceptable range.

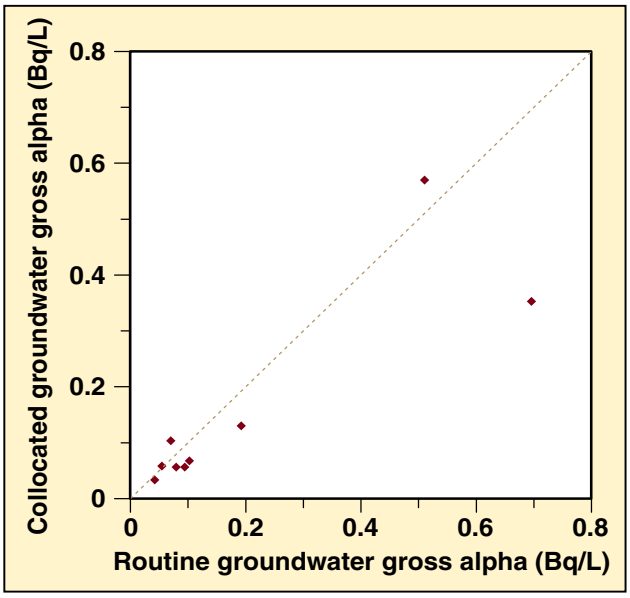

Figure 14-2. Example of data outliers using groundwater gross alpha concentrations from collocated samples

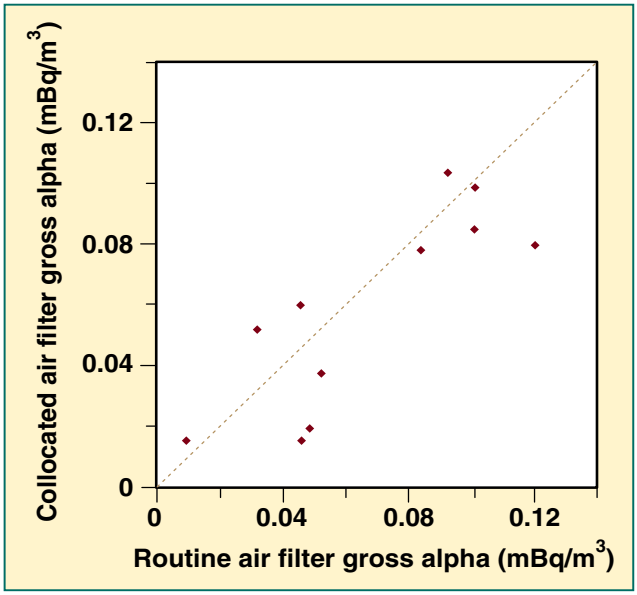

Figure 14-3. Example of scatter using air filter gross alpha concentrations from collocated samples

Radiation Units

Data for 2002 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 sieverts (Sv); equivalent values in curies (Ci) and rems (rem) are given in parentheses.

See Appendix D for a more detailed discussion of radiation units.

Radiological Data

Most of the Data Supplement tables display radiological data as a result plus-or-minus an associated 2σ uncertainty. The uncertainties are not used in summary statistic calculations. Any radiological result exhibiting a 2σ uncertainty greater than or equal to 100% of the result is considered to be a nondetection.

Radiological results are derived from the number of sample counts minus the number of background counts inside the measurement apparatus. 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 a limit-of-sensitivity value instead of an uncertainty when the radiological result is below the detection criterion. Such results are displayed with the limit-of-sensitivity value in parentheses.

Nonradiological Data

Nonradiological data reported as being below the reporting limit are 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, and radiological data sets that include reported 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 that include one or more values below the detection criterion, but do not include reported values below the detection criterion, the summary statistic calculations take into account the detection limit values. When 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. See Chapter 14 of the Data Supplement for additional discussion.

The median and the IQR are not calculated for data sets having no detections. The median is not calculated for data sets having fewer than four samples; the IQR is not calculated for data sets having fewer than six samples.

Table Preparation and Data Presentation

The process for creating data tables in the Data Supplement changed with this report. The new process incorporates a larger degree of automation to make the task of preparing data tables more efficient and less error-prone. For additional information see Chapter 14 of the Data Supplement.

Analytical laboratory data, and values calculated from analytical laboratory data, are normally displayed with at most two or 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. See Chapter 14 in the Data Supplement for additional discussion of significant digits and uncertainty.

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 used for this report concentrated on the tables and figures and enlisted authors, contributors, and technicians to check the accuracy of sections other than those they had authored or contributed to. In 2002, the tables and figures 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.

Appendix A. Wildlife and Rare Plant Monitoring

Lisa Paterson
Tina Carlsen

Introduction

This appendix summarizes wildlife and rare plant research and monitoring conducted at Site 300 and at the Livermore site during 2002. This includes monitoring programs that are required by existing permits; baseline surveys conducted to determine the distribution of special-status species on LLNL property; and additional monitoring programs designed to track the distribution and abundance of rare species.

Wildlife

Alameda Whipsnake

In 2002, LLNL began participation in a study, in cooperation with the U.S. Fish and Wildlife Service (USFWS) and four other agencies, to determine the effects of prescribed burns on federally-threatened Alameda whipsnakes *(Masticophis lateralis euryxanthus)*. In April 2002, the USFWS issued a Biological Opinion for this study that outlined the general conditions for conducting prescribed burns and gathering information about potential impacts to Alameda whipsnakes. Through participation in this study, LLNL obtained USFWS approval to conduct controlled burns necessary for Site 300 operation in areas that support Alameda whipsnakes. A prescribed burn will be conducted at the burn site in the summer of 2003. Baseline studies were conducted in 2002 at Site 300 at a control site and a burn site that are both vegetated by coastal scrub and annual grasslands. Baseline studies consisted of live trapping Alameda whipsnakes, recording the location of individuals, and marking the snakes for future identification. Eighteen Alameda whipsnakes were observed at the control and burn sites in 2002 (16 captures of 9 individuals in the burn site and 12 captures of 9 individuals in the control site; one snake moved between the burn and control plots). Long-term monitoring of the burn and control sites will be conducted for five years following the prescribed burn to determine if the burn has an effect on whipsnake distribution and abundance.

California Red-Legged Frog

Livermore site populations of the California red-legged frog *(Rana aurora draytonii)* were monitored in accordance with the 1997 and 1998 amended USFWS Biological Opinion for the Arroyo Las Positas Maintenance Project. A checkerboard pattern of Arroyo sections ranging in length from one-hundred feet to three-hundred feet were managed for excess in-stream vegetation, and 73 California red-legged frogs were temporarily moved from or relocated from project locations during the maintenance process.

California red-legged frog egg mass surveys were conducted in 2002 at the Livermore site. Egg masses were counted, and the location of each egg mass was recorded using global positioning system (GPS). Unlike the the adult frog life stage, which are highly secretive and cryptic, egg masses are rela-

tively conspicuous. This makes them a good indicator of productivity. The oviposition site (location and attachment point) was quantified to yield greater insight into micro-habitat characteristics that might be important to California red-legged frog breeding ecology in the Arroyo Las Positas. Although preliminary, survey results suggest that the Livermore site Arroyo Las Positas population is small but viable, even though the total number of California red-legged frog egg masses detected in the Arroyo Las Positas was down to 31 in 2002 from 37 in 2001. Because predation is high, the actual number of frogs produced per egg mass is unknown. Further annual surveys will help to evaluate the long-term viability of this population.

Nesting Raptors and Loggerhead Shrikes

The location of nesting raptors is monitored annually to ensure compliance with the federal Migratory Bird Treaty Act and for use in the preparation of the site-wide environmental impact statement (EIS) for continued operations at LLNL. At the Livermore site, one pair of white-tailed kites *(Elanus leucurus),* a California Fully Protected Species, successfully fledged three young, and a pair of red-shouldered hawks *(Buteo lineatus)* fledged two young.

The purpose of this study was to determine the composition, abundance, and distribution of nesting raptors and loggerhead shrikes at Site 300 (Bloom 2002). Surveys included nest searches of all potential nesting sites at Site 300 including power poles, cliffs, oaks, large junipers, and ground squirrel colonies. Nest searches were accomplished by walking to the potential nest sites or examining them with a spotting scope. These surveys were conducted in 2002 on April 18, 19, and 20 and July 29, 30, and 31.

Six species of nesting raptors including red-tailed hawk *(Buteo jamaicensis)*, American kestrel *(Falco sparverius)*, barn owl *(Tyto alba)*, western screech owl *(Otus asio)*, great horned owl *(Bubo virginianus)*, and burrowing owl *(Athene cunicularia)* were observed during this survey. White-tailed kites *(Elanus leucurus)* and golden eagles *(Aquila chrysaetos)* have also been known to nest at Site 300 in the recent past (Woollett 2002). Although not found nesting, the regular presence of two turkey vultures at Site 300 during surveys suggests one pair may nest there. Active nests for red-tailed hawk (four nests), great horned owl (four nests), and burrowing owl (three nests) were found. One inactive barn owl nest was found on the outside of the ATA building. Numerous recently fledged American kestrels and one young western screech owl were also observed. Valley oaks (*Quercus lobata*) and conglomerate cliffs were the most frequently used nest structures. In addition, 18 pairs of loggerhead shrikes *(Lanius ludovicianus)* were found. Highlights of the survey included a small population of nesting burrowing owls and a relatively large population of both breeding and nonbreeding loggerhead shrikes.

Tricolored Blackbirds

A nest searching technique was used to determine the distribution and productivity of the Elk Ravine tricolored blackbird (*Agelaius tricolor*) colony (van Hattem et al. 2002). The tricolored blackbird is a California and federal species of concern and is protected under the Migratory Bird Treaty Act. 835 nests were located and productivity was estimated for the colony at 2505 to 3340 fledglings (clutch size 3 to 4) or more conservatively estimated at 835 to 2505 fledglings (clutch size 1 to 3), representing the largest overall concentration of vertebrate special status species at Site 300. Information gathered from the tricolored blackbird colony will enhance planning and management of

Site 300 in addition to improving regional understanding of the distribution and abundance of this declining species.

Rare Plants

No rare plants are known to occur at the Livermore site despite previous survey efforts (Preston 1997, 2002a). Eight species of rare plants are known to occur at Site 300. A rare plant survey of Site 300 was conducted in 1997 and 2002 during which the locations of these eight species at Site 300 were mapped. This survey is described in the "Baseline Surveys" section of this appendix.

Restoration and/or monitoring activities were conducted for three of these species in 2002: the large-flowered fiddleneck *(Amsinckia grandiflora),* a federally endangered species; the big tarplant *(Blepharizonia plumosa)*; and the diamond-petaled poppy *(Eschscholzia rhombipetala)*. These three plants are all included in the California Native Plant Society's (CNPS) List 1B (CNPS 2001). This list includes species that are rare or endangered in California and elsewhere. The results of this work are described in more detail in an annual progress report (Carlsen et al. 2003). The round-leaved filaree *(Erodium macrophyllum)* is a CNPS List 2 species (CNPS 2001). List 2 species are rare or endangered in California but more common elsewhere.

The gypsum-loving larkspur *(Delphinium gypsophilum* ssp. *gypsophilum)*, California androsace *(Androsace elongata* ssp. *acuta)*, stinkbells *(Fritillaria agrestis)*, and hogwallow starfish *(Hesperevax caulescens)* are all included on the CNPS List 4 (CNPS 2001), which includes plants of limited distribution.

Site 300 has had two of the three known natural populations of the large-flowered fiddleneck. LLNL has established an experimental population within the *Amsinckia grandiflora* Reserve and is working with the USFWS and the U.S. Bureau of Reclamation on continued monitoring of native and experimental *Amsinckia* populations, and to further develop habitat restoration and maintenance techniques. An annual progress report is currently being prepared by LLNL and will be submitted to the USFWS and U.S. Bureau of Reclamation in 2003 (Carlsen et al. 2003).

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, the other natural and experimental fiddleneck populations have suffered severe declines in recent years. The number of fiddleneck plants in the larger native population has been at historic lows for the past four years. The number of fiddleneck plants observed in 2002 in the original experimental population area (9 plants) is lower than that observed during the past three years (59 plants in 2001, 45 plants in 2000, 42 plants in 1999). The experimental population was expanded in 2000 to investigate more fully the use of fire as a management tool. A total of 57 *Amsinckia grandiflora* flowering plants were observed in this area in 2002; however, the vast majority of these plants were located in areas that were not burned in 2001. Therefore, to investigate the effects of seed burial on burn survival, seeds were planted in areas that were burned in 2002 as well as in areas that were not burned. Plant establishment in both areas will be monitored in 2003.

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. Encroachment of bush lupine *(Lupinus albifrons)* has been observed both at the native population at Site 300 and at an

experimental population at Lougher Ridge in the Black Diamond Mines East Bay Regional Park. A significant level of spring and summer seed predation has been observed at the Site 300 experimental population, although its magnitude does not appear to correlate with plant establishment the following year. In order to enhance the experimental population at Site 300 and Lougher Ridge, LLNL began a rapid seedbank enhancement project in October 2003 with funding provided by the U.S. Bureau of Reclamation.

Monitoring of the big tarplant *(Blepharizonia plumosa)* and the diamond-petaled poppy *(Eschscholzia rhombipetala)* continued in 2002. The big tarplant remained widespread throughout Site 300. Populations were somewhat larger than those observed in 2001, particularly in areas that were burned in the past (and contained small big tarplant populations), but not burned in the spring of 2002. Detailed monitoring of populations located in areas undergoing controlled burning is being conducted to determine the impacts of fire on the population dynamics of this species. Data show the plants do not survive direct contact with the burn, but do benefit from reduced competition resulting from a burn. This suggests an intermittent burn frequency in some areas may further increase populations of this species. A second population of diamond-petaled poppy was identified during the special-status plant surveys (Preston 2002a). This population contained a total of 76 plants. A total of 285 diamond-petaled poppy plants were observed in the original site in 2002 (up from 189 in 2001 and similar to the 273 plants observed in 2000, but significantly higher than the 9 plants observed in 1999). The majority of these plants produced seed-bearing pods.

Invasive Species

Bullfrog *(Rana catesbeiana)* control continued in 2002 with the direct removal of both breeding adults and eggs from the Drainage Retention Basin (DRB) at the Livermore site. The control program appears to be stabilizing or reducing the overall numbers of bullfrogs 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 nonnative predators) in January 2001. No bullfrogs have been observed at Site 300 to date.

Baseline Surveys

Several baseline surveys were conducted in 2002 to determine the presence, abundance and distribution of plants, wildlife, and special habitats (i.e., wetlands) at Site 300 and at the Livermore site. These surveys were initiated to obtain baseline information for the preparation of the new site-wide EIS. Each survey described below was completed to facilitate accurate analyses of the impacts of continued operation of LLNL to environmental sensitive resources, including wetlands and threatened and endangered species. In particular, the purpose of these surveys was to determine the presence or absence and distribution of environmentally sensitive resources.

The following surveys or inventories were completed in 2002: mesocarnivore surveys (Clark et al. 2002), a small mammal inventory (West 2002), bat surveys (Rainey 2003), an avian monitoring program (van Hattem 2003a), special status reptile surveys (Swaim 2002), amphibian surveys (van Hattem 2003b), valley elderberry longhorn beetle surveys (Arnold 2002), wet season branchiopod surveys (Weber 2002), a rare plant survey

and vegetation mapping (Preston 2002a), and wetland delineations and mapping (Preston 2002b).

Mesocarnivore Surveys

The purpose of this study was to determine the presence and distribution of mesocarnivores (medium-sized carnivores) at Site 300 (Clark et al. 2002). Three survey techniques were used: nocturnal spotlighting, infrared-triggered camera stations, and scat detection dogs. These surveys were conducted in September and October of 2002. Eight spotlighting sessions were conducted. Spotlighting consisted of two or more people scanning habitat adjacent to fire trails from a vehicle traveling approximately 10 to 15 mph with a spotlight. Spotlighting began at sunset and lasted for two to three hours. Camera stations equipped with motion detectors were set up at 30 different locations and left to operate for seven or more days at each site. In addition, a scat detection dog, trained in the identification of kit fox *(Vulpes macrotis)*, red fox *(Vulpes vulpes)* and gray fox *(Urocyon cinereoargenteus),* was used to survey appropriate habitats across the site.

The three survey methods resulted in a total of 11 badger *(Taxidea taxus)* observations, two bobcat *(Lynx rufus)* observations, and 17 coyote *(Canis latrans)* observations. Additionally, there were 15 burrowing owl *(Athene cunicularia)* sightings during this study. (The burrowing owl is a California and federal species of concern known to occur at Site 300.) There were no observations of the endangered San Joaquin kit fox *(Vulpes macrotis mutica)* at Site 300 during the study, which validates earlier study results. Additional species observed in the study are included in **Table A-1**.

Small Mammal Inventory

A small mammal inventory was conducted in 2002 to assess the diversity and habitat associations of small mammal species (including special-status species) in annual grassland, native grassland, oak savanna, riparian corridor, coastal scrub and seep/spring wetland habitats at Site 300 (West 2002). Two plots of 50 Sherman live traps were set in each of the six habitat types. Trapping was conducted for three consecutive days at each plot between May 14 and August 1, 2002. Traps were set within two hours of sunset and checked within three hours of sunrise. This represents 2689 trap-nights of effort. During this effort, 210 small mammals of ten species were captured. The largest numbers of individuals and species were captured in riparian (65 individuals and 7 species) and coastal scrub (63 individuals and 5 species) habitats. The lowest numbers of individuals were captured in oak savanna (5 individuals and 3 species) and native grasslands (4 individuals and 3 species). Three species were captured in seep/spring wetlands. All species captured are listed in **Table A-1**.

Trapping in the native grassland habitat was conducted before and after a prescribed burn to help determine the effects of fires on the small mammal population. The number of individuals and species captured was low before and after the prescribed burn. Three species of small mammals where captured during three days of trapping conducted before the prescribed burn. During the three nights immediately following the prescribed burn, only four deer mice *(Peromyscus maniculatus)* were captured. During three nights of trapping conducted four weeks after the prescribed burn, four deer mice and one California vole *(Microtus californicus)* were captured. Although this data is not sufficient to allow statistical comparison of the pre- and post-burn species abundance

and diversity, immediate post-burn trapping indicated some animals survived and remained active in prescribed burn areas.

One of the species captured during this study is the dusky-footed woodrat (*Neotoma fuscipes)*. There are 11 subspecies of the dusky-footed woodrat; one of these subspecies, the riparian woodrat *(Neotoma fuscipes riparia),* is a federal endangered species (USFWS 2000). The woodrats captured at Site 300 had characteristics that are intermediate of those of the riparian woodrat and more common subspecies. Because of this, a subspecies determination was not made for the Site 300 woodrats. Although the riparian woodrat's current known range is restricted to the vicinity of Caswell Memorial State Park in San Joaquin County, a historic record exists of the riparian woodrat from the Corral Hollow area (USFS 2000). The San Joaquin pocket mouse *(Perognathus inornatus),* a federal species of concern, was also observed at Site 300 during these surveys in annual grassland and oak savannah habitats.

Bat Surveys

Surveys for bats, including special status species, at Site 300 were conducted in spring and summer of 2002 (Rainey 2003). These surveys included mist netting, acoustic sampling, and roust surveys. At minimum, six bat species were observed during these surveys, including one California Special Concern species, the pallid bat (*Antrozous pallidus*). These species are shown in **Table A-1**.

Avian Monitoring Program

An avian monitoring program was initiated at Site 300 in 2002 (van Hattem 2003a). This program included variable circular plot point counts and constant effort mist netting. Variable circular plot point count stations were systematically distributed through Site 300. Each point was surveyed in the morning on calm dry days between sunrise and 0900 hours during March, April and May of 2002. Each site was surveyed once during this time period. Surveys included recording all bird species identified visually using binoculars or by their vocalization in 10 minutes. A constant effort mist netting station was also established in Elk Ravine and Gooseberry Canyon at Site 300. Birds were captured using ten standard passerine mist nets once every ten days throughout the breeding season (May 14 through August 2, 2002). Birds captured in the mist nets were identified to species, banded, aged, sexed, measured, and weighed before being released. Ninety species of birds were identified at Site 300 as a result of this effort. All of the species identified in these surveys are listed in **Table A-1**.

Reptile Surveys

This effort consisted of determining the presence and distribution of four special-status reptiles: the Alameda whipsnake *(Masticophis lateralis euryxanthus),* the San Joaquin coachwhip *(Masticophis flagellum ruddockii),* the California legless lizard *(Anniella pulchra)*, and the coast horned lizard *(Phrynosoma coronatum frontale)* at Site 300. This study included trapping and visual surveys conducted in two areas in the southwest quarter of Site 300 during the spring and fall of 2002 (Swaim 2002). Information about the presence and abundance of reptiles at Site 300, obtained during the Alameda whipsnake burn study, is also included in the report for this study. A total of 63 days of surveys were conducted between April 16 and July 1, 2002 and 30 days of fall surveys between August 14 and October 15, 2002. Study areas were chosen that were most likely to support the target species. Visual surveys consisted of walking fire trails in the study areas. Two types of traps were used: funnel traps and pit fall traps. Traps were placed at the ends of 50-foot drift fences that direct animals to the traps. When active, all traps were

monitored daily. All vertebrate animals captured were identified to species level with the exception of small mammals, which were identified to genus. All snakes were marked for future identification of recaptures.

During this study and the Alameda whipsnake burn study, Alameda whipsnakes (19 individuals), San Joaquin coachwhips (6 individuals) and California legless lizards (1 individual) were observed. Although coast horned lizards were not observed during these trapping and survey efforts, they have been observed by LLNL wildlife biologists at Site 300 during 2002 and in previous years at several locations. This is the first recorded observation of a silvery legless lizard, a species of special concern, at Site 300. All species identified during this survey are listed in **Table A-1**.

Amphibian Surveys

An amphibian study was completed in 2002 to assess the distribution and abundance of special-status amphibians at Site 300 and at the Livermore site (van Hattem 2003b). This study included field surveys and an analysis of historic records. Sixty-five field surveys were completed in 2002 at the Livermore site and Site 300. Surveys consisted of systematically searching all available habitat within the littoral zone, open water and immediately adjacent terrestrial habitat on foot. A minimum of two daytime and two nighttime surveys were conducted at each site when conditions allowed. In most areas, surveys were not conducted after pools or wetlands had become dry.

At the Livermore site, California red-legged frogs *(Rana aurora draytonii)* were detected in Arroyo Las Positas, the Drainage Retention Basin, and in the West Perimeter Drainage Ditch. In addition, egg masses of California red-legged frogs were observed in Arroyo Las Positas. Although California tiger salamanders *(Ambystoma californiense)* were not observed at the Livermore site, there has been observation of this species in close proximity to the site.

At Site 300, California red-legged frogs were observed in seven locations (Elk Ravine at B812, Elk Ravine at ATA, in the mine shaft in upper Draney Canyon, slide pond, lower juniper pond, upper juniper slide pond, and Ambrosino Pool). California tiger salamander eggs and larva were observed at Ambrosino Pool, pools in the fire trail just south of Ambrosino Pool, and Danger Pool.

Valley Elderberry Longhorn Beetle Surveys

Four specific habitat surveys for the presence of Valley Elderberry Longhorn Beetles (VELB) (*Desmocerus californicus dimorphus*) at Site 300 were conducted on April 8 and 22, and May 14 and 30, 2002 (Arnold 2002). Both adult and larval VELB primarily rely on elderberry plants (typically *Sambucus mexicana)* for their development and survival.

During each site visit, visual surveys were conducted of stands of elderberry shrubs at Site 300. These visual surveys consisted of searching foliage, flowers, and stems for VELB adults. In addition, stems were checked for emergence holes. The location of adults and emergence holes were recorded using a GPS. The locations of all known elderberry plants at Site 300 were also recorded using a GPS. A total of 338 elderberry plants were found in areas previously identified by LLNL wildlife biologists. 248 of these plants were located in six areas at Site 300, and 90 plants were identified in two areas in the adjacent California Department of Fish & Game (CDFG) reserve. These elderberry plants were found in a variety of habitats including intermittent drainage, seeps, riparian corridors, and in association with rock outcrops. Adult VELB and exit holes where

observed at two of the eight elderberry stands surveyed (at Site 300 in the canyon north of Linac Road that flows into Elk Ravine and at the CDFG reserve). Higher densities of elderberries growing in proximity of seasonal water characterize both of these locations.

The discovery of VELB at Site 300 is a range extension for this species. The closest previous observations of VELB are from the floor of the Central Valley.

Branchiopod Survey

A branchiopod survey was conducted in 2001/2002 to determine the distribution of federally listed branchiopods at Site 300 (Weber 2002). This survey was conducted according to the USFWS interim survey guidelines for listed vernal pool branchiopods (USFWS 1996). These guidelines require that the survey protocol be conducted during two consecutive wet seasons. (The second season of surveys was conducted in spring 2003.) Fairy shrimp, tadpole shrimp, and clam shrimp are the groups within the class Branchiopoda that contain species that are currently on the federal endangered species list.

At Site 300, potential habitat for these species exists in the two vernal pools located in the northwest corner of the site, nine relatively large pools in roadbeds, and three ephemeral pools in intermittent drainages. Surveys consisted of sampling these pools at the water surface, throughout the water column, along the pool margins and at the bottom using a fine-meshed aquarium net. Specimens were identified using a 10X hand lens. Surveys were begun on January 18 and continued approximately every two weeks after that date until April 26, 2002. Two branchiopod species that are not federal or California endangered species, California fairy shrimp *(Linderiella occidentalis),* and California clam shrimp *(Cyzicus californicus)* were found during the 2002 surveys. No listed branchiopods were observed at Site 300.

Rare Plant Survey/Vegetation Mapping

In 1997 and 2002, a rare plant survey of Site 300 was completed and the vegetation communities of Site 300 were mapped (Preston 2002a). A preliminary vegetation map was prepared using false color photographs taken on April 20, 1998. This map was corrected during field visits conducted in August 2001. Vegetation communities were classified using the list of California natural communities recognized by the Natural Diversity Database (California Natural Diversity Database 1999). Thirteen vegetation communities were identified at Site 300: coastal scrub, California sage scrub, poison oak scrub, native grassland, one sided bluegrass, annual grassland, cottonwood riparian/woodland, great valley willow scrub, Mexican elderberry, blue oak woodland, valley oak forest/woodland, juniper woodland/scrub, and juniper-oak cismontane woodland. Urban and disturbed areas were also mapped.

Before any field surveys for rare plants were conducted, existing information, including the California Natural Diversity Database and lists compiled in previous reports, relating to the occurrence of rare plants at Site 300 and surrounding areas was reviewed. Based on this review, a list of potential rare plants that may occur at Site 300 was prepared. This list includes species included in the Inventory of Rare and Endangered Plants of California (CNPS 2001).

Field surveys for rare plants were conducted between April 20 and May 12 and on September 23 in 1997 and between March 27 and April 3 in 2002. These surveys consisted of covering the entire site on foot while recording all plant species observed. The site was surveyed using

meandering transects that emphasized areas with the most likelihood to support rare plants. Thirty-five transects were sampled over approximately 223 person-hours. Eight rare plants species were observed at Site 300 during these surveys. The first recorded observations of diamond-petaled poppy *(Eschscholzia rhombipetala)*, stinkbells *(Fritillaria agrestis)* and round-leaved filaree *(Erodium macrophyllum)* at Site 300 occurred during the 1997 and 2002 surveys. California androsace *(Androsace elongata* ssp. *acuta)* and hogwallow starfish *(Hesperevax caulescens)* were observed at Site 300 during the 1997 and 2002 surveys and during the 1986 rare plant surveys conducted by Biosystems (although these species were not recognized as rare until after 1986). Three additional rare plant species, large-flowered fiddleneck *(Amsinckia grandiflora),* big tarplant *(Blepharizonia plumosa),* and gypsum-loving larkspur *(Delphinium gypsophilum* ssp. *gypsophilum),* previously known to occur at Site 300 were also observed during the 1997 and 2002 surveys.

Wetland Delineation

During 2001 and 2002, a delineation of the wetlands of Site 300 was completed (Preston 2002b). The purpose of this study was to identify wetland areas at Site 300 including those that are federal jurisdictional wetlands subject to Section 404 of the Clean Water Act (ACOE 1987). Wetlands were identified based on the presence of wetland vegetation. Wetland areas were first identified using false color aerial photographs. The locations of wetland sites were verified in the field and mapped using a GPS. A total of 8.6 acres of wetlands in 46 separate areas were identified during this study. Of these wetlands, 4.4 acres appear to be federal jurisdictional wetlands. The wetlands identified in this study were characterized as vernal pools, freshwater seeps, or seasonal ponds. Freshwater seeps were the most abundant type of wetland identified at Site 300. Thirty-seven areas were mapped as freshwater wetlands. These wetlands typically occur within intermittent drainages and were dominated by emergent perennial plants such as cattails *(Typha* spp.*)* and willows *(Salix* spp.*)*. Three of the Site 300 wetlands were characterized as vernal pools. The Site 300 vernal pools are vegetated by wetland generalists that are restricted to saturated areas, but not restricted to vernal pools. Five seasonal ponds were observed during this study. Seasonal ponds have hydrology similar to vernal pools, but the vegetation around these ponds includes ruderal herbaceous species.

Table A-1. Site 300 Wildlife Species List. (This list includes species for which there are verified observations. It is not intended to be a complete list of Site 300 species.)

Common Name	Scientific Name	Regulatory Status[a]	Source
Mammals			
Pallid bat	*Antrozous pallidus*	CASSC	Rainey 2003
Western red bat	*Lasiurus blossevillii*		Rainey 2003
Hoary bat	*Lasiurus cinereus*		Rainey 2003
California myotis	*Myotis californicus*		Rainey 2003
Western pipistrelle	*Pipistrellus hesperus*		Rainey 2003
Brazilian free-tailed bat	*Tadarida brasiliensis*		Rainey 2003
Desert cottontail	*Sylvilagus audubonii*		LLNL 2003 Clark et al. 2002
Black-tailed jackrabbit	*Lepus californicus*		LLNL 2003 Clark et al. 2002
Heermann's kangaroo rat	*Dipodomys heermanni*		LLNL 2003 West 2002
California pocket mouse	*Chaetodipus californicus*		LLNL 2003 West 2002
California ground squirel	*Spermophilus beecheyi*		
San Joaquin pocket mouse	*Perognathus inormatus inornatus*	FSC	Clark et al. 2002
Botta's pocket gopher	*Thomomys bottae*		LLNL 2003 West 2002
California vole	*Microtus californicus*		LLNL 2003 West 2002
House mouse	*Mus musculus*		LLNL 2003 West 2002
Dusky-footed woodrat	*Neotoma fuscipes*		LLNL 2003 West 2002
Brush mouse	*Peromyscus boylii*		LLNL 2003 West 2002
Deer mouse	*Peromyscus maniculatus*		LLNL 2003 West 2002
Western harvest mouse	*Reithrodontomys megalotis*		LLNL 2003 West 2002
Coyote	*Canis latrans*		LLNL 2003 Clark et al. 2002
Raccoon	*Procyon lotor*		LLNL 2003 Orloff 1986
Long-tailed weasel	*Mustela frenata*		LLNL 2003 Orloff 1986
Striped skunk	*Mephitis mephitis*		LLNL 2003 Orloff 1986

Table A-1. Site 300 Wildlife Species List. (This list includes species for which there are verified observations. It is not intended to be a complete list of Site 300 species.) (continued)

Common Name	Scientific Name	Regulatory Status[a]	Source
Western spotted skunk	*Spilogale gracilis*		LLNL 2003 Orloff 1986
American badger	*Taxidea taxus*		LLNL 2003 Clark et al. 2002
Bobcat	*Lynx rufus*		LLNL 2003 Clark et al. 2002
Mountain Lion	*Felis concolor*		LLNL 2003
Mule deer	*Odocoileus hemionus*		LLNL 2003 Clark et al. 2002
Wild pig	*Sus scrofa*		LLNL 2003 Clark et al. 2002
Herpetofauna			
California red-legged frog	*Rana aurora draytonii*	FT	LLNL 2003
Pacific tree frog	*Hyla regilla*		LLNL 2003
California tiger salamander	*Ambystoma californiense*	PT, CASSC	LLNL 2003
Western spadefoot toad	*Spea hammondii*	FSC, CASSC	LLNL 2003
Western toad	*Bufo boreas*		LLNL 2003
Alameda whipsnake	*Masticophis lateralis euryxanthus*	FT, ST	Swaim 2002
San Joaquin coachwhip	*Masticophis flagellum*	FSC, CASSC	LLNL 2003
Coast horned lizard	*Phrynosoma coronatum*	FSC, CASSC	LLNL 2003
California legless lizard	*Anniella pulchra*	FSC	Swaim 2002
Side-blotched lizard	*Uta stansburiana*		LLNL 2003 Swaim 2002
Western whiptail	*Cnemidophorus tigris*		LLNL 2003 Swaim 2002
Western fence lizard	*Sceloporus occidentalis*		LLNL 2003 Swaim 2002
Western skink	*Eumeces skiltonianus*		LLNL 2003 Swaim 2002
Gilbert skink	*Eumeces gilberti*		LLNL 2003 Swaim 2002
Southern alligator lizard	*Gerrhonotus multicarinatus*		LLNL 2003 Swaim 2002
Western yellow bellied racer	*Coluber constrictor*		LLNL 2003 Swaim 2002
Pacific gopher snake	*Pituophis melanoleucus*		LLNL 2003 Swaim 2002
Common kingsnake	*Lampropeltis getulus*		LLNL 2003 Swaim 2002

Table A-1. Site 300 Wildlife Species List. (This list includes species for which there are verified observations. It is not intended to be a complete list of Site 300 species.) (continued)

Common Name	Scientific Name	Regulatory Status[a]	Source
Western rattlesnake	*Crotalus viridis*		LLNL 2003 Swaim 2002
Night snake	*Hypsiglena torquata*		LLNL 2003 Swaim 2002
Glossy Snake	*Arizona elegans*		LLNL 2003 Swaim 2002
Long-nosed snake	*Rhinocheilus lecontei*		LLNL 2003 Swaim 2002
California black-headed snake	*Tantilla planiceps*		Swaim 2002
Birds			
Cooper's hawk	*Accipiter cooperii*	CASSC, MBTA	LLNL 2003
Sharp-shinned hawk	*Accipiter striatus*	CASSC, MBTA	LLNL 2003
Golden eagle	*Aquila chrysaetos*	CASSC, MBTA	LLNL 2003
Red-tailed hawk	*Buteo jamaicensis*	MBTA	LLNL 2003
Rough-legged hawk	*Buteo lagopus*	MBTA	LLNL 2003
Red-shouldered hawk	*Buteo lineatus*	MBTA	LLNL 2003
Ferruginous hawk	*Buteo regalis*	FSC, CASSC, MBTA	LLNL 2003
Swainson's hawk	*Buteo swainsoni*	ST, MBTA	LLNL 2003
Northern harrier	*Circus cyaneus*	CASSC, MBTA	LLNL 2003
White-tailed kite	*Elanus leucurus*	CAFPS, MBTA	LLNL 2003
Osprey	*Pandion haliaetus*	CASSC, MBTA	LLNL 2003
Bushtit	*Psaltriparus minimus*	MBTA	LLNL 2003
Horned lark	*Eremophila alpestris*	CASSC, MBTA	LLNL 2003
Northern shoveler	*Anas clypeata*	MBTA	LLNL 2003
Cinnamon teal	*Anas cuamptera*	MBTA	LLNL 2003
Mallard	*Anas platyryynchos*	MBTA	LLNL 2003
Bufflehead	*Blucephala albeola*	MBTA	LLNL 2003
Common goldeneye	*Bucephala clangula*	MBTA	LLNL 2003
White-throated swift	*Aeronautes saxatalis*	MBTA	LLNL 2003
Great egret	*Ardea alba*	MBTA	LLNL 2003
Virginia rail	*Rallus limicola*	MBTA	DOE 1992
Cedar waxwing	*Bombycilla garrulus*	MBTA	LLNL 2003
Common poorwill	*Phalaenoptilus nuttalii*	MBTA	LLNL 2003
Blue-grosbeak	*Guiraca caerulea*	MBTA	LLNL 2003
Black-headed grosbeak	*Pheucticus melanocephalus*	MBTA	DOE 1992
Lazuli bunting	*Passerina amoena*	MBTA	LLNL 2003

Table A-1. Site 300 Wildlife Species List. (This list includes species for which there are verified observations. It is not intended to be a complete list of Site 300 species.) (continued)

Common Name	Scientific Name	Regulatory Status[a]	Source
Turkey vulture	*Cathartes aura*	MBTA	LLNL 2003
Killdeer	*Charadrius vociferus*	MBTA	LLNL 2003
Rock dove	*Columba livia*		DOE 1992
Mourning dove	*Zenaida macroura*	MBTA	LLNL 2003
Western scrub jay	*Aphelocoma californica*	MBTA	LLNL 2003
American crow	*Corvus brachyrhynchos*	MBTA	LLNL 2003
Common raven	*Corvus corax*	MBTA	LLNL 2003
Greater roadrunner	*Geococcyx californianus*	MBTA	LLNL 2003
Bell's sage sparrow	*Amphispiza belli*	FSC, MBTA	LLNL 2003
Black-throated sparrow	*Amphispiza bilineata*	MBTA	LLNL 2003
Rufous crowned sparrow	*Aimophila ruficeps*	MBTA	LLNL 2003
Grasshopper sparrow	*Ammodramus savannarum*	FSC, MBTA	LLNL 2003
Lark sparrow	*Chondestes grammacus*	MBTA	LLNL 2003
California towhee	*Carpodacus mexicanus*	MBTA	LLNL 2003
Oregon junco	*Junco hyemalis*	MBTA	LLNL 2003
Lincoln's sparrow	*Melospiza lincolnii*	MBTA	LLNL 2003
Song sparrow	*Melospiza melodia*	MBTA	LLNL 2003
Vesper sparrow	*Pooecetes gramineus*	MBTA	DOE 1992
Fox sparrow	*Passerella iliaca*	MBTA	LLNL 2003
Savannah sparrow	*Passerculus sandwichensis*	MBTA	LLNL 2003
Golden-crowned sparrow	*Zonotrichia atricapilla*	MBTA	LLNL 2003
White-crowned sparrow	*Zonotrichia leucophrys*	MBTA	LLNL 2003
American kestrel	*Falco columbarius*	MBTA	LLNL 2003
Prairie falcon	*Falca mexicanus*	CASSC, MBTA	LLNL 2003
House finch	*Carpodacus mexicanus*	MBTA	LLNL 2003
Lesser goldfinch	*Carduelis psaltia*	MBTA	LLNL 2003
Cliff swallow	*Petrochelidon pyrrhonota*	MBTA	LLNL 2003
Northern rough winged swallow	*Stelgidopteryx serripennis*	MBTA	LLNL 2003
Tree swallow	*Tachycineta bicolor*	MBTA	LLNL 2003
Western wood-pewee	*Contopus sordidulus*	MBTA	DOE 1992
Red-winged blackbird	*Agelaius phoeniceus*	MBTA	LLNL 2003
Tricolored blackbird	*Agelaius tricolor*	FSC, CASSC, MBTA	LLNL 2003
Brewer's blackbird	*Euphagus cyanocephalus*	MBTA	LLNL 2003
Bullock's oriole	*Icterus bullockii*	MBTA	LLNL 2003
Brown-headed cowbird	*Molothrus ater*	MBTA	LLNL 2003

Table A-1. Site 300 Wildlife Species List. (This list includes species for which there are verified observations. It is not intended to be a complete list of Site 300 species.) (continued)

Common Name	Scientific Name	Regulatory Status[a]	Source
Western meadowlark	*Sturnella magna*	MBTA	LLNL 2003
Loggerhead shrike	*Lanius ludovicianus*	FSC, CASSC, MBTA	LLNL 2003
Northern mockingbird	*Mimus polyglottos*	MBTA	LLNL 2003
California thrasher	*Toxostoma redivivum*	FSC, MBTA	LLNL 2003
California quail	*Callipepla californica*		LLNL 2003
Oak titmouse	*Baeolphus inornatus*	FSC, MBTA	LLNL 2003
Yellow-rumped warbler	*Dendroica coronata*	MBTA	LLNL 2003
Black-throated gray warbler	*Dendroica nigrescens*	MBTA	LLNL 2003
Yellow warbler	*Dendroica petechia*	CASSC, MBTA	LLNL 2003
Common yellowthroat	*Geothlypis trichas*	CASSC, MBTA	LLNL 2003
MacGillivary's warbler	*Oporornis tolmiei*	MBTA	LLNL 2003
Orange-crowned warbler	*Vermivora bachmanii*	MBTA	LLNL 2003
Wilson's warbler	*Wilsonia pusila*	MBTA	LLNL 2003
Double-crested cormorant	*Phalacrocorax auritus*	CASSC, MBTA	LLNL 2003
Wild turkey	*Meleagris gallopavo*		LLNL 2003
Northern flicker	*Colaptes auratus*	MBTA	LLNL 2003
Nuttal's woodpecker	*Picoides nuttallii*	FSC, MBTA	LLNL 2003
Acorn woodpecker	*Melanerpes formicivorus*	MBTA	DOE 1992
Pied-billed grebe	*Podilymbus podiceps*	MBTA	LLNL 2003
Phainopepela	*Phainopepla nitens*	MBTA	LLNL 2003
Ruby-crowned kinglet	*Regulus calendula*	MBTA	LLNL 2003
Common snipe	*Gallinago gallinago*	MBTA	LLNL 2003
Greater yellowlegs	*Tringa melanoleuca*	MBTA	LLNL 2003
Burrowing owl	*Athene cunicularia*	FSC, CASSC, MBTA	LLNL 2003
Short-eared owl	*Asio flammeus*	FSC, CASSC, MBTA	LLNL 2003
Great horned owl	*Bubo virginianus*	MBTA	LLNL 2003
Western screech owl	*Otus kennicottii*	MBTA	LLNL 2003
European starling	*Sturnus vulgaris*		LLNL 2003
Western tanager	*Piranga ludoviciana*	MBTA	LLNL 2003
Anna's hummingbird	*Calypte anna*	MBTA	LLNL 2003
Costa's hummingbird	*Calypte costae*	FSC, MBTA	LLNL 2003
Rufous hummingbird	*Selasphorus rufus*	FSC, MBTA	LLNL 2003
Allen’s hummingbird	*Selasphorus sasin*	MBTA	DOE 1992
Rock wren	*Salpinctes obsoletus*	MBTA	LLNL 2003
Bewick's wren	*Thyothorus ludovicianus*	MBTA	LLNL 2003

Table A-1. Site 300 Wildlife Species List. (This list includes species for which there are verified observations. It is not intended to be a complete list of Site 300 species.) (continued)

Common Name	Scientific Name	Regulatory Status[a]	Source
House wren	*Troglodytes aedon*	MBTA	LLNL 2003
Hermit thrush	*Catharus guttatus*	MBTA	LLNL 2003
Swainson's thrush	*Catharus ustulatus*	MBTA	LLNL 2003
Varied thrush	*Ixoreus naevius*	MBTA	LLNL 2003
Mountain bluebird	*Sialia currucoides*	MBTA	LLNL 2003
Western bluebird	*Sialia mexicana*	MBTA	LLNL 2003
American robin	*Turdus migratorius*	MBTA	LLNL 2003
Pacific-slope flycatcher	*Empidonax difficillis*	MBTA	LLNL 2003
Ash-throated flycatcher	*Myiarchus cinerascens*	MBTA	LLNL 2003
Western wood-pewee	*Contopus sordidulus*	MBTA	DOE 1992
Black phoebe	*Sayornis nigricans*	MBTA	LLNL 2003
Say's phoebe	*Sayornis saya*	MBTA	LLNL 2003
Western kingbird	*Tyrannus verticalis*	MBTA	LLNL 2003
Cassin's kingbird	*Tyrannus vociferans*	MBTA	LLNL 2003
Barn owl	*Tyto alba*	MBTA	LLNL 2003
Invertebrates			
Valley elderberry longhorn beetle	*Desmocerus californicus dimorphus*	FT	Arnold 2002
California fairy shrimp	*Linderiella occidentalis*	FSC	Weber 2002
California clam shrimp	*Cyzicus californicus*		Weber 2002

a CAFPS = California Department of Fish and Game Fully Protected Species (CA Dept. of Fish and Game 2001)

CASSC = California Species of Special Concern (CA Dept. of Fish and Game 2001)

FE = Endangered under the Federal Endangered Species Act

FT = Threatened under the Federal Endangered Species Act

MBTA = Protected under the Federal Migratory Bird Treaty Act

PT = Proposed as trheatened under the Federal Endangered Species Act

ST = Threatened under the State Endangered Species Act

FSC = Federal Species of Concern for Alameda and San Joaquin Counties. May be endangered or threatened. Not enough biological information has been gathered to support listing at this time. (U.S. Fish and Wildlife Service 1-1-03-SP-0162)

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 Opertions, 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 3, Facility Safety	§ 4.4 Natural Phenomena Hazards Mitigation for DOE facilities—included in DOE O 420.1 Chg. 2, Facility Safety, Attachment 2, Contractor Requirments 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. 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 generally overestimates doses to the public in the direction towards which the prevailing wind blows, doses calculated from environmental measurements for these wind directions should be lower, even when assumptions about intake rates are conservative. Regardless of wind direction, doses calculated from measured environmental concentrations will be more accurate and have less uncertainty than doses calculated using a dispersion model.

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 about intake rates 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 2002 by NEWTRIT, the other model used to calculate doses from environmental measurements in this appendix. NEWTRIT (Peterson and Davis 2002), an improved tritium model to calculate dose contributions from OBT and doses from releases of both HTO and HT, has recently been coded into

GENII-NESHAPs by the EPA. GENII-NESHAPs is a version of GENII (Napier et al. 1988) developed for compliance with the National Emissions Standards for Hazardous Air Pollutants ((NESHAPs; 40 CFR Part 61, Subpart H). GENII-NESHAPs is undergoing peer review in 2003.

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., µSv/Bq). Calculating the dose contribution from inhalation will be similar (e.g., $m^3/y \times Bq/m^3 \times \mu Sv/Bq$).

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 g/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 food ingestion dose) 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 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 g/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 OBT, as well as HTO. Based on experimental data, NEWTRIT accounts for the conversion of HT to HTO in soil and the consequent emission of HTO to the atmosphere from 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 OBT 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 food ingested has been grown at the location at which air concentrations have been estimated.

Each model recommends different consumption rates (see **Table C-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 C-1**), doses from these models will be different.

Table C-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 C-2**.

Table C-2. Comparison of dose coefficients for tritium (μSv/Bq)

	DOE	CAP88-PC[a]	ICRP
HTO (inhalation, skin absorption)[b]	1.73×10^{-5}	3.41×10^{-5}	1.8×10^{-5}
HT (inhalation)	3.31×10^{-13}[c]	—[d]	1.8×10^{-9}
HTO (ingestion)	1.73×10^{-5}	2.43×10^{-5}	1.8×10^{-5}
OBT (ingestion)	—[d]	—[d]	4.2×10^{-5}

a Computer code required by the EPA for modeling air emissions of radionuclides

b CAP88-PC's dose coefficient includes skin absorption; to account for skin absorption, DOE and ICRP multiply inhalation rate by 1.5.

c Units are $\mu Sv/Bq \times s/m^3$ because dose is considered external from air submersion.

d Not taken into account

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.

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 Bq = 27 pCi
1 mSv = 100 mrem; 1 μSv = 0.1 mrem; 1 nSv = 0.1 μrem

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.

In the past, median or maximum concentrations in environmental media were used to calculate doses. The median is used as the default average for the Site Environmental Annual Report for a variety of reasons. However, for calculations of dose from inhalation and ingestion, the mean, not the median, should be used. For example, if a cow ingests equal quantities of vegetation quarterly, the cow's exposure is properly assessed by the mean. Thus, for dose calculations, the use of the mean is justified and will be used henceforth.

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 mean or maximum observed values for 2002.

Calculating Annual Dose from Potable Water (Chapter 7)

The effective dose equivalent for tritium in drinking water (D_{water}) in µSv/y is calculated using the following equation:

$$D_{water}\,(\mu Sv/y) = U_w \times DC_{HTO} \times C_w \qquad \text{(C-1)}$$

where

U_w = water consumption rate (L/y)

DC_{HTO} = dose coefficient for HTO (µSv/Bq) (U.S. DOE 1988)

C_w = mean or maximum concentration of tritium measured in drinking water (Bq/L)

The tritium dose from ingestion of potable water, assuming maximum intake of water, is then

$$D_{water}\,(\mu Sv/y) = 730\,(L/y) \times 1.73 \times 10^{-5}\,(\mu Sv/Bq) \times C_w\,(Bq/L)$$

$$= 1.3 \times 10^{-2} \times C_w\,(Bq/L)$$

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.

$$D_{veg}\,(\mu Sv/y) = U_{veg} \times DC_{HTO} \times C_{veg} \qquad \text{(C-2)}$$

where

U_{veg} = intake rate of leafy vegetables (kg/y)

DC_{HTO} = dose coefficient for HTO (μSv/Bq) (U.S. DOE 1988)

C_{veg} = mean or maximum concentration measured in annual grasses and weeds (Bq/L)

The tritium dose from ingestion of leafy vegetables, assuming maximum intake, is then

$$D_{veg}\,(\mu Sv/y) = 64\ (kg/y) \times 1.73 \times 10^{-5}\ (\mu Sv/Bq) \times C_{veg}\,(Bq/kg)$$

$$= 1.1 \times 10^{-3} \times C_{veg}\,(Bq/L)$$

Meat (Beef): To calculate dose from ingestion of meat, first the concentration of tritium in the meat must be calculated from the measured mean or maximum concentration of tritium in vegetation.

$$C_{meat\_veg} = F_f\,(d/kg) \times Q_f\,(kg/d) \times C_{veg}\,(Bq/kg) \times \exp(-\lambda_i t_s) \qquad \text{(C-3)}$$

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} = mean or maximum 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

$$C_{meat\_veg} = 1.2 \times 10^{-2}\ (d/kg) \times 50\ (kg/d) \times C_{veg}\,(Bq/kg) \times \exp[(-1.5 \times 10^{-4}) \times 20]$$

$$= 0.6 \times C_{veg}\,(Bq/kg)$$

The dose from ingestion of meat is calculated:

$$D_{meat}\,(\mu Sv/y) = U_{meat} \times C_{meat} \times DC_{HTO} \qquad \text{(C-4)}$$

where

U_{meat} = maximum intake rate (kg/y)

C_{meat} = predicted concentration in meat at time of consumption from the contribution of vegetation
= C_{meat_veg} (Bq/kg)

DC_{HTO} = dose coefficient for HTO (µSv/Bq) (U.S. DOE 1988)

The tritium dose rate from meat consumption is then

$$D_{meat}\,(\mu Sv/y) = 110\,(kg/y) \times [0.6 \times C_{veg}\,(Bq/kg)] \times 1.73 \times 10^{-5}\,(\mu Sv/Bq)$$

$$= 1.1 \times 10^{-3} \times C_{veg}\,(Bq/L)$$

Cow Milk: To calculate dose from ingestion of milk, first the concentration of tritium in the milk must be calculated from the measured mean or maximum tritium concentration in vegetation.

$$C_{milk\_veg} = F_m\,(d/L) \times Q_f\,(kg/d) \times C_{veg}\,(Bq/kg) \times \exp\,(-\lambda_i t_f) \qquad (C\text{-}5)$$

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} = mean or maximum 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

$$C_{milk\_veg} = 1.0 \times 10^{-2}\,(d/L) \times 50\,(kg/d) \times C_{veg}\,(Bq/kg) \times \exp[(-1.5 \times 10^{-4}) \times 2]$$

$$= 0.5 \times C_{veg}\,(Bq/L)$$

The dose from consumption of milk is calculated:

$$D_{milk}\,(\mu Sv/y) = U_{milk} \times C_{milk} \times DC_{HTO} \qquad (C\text{-}6)$$

where

U_{milk} = maximum intake rate (L/y)

C_{milk} = predicted concentration in milk at time of consumption from the contribution of vegetation
= C_{milk_veg} (Bq/kg)

DC_{HTO} = dose coefficient for HTO (µSv/Bq)

The tritium dose rate from directly consumed milk is then

$$D_{milk}\,(\mu Sv/y) = 310\ (L/y) \times [0.5 \times C_{veg}\,(Bq/kg)] \times 1.73 \times 10^{-5}\ (\mu Sv/Bq)$$

$$= 2.7 \times 10^{-3} \times C_{veg}\,(Bq/L)$$

Total Food Ingestion: The annual dose from food ingestion as calculated in Chapter 11 based on measured HTO in vegetation is then:

$$D_{food}\,(\mu Sv/y) = D_{veg} + D_{meat} + D_{milk} \qquad (C\text{-}7)$$

where

D_{veg} = dose from ingestion of leafy vegetables (µSv/y)

D_{meat} = dose from ingestion of meat (µSv/y)

D_{milk} = dose from ingestion of milk (µSv/y)

Therefore

$$D_{food}\,(\mu Sv/y) = 1.1 \times 10^{-3} \times C_{veg}\,(Bq/L) \qquad \text{(dose from leafy vegetables)}$$

$$+\ 1.1 \times 10^{-3} \times C_{veg}\,(Bq/L) \qquad \text{(dose from meat)}$$

$$+\ 2.7 \times 10^{-3} \times C_{veg}\,(Bq/L) \qquad \text{(dose from milk)}$$

$$= 4.9 \times 10^{-3} \times C_{veg}\,(Bq/L)$$

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 must be 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

$$D_{\text{inh/sa}}\,(\mu\text{Sv/y}) = 1.5 \times U_{\text{air}} \times C_{\text{air}} \times DC_{\text{HTO\_inh}} \qquad \text{(C-8)}$$

where

1.5 = factor that accounts for skin absorption

U_{air} = air intake rate (m^3/y)

C_{air} = mean HTO concentration measured in air at the receptor (Bq/m^3)

$DC_{\text{HTO\_inh}}$ = dose coefficient for inhalation (μSv/Bq) (U.S. DOE 1988)

The whole-body inhalation/skin-absorption dose rate from HTO is then

$$D_{\text{inh/sa}}\,(\mu\text{Sv/y}) = 1.5 \times 8000\ m^3/\text{y} \times C_{\text{air}} \times 1.73 \times 10^{-5}\ \mu\text{Sv/Bq}$$

$$= 0.21 \times C_{\text{air}}\,(\text{Bq}/m^3)$$

Doses in Chapter 5 are calculated as shown here. The breathing rate of 8000 m^3/y is that of 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 C-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 C-3 and C-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 C-4 and C-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 C-1** are substituted into eqs C-1, C-2, C-4, and C-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 C-1 through C-6. They are summarized and compared in **Table C-3** with the values used for the calculations in Chapters 5, 7, and 11.

Table C-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 x C_{air} (Bq/m^3)	0.21 x 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 x C_{veg} (Bq/kg)	Factor x C_{veg} (Bq/kg)	Factor x 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 OBT

Models that account only for dose from HTO have come under attack in recent years. As shown in **Table C-2**, the dose coefficient for OBT 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 OBT 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 (OBT):

$$\text{Bq/kg fresh weight plant} = (\text{Bq/ L (measured HTO)} \times F_{fw}) + (\text{Bq/ L (measured HTO)} \times F_{dm} \times W_{eq}) \quad \text{(C-9)}$$

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 × 0.07) + (percent fat × 0.12) + (percent carbohydrate × 0.062)]/ 100 × (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 fiber 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 vegetables 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 C-3 and C-5, including the contribution of drinking water. A median value of W_{eq} for animal products is about 0.8 L/kg.

Examples of concentrations of various foodstuffs based on the 2002 mean tritium concentrations in plant water (4.7 Bq/L) and rainwater (2.3 Bq/L) at VIS (**Table C-4**) are shown below. These equations follow the format of eq C-9, where the total concentration of tritium per kilogram edible food is the sum of the HTO and OBT contributions, respectively.

Lettuce $(4.7 \times 0.948) + (4.7 \times 0.052 \times 0.602) = 4.46 + 0.15 = 4.61$ Bq/kg fresh weight

Potato $(4.7 \times 0.798) + (4.7 \times 0.202 \times 0.568) = 3.75 + 0.54 = 4.29$ Bq/kg fresh weight

Whole milk $(3.73 \times 0.885) + (3.73 \times 0.115 \times 0.746) = 3.30 + 0.32 = 3.62$ Bq/kg fresh weight

Lean sirloin $(4.20 \times 0.718) + (4.20 \times 0.282 \times 0.724) = 3.02 + 0.86 = 3.88$ 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 C-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

$$D_{inh\_HT}\ (\mu Sv/y) = C_{air\_HT} \times U_{air} \times DC_{HT} \qquad \text{(C-10)}$$

where

C_{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 (µSv/Bq) (ICRP 1995)

Therefore

$$D_{inh\_HT}\ (\mu Sv/y) = C_{air\_HT}\ (Bq/m^3) \times 8000\ m^3/y \times 1.8 \times 10^{-9}\ \mu Sv/Bq$$

The tritium dose rate from inhalation of HT is then (based on predicted HT in air):

$$D_{inh\_HT}\ (\mu Sv/y) = 1.4 \times 10^{-5} \times C_{air\_HT}\ (Bq/m^3)$$

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:

$$D_{imm\_HTO}\ (\mu Sv/y) = C_{pool}\ (Bq/L) \times U_{pool}\ (L/y) \times DC_{HTO}\ (\mu Sv/Bq) \qquad (C\text{-}11)$$

where

C_{pool} = mean 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 (µSv/Bq) (ICRP 1996)

The whole-body skin absorption dose from swimming is:

$$D_{imm\_HTO}\ (\mu Sv/y) = C_{pool}\ (Bq/L) \times 6\ L/y\ \times 1.8 \times 10^{-5}\ \mu Sv/Bq$$

$$= 1.1 \times 10^{-4}\ C_{pool}\ (Bq/L)$$

Dose Predictions

Regulatory Dose Predictions

Observed and Predicted Input to Models

Concentrations of tritium in air (Chapter 5) are monitored at eight 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.

Mean concentrations measured in the air, vegetation (Chapter 11) and rainwater (Chapter 7) for VIS are shown in **Table C-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 C-4**.

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.

Table C-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 2002.

	Mean Observed HTO Concentrations	Predicted Tritium Concentrations
Air concentration (Bq/m^3) at VIS		
HTO	0.064	0.094
HT	n/a[a]	0.0048
Vegetation (Bq/L) at VIS	4.7	n/a[a]
Rain (Bq/L) at VIS	2.3[b]	n/a[a]
Livermore Valley Wine (Bq/L)	1.4	n/a[a]
LLNL Swimming Pool (Bq/L)	0.47[b]	n/a[a]

a n/a = not applicable

b = Below the normal limit of detection

Drinking water for both animals and people (in NRC 1.109) is rainwater at the mean concentration for the entire year. The assumption that drinking water has the concentration of rainwater 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 for people comes primarily from distant sources or from groundwater, neither of which is affected by locally emitted tritium. Drinking water for animals may come from small basins that receive some tritium from rainwater, although the drinking water for animals is expected to have a much lower concentration of tritium than rainwater. The use of different models and different assumptions will result in very different dose predictions (**Table C-5** and **Table C-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 C-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 C-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 0.12 Bq/L in 2002); in NRC 1.109, the assumption has been made that the individual is drinking water with a concentration of 2.3 Bq/L (equal to rainwater). Thus, for 2002, the dose from drinking water in

NRC 1.109 can be as much as nearly 45% 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.

Table C-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	26	13	13
Vegetables	82	5.2	16
Milk	[50]	13	7.0
Meat	30	5.2	6.9
Drinking water	1.5	30	15
Total ingestion dose (food and water)	114 [164]	53	44
Total dose from HTO	140 [190]	66	58

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 C-4**).

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 C-6**). The contribution of OBT increases the doses over those shown for NRC 1.109 in **Table C-5** by 31%, 16% and 43% for vegetables (including grain), milk, and meat respectively.

In **Table C-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 C-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 (8.0 Bq/L, the 2002 mean air concentration divided by the default absolute humidity of 8 $g/m^{3)}$, which results in a higher concentration in vegetation water (6.4 – 7.2 Bq/L depending upon the type of vegetable) than was observed (4.7 Bq/L). Furthermore, the drinking water tritium contribution to milk is greater for NEWTRIT than for NRC 1.109 for 2002; the contribution of drinking water to meat is approximately the same for the two models. In spite of NEWTRIT's conservative assumption that drinking water has the concentration of 10% that of air moisture, NEWTRIT's drinking water dose is less than half that of NRC

Table C-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	13	15	22	0.071
Vegetables[b]	21	38	56	0.33
Milk	8.1	24	35	0.16
Meat	9.9	12	18	0.073
Drinking water	15	6.3	9.3	0.031
Total ingestion (food and water)	54	80	118	0.59
Total dose from HTO and OBT	67	95	139	0.67

a This column corresponds to the far right column in **Table C-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 inhalation doses for predicted air concentrations plus the HTO doses based on observed air concentrations. NEWTRIT was used in default mode.

c Includes leafy vegetables, fruit, fruit vegetables, root vegetables and grain

1.109 because the concentration in rainwater for 2002 (2.3 Bq/L) is more than twice as high as NEWTRIT's drinking water concentration (0.8 Bq/L). Note, however, that both concentrations are below the lower limits of detection and therefore the differences calculated between doses are not very meaningful.

Also shown in **Table C-6** is the estimated dose from the release of HT from the Tritium Facility. A tiny contribution to total dose from inhalation (7.4×10^{-5} nSv/y, not shown explicitly) arises from air concentrations of tritiated hydrogen (HT) gas, based on an air concentration of 0.0048 Bq/m^3 estimated by the dispersion model in CAP88-PC. The inhalation dose, shown in **Table C-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 2002, the release rate of HT was very small compared with the release rate of HTO from the Tritium Facility. As a result, the dose from released HT is only about 0.5% 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 C-5** and **Table C-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 C-5** and **Table C-6** (58 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 CAP88PC 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 2002 at LLNL (7.8 g/m^3) was used instead of the default (8 g/m^3). 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 2002, based on realistic yet conservative assumptions, are shown in **Table C-7**.

Table C-7. Realistic, yet conservative, assumptions and consequent doses for the tritium exposure of an individual living at the Visitors Center in 2002 based on observed HTO in air concentrations and predicted HT in air concentrations

Source of dose	Annual dose (nSv)	Assumption
Inhalation	9.8	Breathes air at VIS 16 hours a day, all year
Ingesting food, including OBT	14	Raises and eats 50% homegrown leafy vegetables, fruit vegetables, fruits and root crops, no homegrown milk, beef, 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	[5.9][a]	Drinks well water at average concentration of California groundwater
Drinking wine	1.3	Drinks one bottle of Livermore Valley wine each week
Immersion	0.020	Swims in the LLNL pool 100 hours per year
Total tritium	25	

a Drinking water dose should not be included in a realistic estimate of the dose impacts of LLNL releases of tritium to the atmosphere because Livermore drinking water is obtained from the South Bay Aqueduct, Lake Del Valle, and various wells, all unaffected by local atmospheric tritium.

The total annual "realistic" tritium dose from LLNL operations (**Table C-7**) is therefore 25 nSv/y, which is a factor of about 7.6 below the maximum dose predicted by CAP88-PC, and a factor of 3.8 below the dose from observed concentrations predicted by NEWTRIT, neither of which accounts for wine intake or swimming. The drinking water dose shown in **Table C-7**, which is entirely due to global sources of tritium, is nearly 25% of the total tritium dose from LLNL operations. This demonstrates how small the impact of LLNL operations is upon dose to the public.

On average the doses presented here are about a thousand times lower than the EPA's radiation dose limit to the member of the public from an atmospheric release (100 µSv/y). CAP88-PC's dose, by far the highest, is just 1.9% 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 D. Supplementary Topics on Radiological Dose

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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 and smoke detectors.

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 sponta-

* The National Cancer Institute provides a calculator of dose and risk for people in the continental United States exposed during the 1950s and 1960s to iodine-131 from nuclear weapons tests at the Nevada Test Site. The calculator is available at: http://ntsi131.nci.nih.gov/default.asp

neous 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 µSv/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 2.1 and 2.2 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. Work places 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).

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 audit by DOE's Office of Independent Oversight and Performance Assurance of LLNL's environment, safety, and health (ES&H) and emergency management programs in June 2002, the public health assessments conducted by the Agency for Toxic Substances and Disease Registry (ATSDR) at the Livermore site in the 1999-2002 time frame, and the self-assessment of LLNL's NESHAPs Program by the Laboratory's Assurance Review Office (ARO) conducted during 1999 and 2003.

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 the original 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 2001 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 2001 SAER

The following changes have been made to the Internet version of the main volume.

- On page 8-4, in Table 8-1, the value in the "Average extraction rate" column for TFA was changed to 776.4 (from 946.4).

- On page 8-5, in Table 8-2, the following changes were made.
  - The value in the "2001; Water treated" column for TF518 was changed to 6.4 (from 12.1).
  - The value in the "Cumulative total; Water treated" column for TFC was changed to 480 (from 858.5).

The following changes have been made to the Internet version of the Data Supplement.

- Table 7-9a, "Compliance monitoring data for releases from Drainage Retention Basin, dry season, 2001," was added.

- In Table 9-3, in the "W-008; Jan 18" column, the following changes were made:
  - The value for gross alpha was changed to 0.11 ± –0.1 (from 1.1 ± –0.1)
  - The value for gross beta was changed to 0.17 ± –0.1 (from 1.7 ± –0.1)
- In Table 9-5, in the "W-373; Apr 19" column, the following changes were made:
  - The value for aluminum was changed to <50 (from <0.05)
  - The value for copper was changed to <20 (from <0.02)
  - The value for iron was changed to <50 (from <0.05)
  - The value for manganese was changed to <10 (from <0.01)
  - The value for nickel was changed to <50 (from <0.05)
  - The value for zinc was changed to <50 (from <0.05)
- In Table 10-2, in the "Cesium-137" column, the following changes were made:
  - The uncertainty value for location 3-801E-SO was changed to 0.00031 (from 0.0031).
  - The uncertainty value for location 3-801N-SO was changed to 0.00025 (from 0.0025).
  - The uncertainty value for location 3-801W-SO was changed to 0.00023 (from 0.0023).
- In Table 10-4, in the "Water quality objective" column, the value for chloroform was changed to 80 (from 100).

Table 7-9a. Compliance monitoring data for releases from Drainage Retention Basin, dry season, 2001

Parameter	CDBX sampling dates				WPDC sampling dates			
	6/26	7/11	8/6	9/6	6/26	7/11	8/6	9/6
Biological								
Aq. Bioassay, Survival Chronic (percent survival)	*90*	*95*	*100*	*95*	*100*	*95*	*100*	*80*
Metals (mg/L)								
Aluminum	*0.05*	*< 0.05*	*< 0.05*	*< 0.05*	*na[(a)]*	*na*	*na*	*na*
Antimony	*< 0.004*	*< 0.004*	*< 0.004*	*< 0.004*	*0.1*	*< 0.05*	*< 0.05*	*< 0.05*
Arsenic	*0.002*	*0.003*	*0.003*	*0.002*	*0.084*	*0.068*	*0.09*	*0.11*
Barium	*0.093*	*0.075*	*0.1*	*0.097*	*0.93*	*1.2*	*1.4*	*1.6*
Beryllium	*< 0.0002*	*< 0.0002*	*< 0.0002*	*< 0.0002*	*< 0.05*	*< 0.05*	*< 0.05*	*< 0.05*
Boron	*1.5*	*1.4*	*1.8*	*1.8*	*0.18*	*< 0.05*	*< 0.05*	*0.067*
Cadmium	*< 0.0005*	*< 0.0005*	*< 0.0005*	*< 0.0005*	*< 0.01*	*< 0.01*	*< 0.01*	*< 0.01*
Chromium	*0.005*	*0.003*	*0.004*	*0.005*	*< 0.025*	*< 0.025*	*< 0.025*	*< 0.025*
Cobalt	*< 0.05*	*< 0.05*	*< 0.05*	*< 0.05*	*< 0.01*	*< 0.01*	*< 0.01*	*0.01*
Copper	*0.003*	*0.005*	*0.004*	*0.003*	*0.039*	*< 0.02*	*< 0.02*	*< 0.02*
Hexavalent Chromium	*0.004*	*0.004*	*0.005*	*0.004*	*< 0.004*	*< 0.004*	*< 0.004*	*< 0.004*
Iron	*< 0.05*	*< 0.05*	*< 0.05*	*< 0.05*	*0.003*	*0.003*	*0.003*	*< 0.002*
Lead	*< 0.005*	*< 0.005*	*< 0.005*	*< 0.005*	*< 0.0002*	*< 0.0002*	*< 0.0002*	*< 0.0002*
Manganese	*0.12*	*0.03*	*0.043*	*0.047*	*< 0.0005*	*< 0.0005*	*< 0.0005*	*< 0.0005*
Mercury	*< 0.0002*	*< 0.0002*	*< 0.0002*	*< 0.0002*	*0.0079*	*0.01*	*0.0073*	*0.002*
Molybdenum	*< 0.025*	*< 0.025*	*< 0.025*	*< 0.025*	*< 0.005*	*< 0.005*	*< 0.005*	*< 0.005*
Nickel	*0.002*	*< 0.002*	*< 0.002*	*< 0.002*	*< 0.0002*	*< 0.0002*	*< 0.0002*	*< 0.0002*
Selenium	*< 0.004*	*< 0.002*	*< 0.002*	*< 0.002*	*0.005*	*< 0.002*	*< 0.002*	*< 0.002*
Silver	*< 0.001*	*< 0.001*	*< 0.001*	*< 0.001*	*< 0.004*	*< 0.002*	*< 0.002*	*< 0.002*
Thallium	*< 0.001*	*< 0.004*	*< 0.001*	*< 0.001*	*< 0.001*	*< 0.001*	*< 0.001*	*< 0.001*
Vanadium	*< 0.01*	*< 0.01*	*< 0.01*	*< 0.01*	*< 0.001*	*< 0.004*	*< 0.001*	*< 0.001*
Zinc	*< 0.02*	*< 0.02*	*< 0.02*	*< 0.02*	*0.0083*	*0.012*	*0.0072*	*< 0.002*

Table 7-9a. Compliance monitoring data for releases from Drainage Retention Basin, dry season, 2001 (continued)

Parameter	CDBX sampling dates				WPDC sampling dates			
	6/26	7/11	8/6	9/6	6/26	7/11	8/6	9/6
Volatile organic compounds (ug/L)								
1,1,1-Trichloroethane	< 0.5	< 0.5	< 0.5	< 0.5	na	na	na	na
1,1,2,2-Tetrachloroethane	< 0.5	< 0.5	< 0.5	< 0.5	na	na	na	na
1,1,2-Trichloroethane	< 0.5	< 0.5	< 0.5	< 0.5	na	na	na	na
1,1-Dichloroethane	< 0.5	< 0.5	< 0.5	< 0.5	na	na	na	na
1,1-Dichloroethene	< 0.5	< 0.5	< 0.5	< 0.5	na	na	na	na
1,2-Dichlorobenzene	< 0.5	< 0.5	< 0.5	< 0.5	na	na	na	na
1,2-Dichloroethane	< 0.5	< 0.5	< 0.5	< 0.5	na	na	na	na
1,2-Dichloroethene (total)	< 1	< 1	< 1	< 1	na	na	na	na
1,2-Dichloropropane	< 0.5	< 0.5	< 0.5	< 0.5	na	na	na	na
1,3-Dichlorobenzene	< 0.5	< 0.5	< 0.5	< 0.5	na	na	na	na
1,4-Dichlorobenzene	< 0.5	< 0.5	< 0.5	< 0.5	na	na	na	na
2-Chloroethylvinylether	< 10	< 10	< 10	< 10	na	na	na	na
Bromodichloromethane	< 0.5	< 0.5	< 0.5	< 0.5	na	na	na	na
Bromoform	< 0.5	< 0.5	< 0.5	< 0.5	na	na	na	na
Bromomethane	< 0.5	< 1	< 1	< 1	na	na	na	na
Carbon tetrachloride	< 0.5	< 0.5	< 0.5	< 0.5	na	na	na	na
Chlorobenzene	< 0.5	< 0.5	< 0.5	< 0.5	na	na	na	na
Chloroethane	< 1	< 1	< 0.5	< 0.5	na	na	na	na
Chloroform	< 0.5	< 0.5	< 0.5	< 0.5	na	na	na	na
Chloromethane	< 1	< 1	< 0.5	< 0.5	na	na	na	na
cis-1,2-Dichloroethene	< 0.5	< 0.5	< 0.5	< 0.5	na	na	na	na
cis-1,3-Dichloropropene	< 0.5	< 0.5	< 0.5	< 0.5	na	na	na	na
Dibromochloromethane	< 0.5	< 0.5	< 0.5	< 0.5	na	na	na	na
Dichlorodifluoromethane	< 0.5	< 0.5	< 0.5	< 0.5	na	na	na	na
Freon 113	< 0.5	< 0.5	< 0.5	< 0.5	na	na	na	na
Methylene chloride	< 1	< 1	< 1	< 1	na	na	na	na
Tetrachloroethene	< 0.5	< 0.5	< 0.5	< 0.5	na	na	na	na
Total Trihalomethanes	< 2	< 2	< 2	< 2	na	na	na	na
trans-1,2-Dichloroethene	< 0.5	< 0.5	< 0.5	< 0.5	na	na	na	na
trans-1,3-Dichloropropene	< 0.5	< 0.5	< 0.5	< 0.5	na	na	na	na

Table 7-9a. Compliance monitoring data for releases from Drainage Retention Basin, dry season, 2001 (concluded)

Parameter	CDBX sampling dates				WPDC sampling dates			
	6/26	7/11	8/6	9/6	6/26	7/11	8/6	9/6
Trichloroethene	< 0.5	< 0.5	< 0.5	< 0.5	na	na	na	na
Trichlorofluoromethane	< 0.5	< 0.5	< 0.5	< 0.5	na	na	na	na
Vinyl chloride	< 0.5	< 0.5	< 0.5	< 0.5	na	na	na	na
Polychlorinated biphenyls (ug/L)								
PCB 1016	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
PCB 1221	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
PCB 1232	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
PCB 1242	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
PCB 1248	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
PCB 1254	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
PCB 1260	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Miscellaneous organics (mg/L)								
pH	8.66	9.07	8.93	9.02	8.2	9.03	8.72	8.48
Total suspended solids (TSS)	3.7	5.5	4	12	4.3	2.5	< 2	3.7

a na = Not analyzed because the analysis was not required

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Acronyms and Abbreviations

See also the Glossary for further definition of selected terms.

	%RSD	Percent relative standard deviation
A	**ACEHCS**	Alameda County Environmental Health Care Services
	ACOE	Army Corps of Engineers
	Ag	Silver
	ALARA	As low as reasonably achievable
	ANSI	American National Standards Institute
	As	Arsenic
	AST	Aboveground storage tank
	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
	BMP	Best management practice
	Bq	Becquerel
	BTU	Biotreatment unit
C	**$CaCO_3$**	Calcium carbonate
	CAM	Continuous air monitor
	CAMP	Corrective Action Monitoring Program
	CAREs	(Tri-Valley) Communities Against a Radioactive Environment
	CCB	Change Control Board
	CCR	California Code of Regulations
	CD	Compact disc
	Cd	Cadmium
	CDFG	California Department of Fish and Game
	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
	Chromium(VI)	Hexavalent chromium
	Ci	Curie
	CNPS	California Native Plant Society
	COC	Constituent of concern
	COD	Chemical oxygen demand
	Cr	Chromium
	CRD	Catalytic reductive dehalogenation
	CSA	Container storage area
	CSTP	Conceptual Site Treatment Plan
	Cu	Copper
	CVRWQCB	Central Valley Regional Water Quality Control Board
	CWA	(Federal) Clean Water Act
	CWG	Community Work Group
D	**DAP**	Discipline action plan
	DCG	Derived Concentration Guide
	DfE	Design for Environment
	DHS	Department of Health Services
	DOE	U.S. Department of Energy
	DOT	U.S. Department of Transportation
	DRB	Drainage Retention Basin
	DSTP	Draft Site Treatment Plan
	DTEP	Defense Technologies Evaluations Program
	DTSC	(California Environmental Protection Agency), Department of Toxic Substances Control
	DWTF	Decontamination and Waste Treatment Facility
E	**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
	EMS	Environmental Management System
	EOG	Environmental Operations Group
	EPA	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
	EWSF	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
	FSTP	Final Site Treatment Plan
	FY	fiscal year
G	**GBq**	Gigabecquerel (10^9 Bq)
	GEM	Global Electric Motorcar
	GPS	Global positioning system
	GSA	General Services Area (LLNL Site 300)
	GWP	Ground Water Project
	GWPMP	Ground Water Project Management Program
	Gy	Gray
H	**HCAL**	Hazards Control Department's Analytical Laboratory
	HE	High explosives
	HEPA	High-efficiency particulate air (filter)
	Hg	Mercury

	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
I	**ICRP**	International Commission on Radiological Protection
	IQR	Interquartile range
	ISMS	Integrated Safety Management System
	IWS	Integration work sheet
L	**LBNL**	Lawrence Berkeley National Laboratory
	LEPC	Local Emergency Planning Committee
	LLNL	Lawrence Livermore National Laboratory
	LLW	Low-level (radioactive) waste
	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
	MIXED	Mixed low-level waste
	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 Historic Preservation Act
	Ni	Nickel
	NIF	National Ignition Facility
	NOV	Notice of Violation

	NO_X	Oxides of nitrogen
	NPDES	National Pollutant Discharge Elimination System
	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
	Pb	Lead
	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
	ppb	Parts per billion
	ppm	Parts per million
	PQL	Practical quantitation limit
	PRAG	Permits and Regulatory Affairs Group
	PTU	Portable treatment unit
	PV	Photovoltaic
Q	**QA**	Quality assurance
	QC	Quality control
R	**RAIP**	Remedial Action Implementation Plan
	RCRA	Resource Conservation and Recovery Act of 1976
	RDX	Hexahydro-1,3,5-trinitro-1,3,5-triazine
	RHWM	Radioactive and Hazardous Waste Management Division (of the Environmental Protection Department at LLNL)

	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
	SHPO	State Historic Preservation Office
	SI	Système International d'Unités
	Site 300	LLNL's Experimental Test Site, located approximately 24 km east of the Livermore site
	SJCEHD	San Joaquin County Environmental Health Department
	SJVUAPCD	San Joaquin Valley Unified Air Pollution Control District
	SME	Subject matter expert
		Safety Management Evaluation
	SMS	Sewer Monitoring Station
	SOV	Summary of violations
	STU	Solar-powered treatment unit
	Sv	Sievert
	SW-MEI	Sitewide maximally exposed individual member (of the public)
	SWPPP	Storm Water Pollution Prevention Plan
	SWRCB	(California) State Water Resources Control Board
T	**TAG**	Technical Assistance Grant
	TBOS	Tetrabutyl orthosilicate
	TBq	Terabecquerel (10^{12} Bq)
	TCE	Trichloroethene (or trichloroethylene)

	TCLP	Toxicity characteristic leaching procedure
	TDS	Total dissolved solids
	TEF	Toxic equivalency factor
	TEQ	Toxic equivalency
	TKEBS	Tetrakis (2-ethylbutyl) silane
	TLD	Thermoluminescent dosimeter
	TNT	Trinitrotoluene
	TOC	Total organic carbon
	TOX	Total organic halides
	TRI	Toxics Release Inventory
	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
	USFWS	U.S. Fish and Wildlife Service
	UST	Underground storage tank
	UV/H_2O_2	Ultraviolet/hydrogen peroxide
V	**VELB**	Valley Elderberry Longhorn Beetle
	VOC	Volatile organic compound
W	**WAA**	Waste accumulation area
	WDR	Waste Discharge Requirement
	WSS	Work Smart Standards
Z	**Zn**	Zinc
	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 (l 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

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

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

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

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

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

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

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

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			
°C = (°F–32)/1.8		°F = (°C x1.8) + 32	

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

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 (SJVUAPCD): 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

Zone 7: the common name for the Alameda County Flood Control and Water Conservation District

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